ISSN: 2456-1878

International Journal of Environment Agriculture and Biotechnology

(IJEAB)

An open access Peer-Reviewed InternationalJournal

DOI: 10.22161/ijeab.82

Vol.- 8 | Issue - 2 | Mar-Apr 2023

editor.ijeab@gmail.com | editor@ijeab.com | https://www.ijeab.com/

International Journal of Environment, Agriculture and Biotechnology

(ISSN: 2456-1878)

DOI: 10.22161/ijeab

Vol-8, Issue-2

March-April, 2023

Editor in Chief

Dr. Pietro Paolo Falciglia

Publisher

Infogain Publication

Email: editor.ijeab@gmail.com ; editor@ijeab.com

Web: www.ijeab.com

International Editorial Board/ Reviewer Board

FOREWORD

I am pleased to put into the hands of readers Volume-8; Issue-2: March-April 2023 of **"International Journal of Environment, Agriculture and Biotechnology (IJEAB) (ISSN: 2456-1878)",** an international journal which publishes peer reviewed quality research papers on a wide variety of topics related to **Environment, Agriculture and Biotechnology**. Looking to the keen interest shown by the authors and readers, the editorial board has decided to release issue with DOI (Digital Object Identifier) from CrossRef also, now using DOI paper of the author is available to the many libraries. This will motivate authors for quick publication of their research papers. Even with these changes our objective remains the same, that is, to encourage young researchers and academicians to think innovatively and share their research findings with others for the betterment of mankind.

I thank all the authors of the research papers for contributing their scholarly articles. Despite many challenges, the entire editorial board has worked tirelessly and helped me to bring out this issue of the journal well in time. They all deserve my heartfelt thanks.

Finally, I hope the readers will make good use of this valuable research material and continue to contribute their research finding for publication in this journal. Constructive comments and suggestions from our readers are welcome for further improvement of the quality and usefulness of the journal.

With warm regards.

Editor-in-Chief
Date: May, 2023

Vol-8, Issue-2, March-April 2023

(DOI: 10.22161/ijeab.82)

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

An Assessment of Sustainable Energy Management at a Major United Kingdom Based Hub Airport: A Case Study of London Gatwick Airport

Glenn Baxter

School of Tourism and Hospitality Management, Suan Dusit University, Huahin Prachaup Khiri Khan, Thailand, 77110.

Received: 29 Jan 2023; Received in revised form: 27 Feb 2023; Accepted: 05 Mar 2023; Available online: 13 Mar 2023

Abstract—*Due to their extremely energy intense nature, airports are increasingly focusing on their energy consumption and energy efficiency as a key part of their sustainability policies and strategies. Based on an in-depth longitudinal case study research design, this study has examined London Gatwick Airport, a major United Kingdom-based hub airport, sustainable energy management. The case study covered the period 2014 to 2021. London Gatwick Airport has two principal energy sources: electricity and natural gas. The case study revealed that London Gatwick Airport contributes to a lower carbon grid through its procurement of 100% certified renewable electricity. The airport has purchased this 100% certified renewable electricity since 2013. This measure has enabled the airport to mitigate its environmental impact. An important energy-related development at London Gatwick Airport, has been the airport's waste processing and biomass generation facility, which began operations in November 2016. Category 1 and other types of organic waste are converted into biomass fuel that is used to power the processing plant and provide heating for the airport's North Termina and the airport's waste management site. The waste plant also provides power to the site's water recovery system. Throughout the study period, London Gatwick Airport introduced a range of energy efficiency related measures. These measures include the installation of high efficiency lighting, heating, air conditioning, and ventilation (HVAC) systems, the upgrading of the airport's boiler plant, the installation of an electricity powered hydrant dispenser, and the installation of more energy efficient light emitting diode (LED) lighting. The airport is also replacing its fleet of airport vehicles with electric powered vehicles. In addition, the airport is transitioning towards the use of electricity powered ground service equipment (GSE).*

Keywords— ***Airports, Airport energy efficiency measures, Airport energy consumption, London Gatwick Airport, Sustainable airport energy management.***

I. INTRODUCTION

Air transport infrastructure development is considered crucial for both economic and social development and growth (Karagkouni & Dimitriou, 2022). Airports have substantial economic, and social impacts on local, regional, and often in many instances, national levels as well (Culberson, 2011). However, airports adversely affect the surrounding environment (Chourasia et al., 2021; Culberson, 2011; Dimitriou & Voskaki, 2012; Dimitriou et al., 2014). In recent years, the development of green airports has increased, with this growth partly due to the aviation industry ambition to be a carbon-neutral industry by 2050 (Korba et al., 2022). A "green airport" is an airport which has a minimal impact on the environment and is one that endeavors to become a carbon neutral facility in terms of carbon emissions, with the aim to ultimately produce zero greenhouse gas emissions (González-Ruiz et al., 2017). The notion underpinning a "green airport" is for the airport to create a centre of sustainable practices (Sumathi et al., 2018). Airports play a significant role in the air transport industry; therefore, their effective operation is crucial. Airports must be built

according to sustainable standards to maintain reduced energy, water, or heat consumption (Korba et al., 2022). Furthermore, applying sustainable airport practices can enable airports to improve their economic and social effects and reduce their harmful impact on the environment (Eid et al., 2022).

Airports are critical nodes in the global air transport system. Along with the growth of airport infrastructures, airport-related business, commercial, residential, and spatial development often occurs in the airport surroundings with these developments being connected by surface transport infrastructure (Ferrulli, 2016). Airports are one of the most critical stakeholders in the global air transport industry value chain. This is because airports provide the necessary landside and airfield infrastructure that facilitates both the passengers and air cargo shippers interface between the ground-based and air transport modes. To facilitate the movement and handling of passengers and air cargo consignments, airports provide extensive landside infrastructure and facilities as well as runways, taxiways, and aircraft parking stands. Air traffic, both passenger and air cargo, has increased very significantly over the past 20 years or so and this has led to an increased energy requirements of airports to accommodate this air traffic demand (Ortega Alba & Manama, 2016). Importantly, airport systems and their infrastructure consume large amounts of electrical energy. Airports are thus regarded as being energy intensive (Baxter et al., 2019; Cardona et al., 2006; Ortega Alba & Manama 2016). This is due to the energy requirements of airport buildings and facilities, for example, passenger terminal air conditioning systems, pre-conditioned air and power at aircraft gates, power supply for equipment, and other special airport systems (International Civil Aviation Organization, 2015). Airport passenger terminals are indeed extremely energy intensive (Kareem et al., 2021; Orukpe et al. 2020; Yildiz et al., 2021). The dynamic structure of airports, 24-hour operations, performing flight operations safely, and the provision of comfortable conditions for passengers in the airport's terminal buildings, has often resulted in increased energy consumption of airports. Energy management has become an important focus for airports, and thus, airports are seeking continuous improvement of energy performance as they are sites with high and intense energy consumption (Akyuz et al., 2019). Energy management is now considered as being of critical importance for airports (Almaz, 2022). According to Greer et al. (2020), "energy management refers to a process by which airports can characterize and monitor their energy consumption and enact measures to reduce it". In airports with high energy consumption areas, energy management allows the reduction of both costs and environmental impacts (Akyüz et al., 2021). Considering this, many airports have increased their focus on energy efficiency as part of their efforts to reduce their impact on the environment (Preston, 2015). Moreover, airport managers have become aware of the requirement to reduce energy consumption as well as make a more efficient use of it. In addition, airports are now confronting growing pressure to use energy-efficient systems whilst at the same time ensuring their compliance with increasingly stringent regulations (Taber & Steele, 2020). Accordingly, energy management has become extremely important for airports (Graham, 2018; Uysal & Ziya Sogut, 2017).

The United Kingdom has the biggest aviation network in Europe and the third largest in the world. London has the busiest airport system of any city in the world (Ministry of Transport, 2017). London is a major air travel market for Australia, Canada, India, Singapore, South Africa, and the United States of America. In addition, London is the home base for British Airways and Virgin Atlantic Airways, as well as an essential market for some of the industry's most successful airlines. easyJet and Ryanair, who are low-cost carriers (LCCs) have positioned London as a strategic hub. For many international airlines including Emirates, Qatar Airways, Singapore Airlines, Finnair, Aer Lingus, Qantas, United Airlines and American Airlines, London remains a key market that is core in their strategic growth and investment plans. In more recent times, JetBlue, Vistara and Norse Atlantic have launched services to London (Malik, 2022). The city of London is served by five main airports: London Heathrow Airport, London City Airport, London Gatwick Airport, London Stansted Airport, and Luton Airport (Pels et al., 2009; Saayman, 2012). London Southend Airport also serves London (Pearson, 2022).

The objective of this research is to empirically examine the sustainable aspects of London Gatwick Airport, a major United Kingdom-based hub airport, energy management. A further objective of the study is to examine the airport's energy sources and the trends in the annual consumption of these energy sources and to identify the impact that the growth in passenger traffic and aircraft movements has had on the airport's energy consumption throughout the study period. A final aim of the study is to examine the measures and technologies that have been implemented throughout the study period by London Gatwick Airport to achieve its goal of sustainable energy management. The study period is from 2014 to 2021.

The remainder of the paper is organized as follows: Section 2 presents a review of the literature on airport energy management. The research method used to underpin the study is described in Section 3. The case study of London Gatwick Airport sustainable energy

management is presented in Section 4. Section 5 presents the findings of the study.

II. BACKGROUND

2.1. Airport Energy Sources

The actors operating within the airport's airside and landside precincts require a reliable and highly efficient supply of energy. Historically, an airport's two primary energy sources have been electricity and fuel, for example, diesel, natural gas, and propane (Ortega Alba & Manana, 2016). Electrical energy is normally sourced from different sources. The electrical energy is supplied directly to the airport through dedicated sub-stations. This energy is primarily used for operating the airport's facilities, equipment, and other devices that are necessary in servicing passengers and their baggage and air cargo consignments in the airport's respective passenger and air cargo terminals. Electrical energy is also used for the provision of heating, cooling (air conditioning), and lighting other administrative buildings at airports (Janić, 2011). Normally, airports purchase electricity from the commercial grid and this electricity is supplied by a power company to the airport (Nam, 2019; Ortega Alba & Manana, 2016).

Importantly, airports around the world are shifting toward the utilization of clean energy technologies together with the implementation of practices that reduce local emissions. This environmental-related strategy includes replacing fossil fuel-based with electricity-based operations at airports (Sajed Sadati et al., 2018). Indeed, in recent times, several new energy technologies have undergone development and implementation as energy sources for airports. These new technologies include solar photovoltaic (PV), concentrating solar power, wind power, oil and natural gas extraction, steam-generated power production and electricity transmission (Barrett et al., 2014).

Some airports have also developed and operate new power-generation systems that provide reliable and affordable sustainable energy. Many airports have installed biomass boilers, have worked to improve the natural light and ventilation, and, in some instance, have installed wind turbines to generate electrical energy and some airports have used boreholes to exploit sources of geothermal energy (Budd & Budd, 2013).

2.2. Energy Usage at Airports

Airports and their key stakeholders require power to operate their equipment, systems, heating, ventilation, and air conditioning (HVAC) systems, as well as for the lighting of their buildings. In addition, airports require power for their airfield infrastructure, for example, runway and taxiway lighting. Airport energy usage also includes the fuel necessary to power ground support equipment (GSE) (Nam, 2019).

The principal areas of energy consumption at an airport are heating, cooling, lighting, and the energy required for operating the airport's facilities and systems (Janić, 2011; Radomska et al., 2018). Fuel is also used for airport's heating boiler systems and emergency generators (Ortega Alba & Manana, 2016). Airports consume large quantities of electricity (Sreejaya et al., 2020). Typically, airport terminal buildings consume more energy than other buildings that are located within the airport precinct due to the terminal building's functional and operational characteristics (Yildiz et al., 2022). The airport terminal's heating, ventilation, and air conditioning (HVAC) systems use the largest amount of energy. It has been estimated that around 70% of the energy consumed in airport terminal buildings is used for heating, cooling, and air conditioning purposes. This energy consumption rate is higher in those countries that have a cold climate (Akyüz et al., 2017). Indeed, airport terminals have a high level of energy consumption for space heating in cold climate zones (Liu et al., 2021). Airport terminal buildings also have a high energy demand due to their cooling demand. This is especially so in hot arid climates, where airports cool their terminal buildings to achieve passenger thermal comfort (Abdallah et al., 2021).

Electrical energy is also used at airports for powering the aids that are used to facilitate air transport operations, and for airport buildings, aircraft hangers and other airport facilities (Kazda et al., 2015). As previously noted, airports are extremely energy-intensive areas (Baxter et al., 2019; de Rubeis et al., 2016; Ortega Alba & Manana, 2017). An airport terminal is an industrial building which may be of considerable size. Energy consumption is necessary to provide lighting; to provide operation of electronic devices and the related equipment that is necessary to facilitate passenger boarding activities, and to provide heating and cooling systems (Fossi & Esposito, 2015). Airport terminal buildings also require power to serve the requirements of the airport administration and the airport's tenants so that they can conduct their business activities (Nam, 2019). Airport buildings are thus particularly energy intensive (Danjuma Mambo et al., 2015; Kim et al., 2020; Yildiz et al., 2021). The large energy usage at airports is due to the large buildings, for example, passenger terminal buildings, which are equipped with heating and air-conditioning systems. Also, there is a very high-power demand for lighting and electric equipment, and for the various facilities that are located within the airport precinct (Cardona et al., 2006; Ortega Alba & Manana, 2017). The

passengers handled at the airport significantly affect airport terminal energy consumption and the airport's indoor environmental quality (Tang et al., 2023).

Airports require a guaranteed, appropriately priced, and secure energy supply to satisfy peak demand from their service partners and passengers (Thomas & Hooper, 2013).

Crude oil is often used at airports for producing the gasoline that is used to power the ground service equipment (GSE) and other vehicles that are operated in an airport's airside and landside precincts (Janić, 2011). Ground service equipment (GSE) refers to vehicles and equipment that are used in the airport precinct to service aircraft whilst they are at the gate in between flights (Hazel et al., 2011).

Energy consumed by airports can be broken down into the energy consumed by the airside activities undertaken at the airport as well as the energy consumed in the provision of the airport's landside area activities (Janić, 2011). The airside means the movement area at an airport, adjacent terrain and buildings/infrastructure, or portions, the access to which is restricted. Landside means those parts of an airport as well as the adjacent terrain and buildings or portions thereof that are not in the airside precinct (Rossi Dal Pozzo, 2015). In the airport's airside area, energy requirements include the fuel that is consumed by aircraft during the landing and take-off (LTO) cycles. Also, ground vehicles serving aircraft during the turnaround process at the apron/gate complex consume energy. In the airport landside area, the principal consumers of energy are the airport ground access systems/modes and passenger and air cargo terminals together with other administrative buildings serving the airport. In most cases, the primary energy sources are from non-renewable fossil fuels and to a smaller extent from renewable wind, water, and solar sources (Janić, 2011).

The operation of more efficient heating and cooling systems and the performance of the building envelope can result in significant reductions in energy consumption. This can be achieved without compromising comfort conditions in the airport terminal buildings (Akyüz et al., 2018). To ensure that energy demand can be met when the needs arise, airports are increasingly focusing on energy-conservation measures in the design (and operations) of terminal buildings and infrastructure (Thomas & Hooper, 2013).

2.3. The Factors that Influence an Airport's Energy Consumption

An airport's energy consumption is influenced by a range of factors, which include:

- The airport's size.
- The airport's architecture (compact, finger passenger terminals, satellite passenger terminals, and remote satellite passenger terminals).
- Location and climate.
- Airport operational hours.
- Insulation level of terminal(s) building(s),
- Heating, ventilation, air conditioning (HVAC) system.
- Airport energy actors' energy usage behavior.
- Energy management.
- Level of airport maintenance.
- Capacity of aircraft maintenance facilities.
- Daylight utilization.
- Solar heating.
- Traffic density.
- Number of passengers handled at the airport.
- Smooth operations of electrical and mechanical systems (Akyuz et al., 2019, p. 28).

III. RESEARCH METHODOLOGY

3.1. Research Approach

This study was underpinned by an in-depth qualitative longitudinal research design (Derrington, 2019; Hassett & Paavilainen-Mäntymäki, 2013; Neale, 2018). Qualitative longitudinal research aims to expand and develop theories (Derrington, 2019). A case study enables the researcher(s) to explore complex phenomena (Remenyi et al., 2010; Taber, 2014; Yin, 2018). Case studies also enable the researcher(s) to collect rich, explanatory information that provides in-depth insights into the phenomenon under investigation (Ang, 2014).

3.2. Data Collections

The data used in the study was obtained from a range of documents, company materials available on the internet and records as sources of case evidence. Documents included London Gatwick Airport's annual Decades of Change sustainability reports, London Gatwick Airport's annual reports, and the airport's websites. An extensive search of the leading air transport journals and airport-related magazines was also conducted in the study.

The key words used in the database searches included "London Gatwick Airport's environmental policy", "London Gatwick Airport's energy sources", "London Gatwick Airport's annual energy consumption", "London Gatwick Airport's annual electricity consumption", "London Gatwick Airport's annual natural gas

consumption", "London Gatwick Airport's annual renewable energy consumption", and "London Gatwick Airport's annual renewable energy consumption as a share of total energy consumption".

This study used secondary data. The three principles of data collection as suggested by Yin (2018) were followed: the use of multiple sources of case evidence, creation of a database on the subject and the establishment of a chain of evidence.

3.3. Data Analysis

The data collected for the case study was examined using document analysis. Document analysis is quite commonly used in case studies. Document analysis focuses on the information and data from formal documents and a firm's records that are collected by a researcher(s) when conducting their case study (Andrew et al., 2011; Yin, 2018). The documents gathered for the study were examined according to four key criteria: authenticity, credibility, representativeness and meaning (Scott, 2014; Scott & Marshall, 2009).

The document analysis was undertaken in six distinct phases:

- Phase 1: The first phase involved planning the types of the required documentation and ascertain their availability for the study.
- Phase 2: The data collection phase involved sourcing the documents and developing and implementing a scheme for the document management. The documents were stored in a case study database.
- Phase 3: The collected documents were examined to assess their authenticity, credibility and to identify any potential bias.
- Phase 4: The content of the collected documents was carefully examined, and the key themes and issues were identified and recorded in the case study.
- Phase 5: This phase involved the deliberation and refinement to identify any difficulties associated with the documents, reviewing sources, as well as exploring the documents content.
- Phase 6: In this final phase the analysis of the data was completed (O'Leary, 2004, p. 179).

Following the guidance of Yin (2018), the study's documents were downloaded and stored in a case study database. All the documents gathered for the study were all written in English. Each document was carefully read, and key themes were coded and recorded in the case study research framework (Baxter, 2022).

IV. RESULTS

4.1. An Overview of London Gatwick Airport

The origins of London Gatwick Airport date back to the 1930s. However, the airport was officially opened on the 9th of June 1958 (Woodley, 2014). In 1987, the British government privatized seven major airports through a share flotation (Graham, 2011). London Gatwick Airport was one of the airports that was privatized by the British Government in 1987 (Arblaster, 2017; Augustyniak, 2009). London Gatwick Airport was sold by the British Airport Authority (BAA) in late 2009 to Global Infrastructure Partners (Budd & Ison, 2018). Gatwick Airport Limited is now the company that has been licensed by the Civil Aviation Authority (CAA) to operate London Gatwick Airport. On 14 May 2019, the airport's ownership transferred to new management with VINCI Airports acquiring a shareholding of 50.01%. The remaining shares are owned by a consortium of investors, and these are managed by Global Infrastructure Partners (GIP), who have operated London Gatwick Airport since 2009 (Airport Technology, 2019; Bates, 2019).

London Gatwick Airport (IATA airport code: LGW) is the second largest of the main London airports and is ranked as the second busiest airport in the United Kingdom, as measured by passenger traffic (International Airport Review, 2023, Mann, 2022). London Gatwick Airport is the busiest single runway airport in the World (Budd & Ison, 2017; Irvine et al., 2015; Liaghat et al., 2011; Woodford, 2013). The largest passenger airline at London Gatwick Airport is the low-cost carrier easyJet (Gatwick Airport Limited, 2023a).

London Gatwick Airport's main runway is 3,316 metres long and 45metres wide. The northern runway can only be used on those occasion when the primary runway is not is use. The runways cannot be used simultaneously because there is insufficient separation between aircraft (Bowman & Simmons, 2011). The airport's South passenger terminal opened in 1958, whilst the North terminal opened in 1988. The airport's South Terminal is 160,000 square metres in size, whilst the North Terminal occupies an area of 98,000 square metres. The airport has 119 aircraft parking stands, with a total of 186 centrelines. The ability to use a stand flexibly means a total of 186 aircraft can be parked at the airport (Gatwick Airport Limited, 2023a).

London Gatwick Airport holds the Airport Council International Airport Carbon Accreditation Level 3+ "Neutral" level for direct emissions (Scope 1 and 2 Fuels and Electricity). In 2019, the airport signed the Airports Council Europe pledge to reach Net Zero for direct emissions prior to 2050. In addition, London Gatwick

Airport Gatwick was the first airport to join "RE100", the global coalition committed to renewable electricity (Gatwick Airport Limited, 2023c). In 2010, London Gatwick Airport obtained its ISO14001 Environmental Management System (EMS) accreditation (Gatwick Airport Limited, 2023b).

Figure 1 presents London Gatwick Airport's annual enplaned passengers and the year-on-year growth (%) from 2014 to 2021. One passenger enplanement measures the embarkation of a revenue passenger, whether originating, stop-over, connecting or returning (Holloway, 2016). As can be observed in Figure 1, the airport's annual enplaned passengers displayed an upward growth trend from 2014 to 2019, when the annual passenger volumes handled at the airport increased from 38,127,690 passengers in 2014 to a high of 46,568,000 passengers in 2019. The most significant annual increase in the airport's passenger traffic was recorded in 2016, at which time it increased by 7.12% on the 2015 levels (Figure 1). Figure 1 shows that there was a very substantial decrease in the annual passenger traffic handled at the airport in 2020, when it declined by 78.17% on the 2019 levels. This large decrease could be attributed to the adverse impact that the COVID-19 virus pandemic had on air passenger demand in 2020 (Leppävuori et al., 2022). During the COVID-19 pandemic, the demand for passenger air transportation services declined significantly in 2020 (Barczak et al., 2022; El Zowalaty et al., 2020; Hotle & Mumbower, 2021; Mumbower, 2022) as the COVID-19 pandemic caused a significant decrease in the world air travel market supply and demand chain in 2020 (Dube et al., 2021). Furthermore, due to the global coronavirus crisis, most countries placed restrictive measures to confine the pandemia (Iacus et al., 2020). These pandemic response measures included many countries imposing travel restrictions (Akkucuk, 2020; Fabeil et al., 2020; Mat Dawi et al., 2021). In 2020, British Airways suspended all flights to and from London's Gatwick airport due to the collapse in passenger demand. The airline's passenger demand was affected by the CORONA-19 virus pandemic (BBC News, 2020). Virgin Atlantic Airways also cancelled all operations at London Gatwick Airport at the beginning of the COVID pandemic (Amaro, 2020; Bodell, 2022).

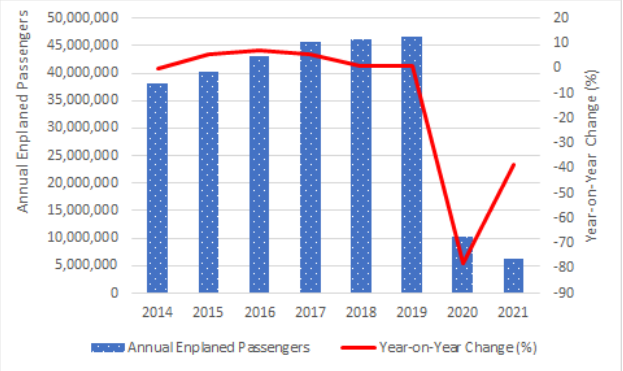


Fig.1: London Gatwick Airport's Annual Enplaned Passengers and the Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2014, 2016, 2018a, 2020a, 2022a).

Figure 2 presents London Gatwick Airport's annual aircraft movements and the year-on-year growth (%) from 2014 to 2021. Figure 2 shows that there was an upward trend in the airport's annual aircraft movements from 2014 to 2018. The airport's annual aircraft movements increased from 247,863 movements in 2014 to a high of 280,792 movements in 2018. In 2019, the airport's annual aircraft movements decreased by 0.04% on the 2018 levels. The airport's annual aircraft movements were adversely impacted by airline aircraft fleet deployment patterns in 2020 in response to the downturn in passenger demand because of the CORONA-19 virus pandemic. In 2020, the airport's annual aircraft movements decreased by 72.79% on the 2019 levels (Figure 2). The same situation occurred in 2021 when the airport's annual aircraft movements decreased by 31.93% on the 2020 levels (Figure 2). The COVID-19 pandemic continued to have an impact on the air transport industry in 2021 (Gao, 2022).

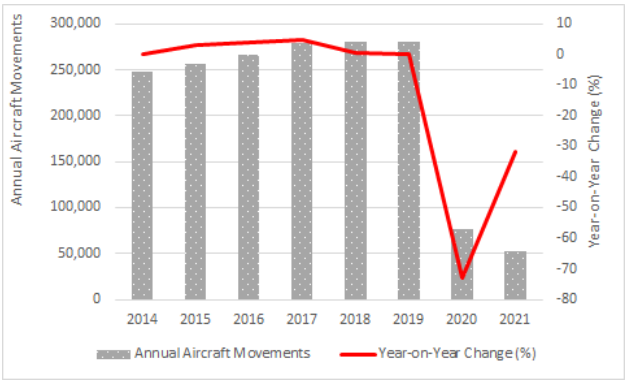


Fig.2: London Gatwick Airport's Annual Aircraft Movements and Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2014, 2016, 2018a, 2020a, 2022a).

4.2. London Gatwick Airport Environmental Policy

In June 2021, London Gatwick Airport implemented its second "Decade of Change Sustainability Policy". This policy contains the airport's 2030 targets. The policy also contains the airport's goals for the transition to becoming a net-zero airport that also contributes to local environmental stewardship as well as supporting the local economy, people, and communities (International Airport Review, 2021a; Gatwick Airport Limited, 2021b).

As part of the policy, London Gatwick Airport aims to be a responsive and responsible airport operator and, in so doing, it undertakes various activities that enable the airport to:

- Deliver a strong community-based program.
- Maximize the airport's local regional and national economic benefits.
- The airport aims to remove or mitigate its direct environmental impacts whilst at the same time collaborating on industry-wide solutions to climate change.
- Set the right standards and practices.
- The airport enables its staff to be sustainability champions.

The airport also endeavors to understand the requirements of its stakeholders and partners (Gatwick Airport Limited, 2021b, p. 3). In-line with the policy, London Gatwick Airport's sustainability policy goals will continue to centre on:

- Enabling London Gatwick Airport to be the airport of choice for its passengers and customers.
- Ensuring the safety and security of our passengers, partners, and staff members.
- Generating national and regional economic wealth, and connectivity.
- The airport aims to increase its traffic catchment area and employment.
- London Gatwick Airport aims to reduce the adverse impacts to the environment.
- The airport aims to develop and maintain constructive relationships with stakeholders.
- The airport aims to recognize the value of its employees, key stakeholders, and communities (Gatwick Airport Limited, 2021b, p. 3).

In delivering and achieving its sustainability goals London Gatwick Airport will continue to:

- Set clearly defined targets and policies for delivery from today to 2030.
- Operate today as efficiently as it can, and the airport will invest appropriately for the future.
- Protect the business and ensure the airport has the appropriate resilience.
- London Gatwick Airport communicates its approach and performance with key stakeholders.
- Partner with organizations who can help the airport to achieve its goals.
- Work with government, industry, and regulators to develop policy and plans; and
- Engage with its community explaining both its positive and negative impacts (Gatwick Airport, 2021b, p. 3).

To achieve its sustainability goals, the airport will continue to set clearly defined targets and policies for delivery from 2021 to 2030. The airport's 2030 goals take into consideration local and national sustainability priorities and will enable the airport to play its part in national and international action to deliver on the Paris Climate Agreement together with the United Nations' (UN) Sustainable Development Goals (SDGs) (Gatwick Airport Limited, 2021b). In 2015, all United Nations Member States adopted the "2030 Agenda for Sustainable Development" (Boeren, 2019; Lenkaitis, 2022; Miola & Schiltz, 2019). The "2030 Agenda for Sustainable Development" has seventeen 17 Sustainable Development Goals (SDGs) (Calabrese et al., 2021; Scholz & Brandi, 2017). Each SDG comprises a range of targets to be achieved by 2030 (Katila et al., 2019). The United Nations (UN) has acknowledged that "the goal to achieve affordable and clean energy is particularly important as it interlinks with its other sustainable development goals (SDGs) (Munguia et al., 2020). At the time of the present study, London Gatwick Airport's environmental policy was aligned with five of the United Nations Sustainable Development Goals (SDG) themes and targets. The UN Sustainable Action Goals (SDGs) adopted by London Gatwick Airport are SDG 8 Decent work and economic growth, SDG 9 Resilient infrastructure, SDG 10 Reduced inequalities, SDG 11 Sustainable cities and communities, and SDG 13 Climate action (Gatwick Airport Limited, 2021b).

At London Gatwick Airport, energy efficiency is incorporated in the airport's refurbishments and capital projects, ranging in scope from the passenger terminals to the airport fire station (Gatwick Airport, 2023b).

4.3. London Gatwick Airport Energy Sources

London Gatwick Airport's two principal energy sources are electricity and natural gas. London Gatwick Airport

uses energy 24 hours a day to operate the airfield, the airport's two terminal buildings and the operation of more than 120 businesses based at the airport. The largest percentage of energy is used for the airport's lighting, heating, and cooling of buildings. The airport buildings have a large number of lifts, escalators, as well as passenger walkways. The airport's baggage handling system, the fixed electrical ground power system (FEGP) for aircraft and the lighting for stands, taxiways, car parks and the runway plus there is a system for the baggage also require energy (Bilton, 2019). Natural gas is primarily used for heating buildings (Gatwick Airport, 2017). England has cold winters (Lamb, 2011), and thus, the airport needs to provide heating for its buildings during the cold winter months.

It is important to note that not all the energy used on the airport is within Gatwick's direct control, as over a third of energy is re-sold to third party businesses (Gatwick Airport Limited, 2017). During the period 2019 to 2021, London Gatwick Airport also procured and used vehicle and equipment fuel (MI), refrigerant gas, and propane (Gatwick Airport Limited, 2022b).

In November 2016, operations commenced at London Gatwick Airport's waste processing and biomass generation facility (Baxter & Srisaeng, 2022). Following the commencement of operations of this new facility, London Gatwick Airport was the first airport in the world that could legally dispose of Category 1 waste on site (Gatwick Airport Limited, 2017; James, 2017; Manuel, 2016). At London Gatwick Airport, Category 1 and other types of organic waste are converted into biomass fuel that is used to power the processing plant and provide heating for the airport's North Terminal (James, 2017; Manuel, 2016). The system also heats Gatwick's waste management site (Bioenergy Insight, 2017). The waste plant also provides power to the site's water recovery system (Lyons Hardcastle, 2017). London Gatwick Airport contributes to a lower carbon grid through its procurement of 100% certified renewable electricity. The airport has purchased this 100% certified renewable electricity since 2013 (Bilton, 2019; Gatwick Airport Limited, 2019).

4.4. London Gatwick Airport Annual Energy Consumption

London Gatwick Airport's total annual energy consumption and the year-on-year change (%) from 2014-2021 is presented in Figure 3. Figure 3 shows that there were two discernible trends in the airport's total annual energy consumption during the study period. There was a general upward trend from 2014 to 2018, at which time it increased from 199,885 MWh in 2014 to a high of 215,392 MWh in 2018 (Figure 3). The most significant annual increase in this metric during this period was recorded in 2016, when the airport's total annual energy consumption increased by 4.21% on the 2015 levels (Figure 3). Over the period 2014 to 2018, London Gatwick Airport annual enplaned passengers and aircraft movements increased on a year-on-year basis. Consequently, there was a slightly greater energy requirement to accommodate the growth in passenger traffic and aircraft movements during the period 2014 to 2018. Figure 3 also shows that the airport's annual energy consumption decreased on a year-on-year basis in 2019. In 2019, the airport's annual energy consumption decreased by 1.61% on the 2018 levels. This was a favorable outcome as the airport handled higher levels of passenger traffic in 2019, and this passenger growth was accommodated without an increase in additional energy consumption. Figure 3 shows that London Gatwick Airport's annual energy consumption decreased by 35.25% on the 2019 levels (Figure 3). This decrease reflected lower levels of passenger traffic and aircraft movements due to the CORONA-19 virus pandemic and the associated government and airline response measures. In 2021, London Gatwick Airport's consumed 136,854.42 MWh of energy (Figure 3). This was the lowest annual amount of energy consumed by the airport during the study period and represented a 0.24% decrease on the 2020 levels.

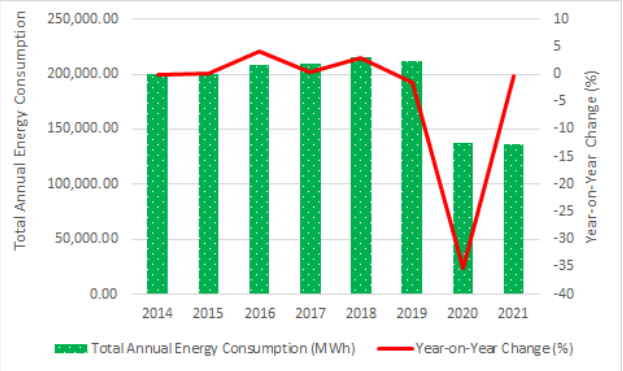


Fig.3: London Gatwick Airport's Total Annual Energy Consumption and Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a, 2022b).

4.5. London Gatwick Airport Annual Electricity Consumption

London Gatwick Airport's annual electricity consumption and the year-on-year change (%) from 2014 to 2021 is presented in Figure 4. As can be observed in Figure 4, London Gatwick Airport's annual electricity consumption fluctuated over the period 2014 to 2021. There were three years in this period where the airport's annual electricity consumption increased on a year-on-year basis. These increases occurred in 2016 (+3.13%), 2017 (+1.39%), and

2018 (+1.8%), respectively (Figure 4). The airport handled higher levels of passenger traffic and aircraft movements in these respective years. These increases in both passengers and aircraft movements had a concomitant impact on the amount of electricity that was needed to handle the increased passenger traffic and aircraft movements. During the period 2014 to 2021, there were four years where the airport's annual electricity consumption decreased on a year-on-year basis. These annual decreases were recorded in 2015 (-3.17%), 2019 (-2.15%), 2020 (-37.75%), and 2021 (-8.05%) respectively (Figure 4). In 2015 and 2019, the airport handled increased passenger volumes and was able to accommodate this traffic growth without an associated increase in its electricity consumption, which is a very favorable outcome. As previously noted, the airport handled significantly fewer passengers and aircraft movements in 2020 and 2021 due to the COVID-19 virus pandemic and this too contributed to the lower electricity requirements in 2020 and 2021. Over the period 2014 to 2021, the airport's highest annual electricity consumption occurred in 2018 (154,212.37 MWh), whilst the lowest annual electricity consumption was recorded in 2021 (89,108.60 MWh) (Figure 4). .

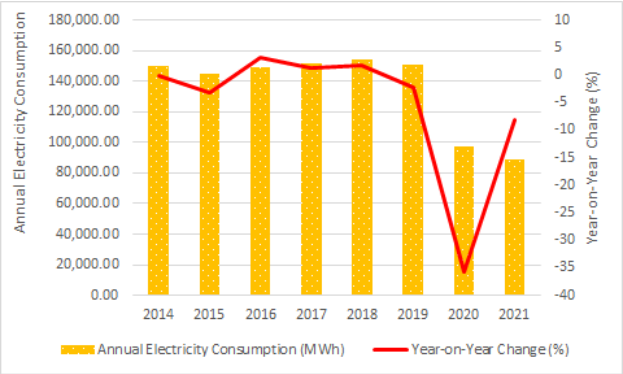


Fig.4: London Gatwick Airport's Annual Electricity Consumption and Year-on-year Change: 2014-2021.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a, 2022b).

An important measure of an airport's energy efficiency is the energy consumption (electricity, gas, or fuel) per enplaned passenger (Graham, 2005) or per workload unit (WLU) (Baxter et al., 2018). One workload (WLU) or traffic unit is equivalent to one passenger, or 100 kilograms of air cargo handled (Doganis, 2005; Graham, 2005; Teodorović & Janić, 2017). London Gatwick Airport's annual electricity consumption per workload unit (kWh/WLU) and the associated year-on-year change (%) from 2014-2021 is presented in Figure 5. Figure 5 shows that there were two discernible trends in this metric during the study period. There was an overall downward trend in this metric over the period 2014 to 2019. This overall downward trend is demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, all bar one value is below the line. Over this period, there was a single year when the annual electricity consumption per workload unit (WLU) increased on a year-on-year basis. This increase occurred in 2018, at which time the annual electricity consumption per workload unit (WLU) increased by 0.90% on the 2017 levels (Figure 5). The airport's annual electricity consumption increased by 1.8% in 2018 and this was higher than the 1.12% increase in passenger traffic in 2018. As a result, the annual electricity consumption per workload unit (WLU) increased on a year-on-year basis in 2018. Over the period 2014 to 2019, the two most significant annual decreases in the airport's electricity consumption per workload unit (WLU) occurred in 2015 (-8.16%) and 2017 (-4.04%) (Figure 5). These annual decreases were very favorable as London Gatwick Airport handled higher passenger traffic volumes in both 2015 and 2017, and the airport was able to accommodate this passenger traffic growth whilst also reducing the amount of electricity consumed per passenger or per workload unit (WLU) in these respective years. Figure 5 shows that in 2020, the airport's annual electricity consumption per workload unit (WLU) increased by 194.13% on the 2019 levels. This was the most significant annual increase in this metric during the study period. This significant annual increase in 2020 could be attributed to the airport's annual electricity consumption decreasing by 35.73% whilst passenger volumes declined by 78.17% in 2020, and thus, there were fewer passengers or workload units (WLUs) available to spread the airport's annual electricity consumption over in 2020. A similar situation occurred in 2021, when this metric increased by 49.52% on the 2020 levels (Figure 5). In 2021. The airport's annual passenger traffic decreased by 38.46% on the 2020 levels, whilst its annual electricity consumption decreased by 8.05% on the 2020 levels. So, once again, there were fewer workload units (WLUs) available to spread the slightly lower electricity consumption over. As noted earlier, in both 2020 and 2021, London Gatwick Airport's passenger traffic was impacted by the COVID-19 pandemic and the related pandemic response measures. This led to the situation where the electricity consumption per workload (WLU) increased on a year-on-year basis in both years. However, it is important to note that London Gatwick Airport procures 100% certified renewable electricity so the higher annual electricity consumption per workload unit (WLU) in 2020 and 2021 is still friendly from an environmental perspective given that renewable energy is

regarded as being an environmentally friendly energy source (Jäger-Waldau et al., 2011). Indeed, renewable electricity reduces environmental harm (Sovacool, 2010).

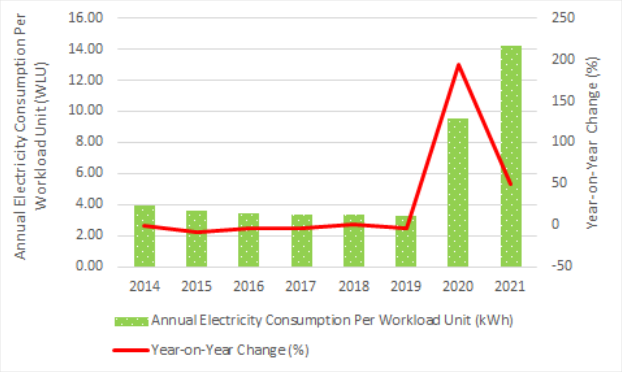


Fig.5: London Gatwick Airport's Annual Electricity Consumption Per Workload Unit (WLU) and Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a, 2022b).

An airport's energy efficiency can also be measured by energy consumed per aircraft movement (Janić, 2011). London Gatwick Airport's annual electricity consumption per aircraft movement and the associated year-on-year change (%) from 2014 to 2021 is depicted in Figure 6. Figure 6 shows that there was a general downward trend in the annual electricity consumed per aircraft movement over the period 2014 to 2019. This overall downward trend is demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, all bar one value is below the line. This is a very favorable result and shows that the airport has been able to handle more aircraft each year without incurring a concomitant increase in the amount of electricity consumed per aircraft movement. Figure 6 shows that the annual electricity consumption per aircraft movement increased by 1.85% in 2018. In 2018, the annual aircraft movements increased by 0.68% whereas the airport's annual electricity consumption increased by 1.80%, and this resulted in the higher annual electricity consumption per aircraft movement in 2018. The largest single annual decrease in electricity consumption per aircraft movement was recorded in 2015, at which time it decreased by 3.57% on the 2014 levels (Figure 6). Figure 6 shows that there was a very pronounced spike in this metric in 2020, at which time it increased by 135.18% on the 2019 level. As noted earlier, the airport's annual electricity consumption in 2020 decreased at a lower level than the annual reduction in the number of aircraft movements at the airport, and thus, this translated into the higher electricity consumption per aircraft movement in 2020. The same situation occurred in 2021, at which time the airport's annual aircraft movements decreased at a higher rate than the decrease in electricity consumption, and thus, there were fewer aircraft movements to spread the reduced electricity consumption over in 2021.

It is important to note that over the past two decades or so, the size of commercial aircraft has increased. The Airbus A380 first entered commercial service with Singapore Airlines in October 2007 (Jackson, 2021; Simons, 2014). Singapore Airlines was the first airline to take delivery of the Airbus A380 (Flottau, 2023). The Airbus A380 is the world's largest passenger aircraft (Marsch, 2016; Vermeeren, 2003). Due to its size, the Airbus A380 can carry at once approximately twice as many passengers as any other medium-sized aircraft (Ussinova et al., 2018). Emirates Airline operates the Airbus A380 to London Gatwick Airport. In February 2000, Boeing Commercial Airplanes announced the launch of two new longer-range Boeing 777s (Kemp, 2007). Depending upon the aircraft cabin configuration selected by airlines, the Boeing B777-300ER can carry around 20% more passengers than the Boeing B777-200 (Aviation Week & Space Technology, 1998). The Boeing B777-300ER entered commercial service in April 2004 (Eden, 2017). The Boeing 747-8 Intercontinental passenger aircraft's first commercial flight took place on 1 June 2012 (Asian Aviation, 2012). The Boeing 787-8 entered commercial service in 2011, whilst the Boeing 787-9 entered commercial service in August 2014 (Hitt et al., 2019; Kumar & Padture, 2018). The Airbus A350-900XWB first commercial flight was operated by Qatar Airways in 2014 (Aircraft Commerce, 2015). Singapore Airlines took delivery of the first Boeing 787-10 on March 14th, 2018 (Davis & Davis, 2020). The Boeing 787-8 is around 20 seats larger than the Boeing 767-300ER, whilst the Boeing 787-9 has about 20 seats more capacity than the A330-200 (Aircraft Commerce, 2016).

London Gatwick Airport's annual electricity consumption as a share of the airport's total annual energy consumption and the associated year-on-year change (%) from 2014 to 2021 is depicted in Figure 7. Figure 7 shows that the airport's annual electricity consumption as a share of total energy consumption has exhibited an overall downward trend, decreasing from a high of 74.85% in 2014 to a low of 65.11% in 2021. This overall downward trend is once again demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, all bar one value is below the line. Figure 7 shows that this metric increased by 1.06% in 2017. This increase could be attributed to the airport's increased annual electricity consumption in 2017 (+1.39%) and the lower annual gas consumption (-2.32%) in the same year. The most

significant annual decrease in this metric was recorded in 2021, at which time it decreased by 7.82% on the 2020 levels. This decrease came about because of the lower annual electricity consumption (-8.05%) and increased gas consumption (+18.54%) in 2021. Figure 7 shows that electricity was still the largest energy source used by the airport during the study period (2014 to 2021).

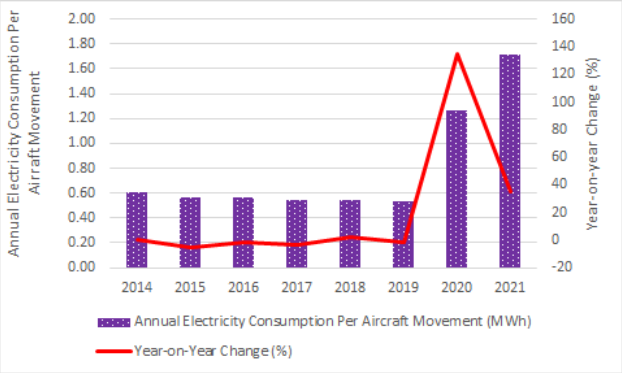


Fig.6: London Gatwick Airport's Annual Electricity Consumption Per Aircraft Movement and Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a, 2022b).

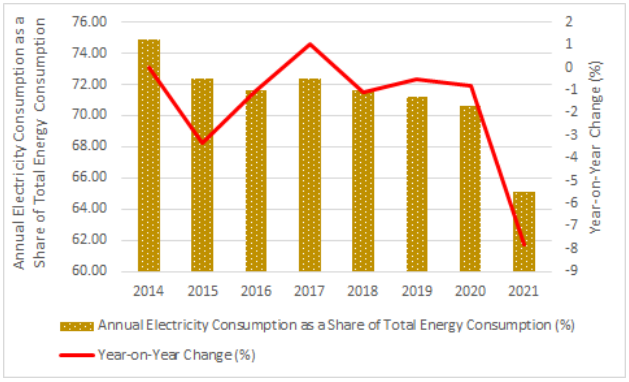


Fig.7: London Gatwick Airport's Annual Electricity Consumption as a Share of Total Energy Consumption and Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a, 2022b).

4.5. London Gatwick Airport Natural Gas Consumption

As previously noted, natural gas is one of London Gatwick Airport's key energy sources. Natural gas (NG) is a naturally gaseous hydrocarbon mixture that is formed beneath the earth's surface (Faramawy et al., 2016; Speight 2019). Natural gas is a clean burning fuel (Papagiannakis et al., 2010). Natural gas (NG) is regarded as the cleanest fossil fuel and is a safe source of energy when transported, stored, and used (Faramawy at al., 2016). Thus, natural gas is widely considered to be an environmentally cleaner fuel than coal (Cathles et al., 2012; Liang et al., 2012; Pilavachi et al., 2009).

London Gatwick Airport's total annual natural gas consumption and the year-on-year change (%) from 2014 to 2021 is presented in Figure 8. As has been previously noted, at London Gatwick Airport, natural gas is primarily used for heating buildings and so gas use at the airport is significantly affected by the prevailing winter weather conditions (Gatwick Airport, 2017). As can be observed in Figure 8, there were two discernible trends in London Gatwick Airport's annual gas consumption during the study period. Over the period 2014 to 2018, there was a general upward trend in London Gatwick Airport's annual gas consumption, when it increased from 50,278.09 MWh in 2014 to a high of 61,179.86 MWh in 2018 (Figure 8). Figure 8 shows that there was quite a pronounced spike in this metric in 2015, when it increased by 11.95% on the 2014 levels due to the higher gas requirements at the airport in 2015 (Figure 8). There was a further increase in this metric in 2016, when it increased by 5.14% on the 2015 levels, with this increase being the result of higher natural gas usage requirements. In 2018, the airport's annual gas consumption increased by 5.82%, the third highest annual increase in the study period, and this increase higher natural gas usage patterns (Figure 8). During the early years of the study period, that is, 2014 to 2018, there was a single year when the airport's annual natural gas consumption decreased on a year-on-year basis. This decrease occurred in 2017, when it decreased by 2.32% on the 2016 levels. This decrease could be attributed to a lower natural gas usage requirement in 2017. Figure 8 shows that the airport's annual natural gas consumption once again decreased on a year-on-year basis in 2019 (-0.26%), and 2020 (-33.99%). As noted earlier, the airport's annual passenger and aircraft movements in 2020 were adversely impacted by the COVID-19 virus pandemic and the related government and airline response measures and these factors led to the airport's lower gas requirements in 2020. Figure 8 shows that London Gatwick Airport's annual natural gas consumption increased by 18.54% in 2021. Colder than average conditions were experienced in England in the early part of 2021 and the 2021 winter was colder than average (The Met Office, 2021).

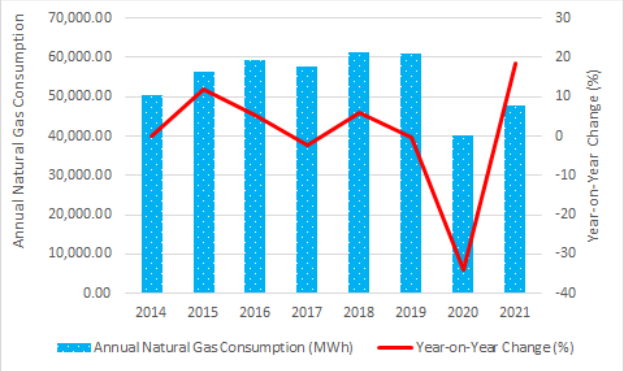


Fig.8: London Gatwick Airport's Annual Natural Gas Consumption and Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a, 2022b).

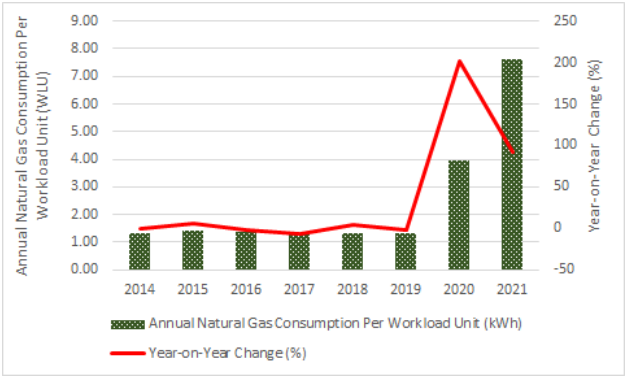


Fig.9: London Gatwick Airport's Annual Natural Gas Consumption Per Workload Unit (WLU) and Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a, 2022b).

London Gatwick Airport's annual natural gas consumption per workload unit (kWh/WLU) and the associated year-on-year change (%) from 2014 to 2021 is depicted in Figure 9. As can be observed in Figure 9, London Gatwick Airport's annual natural gas consumption per workload unit (WLU) oscillated over the study period. Figure 9 shows that there were two years during the period 2014 to 2020 where the airport's annual natural gas consumption per workload unit (WLU) increased on a year-on-year basis. These annual increases were recorded in 2015 (+6.06%), and in 2018 (+4.72%), respectively (Figure 9). These increases were due to the airport's higher natural gas consumption in both 2015 and 2018, which increased at a higher rate than the annual passenger growth rate in these respective years. Figure 9 shows that there was a very significant spike in this metric in 2020, when it increased by 202.29% on the 2019 levels (Figure 9). This increase could be attributed to the lower number of passengers handled at the airport in 2020. In 2020, passenger traffic declined by 78.17%, whist natural gas consumption declined by 33.99%. A different situation occurred, however, in 2021, when this metric increased by 92.67% on the 2020 levels (Figure 9). In 2021, the airport's annual passenger traffic or workload units (WLUs) decreased by 38.46% on the 2020 levels, whilst the airport's natural gas consumption increased by 18.54%. This led to the situation where there were fewer workload units (WLUs) available to spread the increased natural gas consumption over in 2021.

London Gatwick Airport's annual natural gas consumption as a share of the airport's total annual energy consumption and the associated year-on-year change (%) for the period 2014 to 2021 is depicted in Figure 10. Figure 10 shows that there has been a general upward trend in London Gatwick Airport's natural gas consumption as a share of its total energy consumption. This general upward trend is once again demonstrated by the year-on-year percentage change line graph, which is more positive than negative, that is, all bar one value is above the line. Figure 10 shows that there was a spike in this metric in 2015, when it increased by 11.84% on the 2014 levels. The airport's annual electricity consumption decreased on a year-on-year basis in 2015, whereas the natural gas consumption increased by 11.95% in that year. There were several smaller annual increases in this metric during the study period. These increases were recorded in 2016 (+0.88%), 2018 (+2.82%), 2019 (+1.37%), and 2020 (+1.97%), respectively (Figure 10). In 2016 and 2018, the airport's annual natural gas consumption increased at a higher rate than the airport's annual electricity, and hence, this led to the natural gas consumption as a share of total energy consumption being higher in both 2016 and 2018. In 2019 and 2020, the airport's natural gas consumption decreased at a lower rate than the airport's electricity consumption, and this resulted in the natural gas consumption accounting for a greater share of the airport's annual energy consumption. Figure 10 shows that there was a quite pronounced spike in this metric in 2021, at which time it increased by 18.83% on the 2020 levels. As previously noted, London Gatwick Airport's annual natural gas consumption increased by 18.54% in 2021, whilst its annual electricity consumption decreased by 8.05%, and thus, these disparities in the energy consumption trends

resulted in natural gas consumption accounting for a higher share of the airport's total annual energy consumption in 2021.

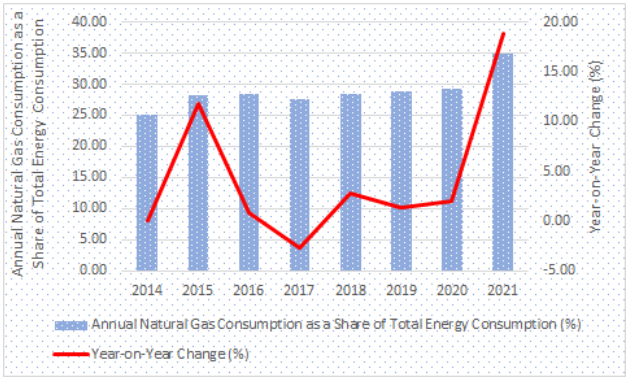


Fig.10: London Gatwick Airport's Annual Natural Gas Consumption as a Share of Total Energy Consumption and Year-on-Year Change (%): 2014-2021.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a, 2022b).

4.6. London Gatwick Airport Annual Onsite Renewable Energy Generation

As noted earlier, London Gatwick Airport has installed a waste-to-energy (WTE) system that produces renewable energy from the biomass boiler and the system also produces heating. London Gatwick Airport's annual onsite renewable energy generation and the associated year-on-year change (%) from 2014 to 2020 is depicted in Figure 11. Figure 11 shows that the airport's annual onsite renewable energy generation oscillated throughout the study period. The highest annual onsite renewable generation was recorded in 2017, at which time the airport produced 57.09 MWh of renewable energy. The lowest annual onsite renewable generation was recorded in 2019, at which time the airport produced 33.99 MWh of renewable energy (Figure 11). Figure 11 shows that there were two pronounced spikes in this metric during the study period. The first spike was recorded in 2017, at which time it increased by 31.74% on the 2016 levels, and in 2020, when it increased by 32.85% on the 2019 levels (Figure 11). The airport was able to increase its operational and commercial waste recovered for energy (%) in both 2017 and 2020. Figure 11 also shows that there were two quite pronounced annual decreases in this metric during the study period. These decreases were recorded in 2016 (-18.35%), and 2019 (-36.97%), respectively (Figure 11). The airport's annual operational and commercial waste recovered for energy (%) declined quite significantly in 2019 (Gatwick Airport Limited, 2020b).

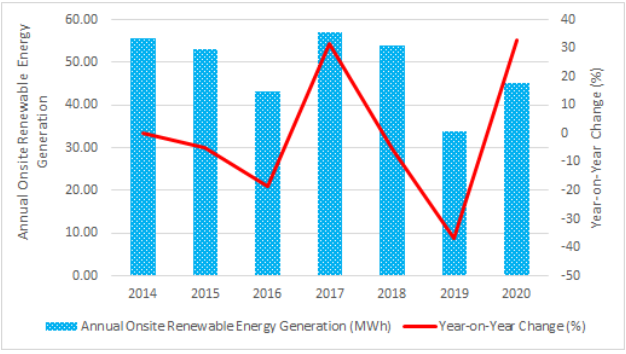


Fig.11: London Gatwick Airport's Annual On-Site Renewable Energy Generation and Year-on-Year Change (%): 2014 -2020).

Note: 2021 data not available.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a).

London Gatwick Airport's annual onsite renewable energy consumption as a share of total energy consumption and the associated year-on-year change (%) from 2014 to 2020 is depicted in Figure 12. Figure 12 shows that this metric oscillated over the study period, decreasing from a high of 74.8% in 2014 to a low of 70.6% in 2020. There was one year in the study period where this metric increased on a year-on-year basis. This increase occurred in 2017, when it increased by 1.1% on the 2016 levels. The most significant single annual decrease in this metric was recorded in 2015, when it decreased by 3.20% on the 2014 levels (Figure 12). This decrease in 2015 reflected differing energy consumption and energy production patterns in that year.

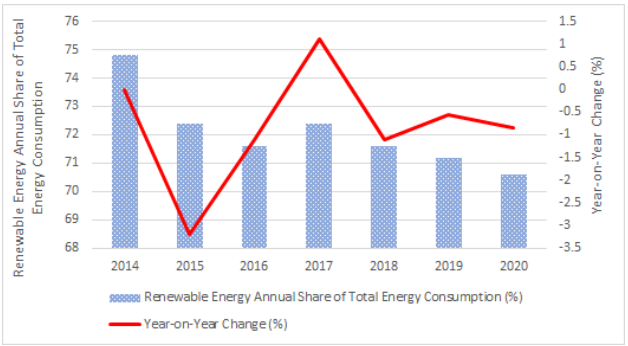


Fig.12: London Gatwick Airport's Annual Renewable Energy Consumption as a Share of Total Energy Consumption and Year-on-Year Change (%): 2014 -2020).

Note: 2021 data not available.

Source: Data derived from Gatwick Airport Limited (2017, 2019, 2021a).

An important environmental benefit of the waste-to-energy (WTE) system at London Gatwick Airport is that it

generates 1MW of renewable energy from the biomass boiler (Walker, 2016). London Gatwick Airport's waste-to-energy plant can also generate 22,500kW of heat each day. Importantly, green, or renewable energy, produces no greenhouse gas emissions from the combustion of fossil fuels. Consequently, this reduces some forms of harmful air pollution (United States Environmental Protection Agency, 2022). In addition, the use of green or renewable energy sources enables a firm or user to reduce their dependency on fossil fuels, improve their energy efficiency, and mitigate their greenhouse gas emissions (Arman & Yuksel, 2013).

4.7. London Gatwick Airport Energy Saving Measures

Airports all around the world are increasingly focusing on energy efficiency and, as a result, are implementing energy saving measures. The improvement of energy efficiency and environmental performance of buildings is increasingly regarded as being a major priority for airports all around the world (Fesanghary et al., 2012). In recent years, there has been a growing interest in targeting energy efficiency as a roadmap for carbon mitigation strategies and measures, limiting energy use, improving buildings' energy performance, and reducing energy consumption for achieving sustainable buildings (Hafez et al., 2023). Energy efficiency through investment in energy saving measures leads to long lasting results for the firm (Henryson et al., 2000). The measures employed to save energy vary in nature, and the decision maker is required to establish an optimal solution, considering multiple and usually competitive objectives such as energy consumption, financial costs, environmental performance, and so forth (Diakaki et al., 2010). Furthermore, saving energy has an important role in the concerted actions to mitigate the effects of global warming, especially the energy consumed by the existing buildings (with various energy consuming functions, or possibly inefficient energy), by implementing environmentally friendly solutions (Prada et al., 2020). Consequently, a very important trend in recent times has been the introduction of a wide range of energy saving measures by airports (Baxter, 2021; Emeara et al., 2020). These energy saving measures are enabling airports to optimize their energy consumption, whilst at the same time mitigating their impact on the environment. Gatwick Airport Limited has been one such company that has implemented various energy efficiency measures and these are discussed below.

During 2016, "Airport Cars", London Gatwick Airport's on-airport taxi provider, began introducing electric and hybrid vehicles to its fleet, including state-of-the-art Tesla cars. The use of electric powered vehicles enabled Airport Cars to provide emission-free travel within a 10-mile radius of the Airport. In 2016, the airport joined the Government's "Go Ultra Low Companies" initiative and in the same year London Gatwick Airport launched a low-emission taxi service with Airport Cars, the airport's on-airport taxi company (Gatwick Airport Ltd, 2017).

In April 2016, the airport opened its new Pier 1, a modern pier and combined baggage handling facility that was designed to meet its latest technical standards. The new Pier 1 incorporated high efficiency lighting, heating, ventilation, and air conditioning (HVAC) and baggage systems. In 2016, major project work was undertaken in the airport's North Terminal to create a new passenger security area, provide a large new airline check-in facility as well as the refurbishment of international arrivals; all these projects enabled the airport to upgrade the energy efficiency of lighting, controls, and plant. The airport also commenced a program to relocate several airlines to different terminals - the "Airline Moves" project. This project involved the refurbishment of offices, passenger lounges, workshops, passenger check-in and other facilities; this work allowed many systems to be upgraded in terms of energy efficiency – many directly by the airport. In particular, third-party office accommodation in Jubilee and Atlantic House, was fully fitted out to Gatwick Airport Limited technical standards which included energy efficient LED lighting and controls. Also, in 2016, London Gatwick Airport announced the first point-to-point electric car sharing service at a UK airport, opened its new Pier 1, which features high efficiency lighting and baggage systems, completed major upgrades to the North Terminal passenger check-in, security, and arrivals areas, which incorporated energy efficient lighting and controls. The airport also commenced a multi-year program to decentralize its South Terminal boiler plant during 2016 (Gatwick Airport, 2017).

London Gatwick Airport is investing in electric vehicle infrastructure for airport operations and public transport. As part of this policy, the airport's fleet of light medium duty vehicles that can be replaced with suitable electric models are being replaced at the end of their life cycles. In 2017, the airport also trialed the Volkswagen e-Crafter van in pre-production, becoming the first UK-based airport to do so. In addition, the airport was the first United Kingdom-based airport to take up the "Bluecity" electric car sharing service (Gatwick Airport Limited, 2018b). The replacement of internal combustion engine powered airport ground support vehicles and equipment with cleaner energy powered vehicles could potentially reduce carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM) (Gellings, 2011). This is because electric powered vehicles (EVs) have high energy efficiency and low pollutant and greenhouse gas (GHG) emissions when compared with

conventional internal combustion engine vehicles (ICEVs) (Zhao et al., 2015).

Airports are increasingly installing light-emitting diodes (LED) systems as an energy efficiency and reduction measure (Budd et al., 2015; Freyssinier, 2014). Light-emitting diodes (LEDs) are regarded as being a practical option for airports due to airport's requirements for colored light as well as low light output requirements (Baxter et al., 2018). In 2017, London Gatwick Airport completed the second phase of a multi-year runway lighting upgrade by installing over 550 light emitting diode (LED) "threshold and approach" lights that are used guide incoming aircraft to the airport. The light emitting diode (LED) lights have a lifespan of 50,000 hours and are 50% more energy efficient than the previous halogen lights. In 2012, the airport's main runway lighting was switched to light emitting diode (LED) lighting, so Gatwick's runway lighting, which is comprised of 1,100 individual lights, is now 100% LED-based (Gatwick Airport, 2018b). Importantly, LED light sources have significantly lower maintenance costs due to their lower power requirements and have a longer life span (Bullough, 2012; Stasinopoulos et al., 2009; Steele et al., 2016). LED lighting is also regarded as being more environmentally friendly (Atlas, 2013; Lee et al., 2020; Roland, 2018). Also, in 2017, the airport completed Phase 2 of the South Terminal boiler plant decentralization program as well as three large scale terminal lighting upgrade projects (Gatwick Airport, 2018b).

London Gatwick Airport has introduced more than 200 charging points that are to charge electric-powered ground service equipment (GSE). Installing electric charging stations enables an airport to support sustainable ground transportation (Nam, 2019). In addition, fixed electrical ground power systems (FEGP) are fitted at all the airport's aircraft parking stands. Also, in 2018, the airport completed the full refurbishment of its airfield maintenance workshop building. The building refurbishment included a complete upgrade of the building fabric, HVAC system, and lighting. The airport also progressed designs for Phase 3 of the South Terminal boiler plant decentralization (Gatwick Airport, 2019).

In 2020, London Gatwick Airport continued to work on infrastructure planning for electric and fuel-cell vehicle with partners including Metrobus, UKPNS, Gridserve and Source London (Gatwick Airport, 2020b).

The low-cost carrier (LCC) Easyjet, in partnership with World Fuel Services, has introduced an electric hydrant dispenser system at London Gatwick Airport which will serve the airline's fleet at the airport (Craig, 2021; Otley, 2021). This system was the first in the United Kingdom. Based on diesel equivalents which are estimated to burn 6,630 litres of diesel every year, the new electric hydrant dispenser can reduce 18,000 kgs of carbon dioxide (CO_2) emissions annually. The electric hydrant dispenser adds to the electric ground services equipment (GSE) already supporting Easyjet aircraft operations at London Gatwick Airport (Otley, 2021). As noted earlier, ground service equipment (GSE) refers to vehicles and equipment that are used in the airport precinct to service aircraft whilst they are at the gate in between flights (Hazel et al., 2011). At London Gatwick Airport, 40% of the airfield's ground support equipment (GSE) is electric, including baggage tugs and an increasing number of pushback tugs and aircraft high loaders (Gatwick Airport, 2023c).

4.8. The Use of Sustainable Aviation Fuel (SAF) at London Gatwick Airport

Prior to examining the deployment of sustainable aviation fuels (SAF) at London Gatwick Airport, it is important to note that one of the most significant trends in the global aviation industry in recent times has been the uptake in the use of sustainable aviation biofuel. Airlines now regard the use of aviation biofuel as being a key environmental sustainability measure (Baxter et al., 2020; Bittner et al., 2015; Cortez et al., 2015). As a result, alternative jet fuel (AJF) technologies have gained considerable interest and are now regarded as a way for the air transport industry to achieve large, near-term emissions reductions (Staples et al., 2014). The use of renewable jet fuels (RJFs) is being viewed as an option for the aviation sector meeting its greenhouse gases (GHG) reduction targets (Capaz et al., 2020). Consequently, aviation biofuels are therefore becoming an important substitute for fossil fuel in the airline industry. The use of aviation biofuels help with an airline's sustainability goals as they are environmentally friendly (Su et al., 2015). Furthermore, the replacement of fossil fuels by sustainable aviation biofuels is one of the principal strategies adopted by airlines to decrease their carbon dioxide (CO_2) emissions by 50% by 2050 (Bauen & Nattrass, 2018; Dodd et al., 2018).

On 3rd October 2018, Gatwick welcomed Virgin Atlantic's history making flight VS16 from Orlando. This was the first commercial flight into the United Kingdom with fuel made partly from industrial waste gas missions. In a process pioneered by LanzaTech, waste emissions are converted into ethanol alcohol which is blended with conventional jet fuel (Gatwick Airport, 2019).

In October 2021, London Gatwick Airport utilized sustainable aviation fuel (SAF) on all Easyjet flights that were operated during the COP26 climate conference that was held in Glasgow, Scotland. The first of a total of 42 Easyjet flights departed the airport on 19 October 2021,

and this flight was powered by a 30 percent Neste SAF blend. This was the first flight to depart from the airport that has used sustainable aviation fuel (SAF). The flight was also the first usage by any easyJet service operating in the United Kingdom (International Airport Review, 2021b; Otley, 2021).

The sustainable aviation fuel (SAF) was delivered by Q8Aviation to Gatwick. The SAF, which was manufactured by Neste, was produced from 100 per cent renewable and sustainable waste and residue raw materials, such as used cooking oil and animal fat waste (Craig, 2021; Otley, 2021). For delivery into aircraft, the sustainable aviation fuel (SAF) is blended with Jet A-1 fuel at a depot upstream of Gatwick Airport to create a drop-in fuel that is compatible with existing aircraft engines and the airport infrastructure. Q8Aviation then delivers the fuel to the main storage tanks at Gatwick Airport for supply to EasyJet aircraft via the airport's hydrant system (International Airport Review, 2021b; Otley, 2021).

V. CONCLUSION

This case study, which was based on an in-depth longitudinal research design, has examined London Gatwick Airport's energy management. The case study covered the period 2014 to 2021. The qualitative data used in the study was examined by document analysis.

London Gatwick Airport has two principal energy sources: electricity and natural gas. During the period 2019 to 2021, London Gatwick Airport also procured and used vehicle and equipment fuel (MI), refrigerant gas, and propane. The case study revealed that London Gatwick Airport contributes to a lower carbon grid through its procurement of 100% certified renewable electricity. The airport has purchased this 100% certified renewable electricity since 2013. This measure has enabled the airport to mitigate its environmental impact. An important energy-related development at London Gatwick Airport, has been the airport's waste processing and biomass generation facility, which began operations in November 2016. At London Gatwick Airport, Category 1 and other types of organic waste are converted into biomass fuel that is used to power the processing plant and provide heating for the airport's North Terminal. The system also heats London Gatwick Airport's waste management site. The waste plant also provides power to the site's water recovery system.

The case study also showed that London Gatwick Airport's annual electricity consumption fluctuated over the period 2014 to 2021. There were four years in this period where the airport's annual electricity consumption increased on a year-on-year basis. These increases occurred in 2016 (+3.13%), 2017 (+1.39%), and 2018 (+1.8%), respectively. The airport handled higher levels of passenger traffic and aircraft movements in these respective years. These increases in both passengers and aircraft movements had a concomitant impact on the amount of electricity that was needed to handle the increased passenger traffic and aircraft movements. During the period 2014 to 2021, there were four years where the airport's annual electricity consumption decreased on a year-on-year basis. These annual decreases were recorded in 2015 (-3.17%), 2019 (-2.15%), 2020 (-37.75%), and 2021 (-8.05%), respectively.

The case study revealed that there were two discernible trends in London Gatwick Airport's annual natural gas consumption. Over the period 2014 to 2018, there was a general upward trend in London Gatwick Airport's annual gas consumption. In the latter years of the study, that is, 2019 and 2020, there was a downward trend in the airport's natural gas consumption. Like other airports around the world, London Gatwick Airport was impacted by the COVID-19 pandemic and the related pandemic response measures in both 2020 and 2021. In 2021, the airport's annual; natural gas consumption increased by 18.54%. England experienced a cold winter in 2021, and thus, this had a concomitant impact on the airport's heating requirements in 2021.

Throughout the study period, London Gatwick Airport introduced a range of energy efficiency related measures. These measures include the installation of high efficiency lighting, heating, air conditioning, and ventilation (HVAC) systems, the upgrading of the airport's boiler plant, the installation of an electricity powered hydrant dispenser, and the installation of more energy efficient light emitting diode (LED) lighting. The airport is also replacing its fleet of airport vehicles with electric powered vehicles. In addition, the airport is transitioning towards the use of electricity powered ground service equipment (GSE).

REFERENCES

[1] Abdallah, A.S.H., Makram, A., & Abdel-Azim Nayel, M. (2021). Energy audit and evaluation of indoor environment condition inside Assiut International Airport terminal building, Egypt. *Ain Shams Engineering Journal*, 12(3), 3241-3253. https://doi.org/10.1016/j.asej.2021.03.003

[2] Aircraft Commerce. (2015). 787 & A350 XWB: How do they reduce maintenance costs? *Aircraft Commerce*, 102, 16-23.

[3] Aircraft Commerce. (2016). Fuel burn & operating performance of the 787-8, 787-9 and A350-900. *Aircraft Commerce*, 108, 16-27.

[4] Airport Technology. (2019). VINCI acquires 50.01% shareholding in London Gatwick Airport. Retrieved from https://www.airport-technology.com/news/vinci-acquires-50-01-shareholding-in-london-gatwick-airport/.

[5] Akkucuk, U. (2020). *Managing inflation and supply chain disruptions in the global economy*. Hershey, PA: IGI Global.

[6] Akyüz, M.K., Altuntaş, Ö., & Söğüt, M. Z. (2017). Economic and environmental optimization of an airport terminal building's wall and roof insulation. *Sustainability*, 9(10), 1849. https://doi.org/10.3390/su9101849

[7] Akyuz, M.K., Altuntas, O., Sogut, M.Z., & Karakoc, T.H. (2019). Energy management at the airports. In T. Karakoc, C. Colpan, O. Altuntas & Y. Sohret (Eds.), *Sustainable aviation* (pp. 9-36). Cham, Switzerland: Springer International Publishing.

[8] Akyüz, M.K., Altuntas O., Sogut M.Z, Karakoc T.H., & Kurama, S. (2018). Determination of optimum insulation thickness for building's walls with respect to different insulation materials: A case study of International Hasan Polatkan Airport terminal. *International Journal of Sustainable Aviation*, 4(2), 147-161. https://doi.org/10.1504/IJSA.2018.094228

[9] Akyüz, M.K., Kafali, H., & Altuntaşc, O. (2021). An analysis on energy performance indicator and GWP at airports: A case study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 43(19), 2402-2418. https://doi.org/10.1080/15567036.2020.1761483

[10] Almaz, F. (2022). Use of renewable energy resources within the scope of sustainable energy management at airports. In H Dinçer & S. Yüksel (Eds.), *Clean energy investments for zero emission projects* (pp. 177-189). Cham, Switzerland: Springer International Publishing.

[11] Amaro, S. (2020). London airport says passenger numbers may not return to pre-coronavirus levels until 2024. Retrieved from https://www.cnbc.com/2020/06/15/gatwick-and-easyjet-criticize-uk-quarantine-as-they-look-to-reopen.html.

[12] Andrew, D.P.S., Pedersen, P.M., & McEvoy CD. (2011). *Research methods and design in sport management*. Champaign, IL: Human Kinetics.

[13] Ang, S.H. (2014). *Research design for business & management*. London, UK: SAGE Publications.

[14] Arblaster, M. (2017). Light-handed regulation of airport services: An alternative approach to direct regulation? In J.D. Bitzan & J.H. Peoples (Eds.), *Advances in airline economics* (pp. 15-47). Bingley, UK: Emerald Group Publishing.

[15] Arman, H., & Yuksel, I. (2013). Preface. In H. Arman & I. Yuksel (Eds), *New developments in renewable energy* (pp. x1-xii). Rijeka, Croatia: InTech.

[16] Asian Aviation. (2012). 747-8I enters commercial service. Retrieved from https://asianaviation.com/747-8i-enters-commercial-service/.

[17] Atlas, R.I. (2013). *21st century security and CPTED: Designing for critical infrastructure protection and crime prevention* (2nd ed.). Boca Raton, FL: CRC Press.

[18] Augustyniak, W. (2009). Impact of privatization on airport performance: Analysis of Polish and British airports. *Journal of International Studies*, 2(1), 59-65.

[19] Aviation Week & Space Technology. (1998). 777-300 wins certifications. *Aviation Week & Space Technology*, 148(19), 67.

[20] Barczak, A., Dembińska, I., Rozmus, D., &; Szopik-Depczyńska, K. (2022). The impact of COVID-19 pandemic on air transport passenger markets-Implications for selected EU airports based on time series models analysis. *Sustainability*, 14, 4345. https://doi.org/10.3390/su14074345

[21] Barrett, S., Devita, P., Ho, C., & Miller, B (2014). Energy technologies' compatibility with airports and airspace: Guidance for aviation and energy planners. *Journal of Airport Management*, 8(4), 318-326.

[22] Bates, J. (2019). Vinci Airports completes acquisition of 50.01% stake in Gatwick. Retrieved from https://airport-world.com/vinci-airports-completes-acquisition-of-50-01-stake-in-gatwick/.

[23] Bauen, A., & Nattrass, L. (2018). Sustainable aviation biofuels: Scenarios for deployment. In M. Kaltschmitt & U. Neuling (Eds.), *Biokerosene: Status and prospects* (pp. 703-721). Berlin, Germany: Springer-Verlag.

[24] Baxter, G. (2021). An assessment of sustainable energy management at a major Scandinavian hub airport: The case of Oslo Airport Gardermoen. *International Journal of Environment Agriculture and Biotechnology*, 6(6), 328-351. https://dx.doi.org/10.22161/ijeab.66.37

[25] Baxter, G. (2022). Assessing the carbon footprint and carbon mitigation measures of a major full-service network airline: A case study of Singapore Airlines. *International Journal of Environment, Agriculture and Biotechnology*, 7(5), 81-107. https://dx.doi.org/10.22161/ijeab.75.9

[26] Baxter, G., & Srisaeng, P. (2022). Optimizing airport sustainable waste management from the use of waste-to-energy technology and circular economy principles: The case of London Gatwick Airport. *International Journal for Traffic and Transport Engineering*, 12(2), 176 – 195.

[27] Baxter, G., Srisaeng, P., & Wild, G. (2018). Sustainable airport energy management: The case of Kansai International Airport. *International Journal for Traffic and Transport Engineering*, 8(3), 334 - 358

[28] Baxter, G., Srisaeng, P., & Wild, G. (2019). Environmentally sustainable airport energy management Using solar power technology: The case of Adelaide Airport, Australia. *International Journal for Traffic and Transport Engineering*, 9(1), 81 – 100.

[29] Baxter, G., Srisaeng P., & Wild G. (2020). The use of aviation biofuels as an airport environmental sustainability measure: The case of Oslo Gardermoen Airport. *Magazine of Aviation Development*, 8(1), 6-17.

[30] BBC News. (2020). Coronavirus: British Airways suspends all Gatwick flights. Retrieved from https://www.bbc.com/news/business-52103171.

[31] Bilton, M. (2019). Energy management at the world's busiest single runway airport. *The EMA Magazine*, March-April, 22-24.

[32] Bioenergy Insight. (2017). Gatwick is 'first' airport in the world to convert waste into energy. Retrieved from https://www.bioenergy-news.com/news/gatwick-is-first-airport-in-the-world-to-convert-waste-into-energy/.

[33] Bittner, A., Tyner, W.E., & Zhao, X. (2015). Field to flight: A techno-economic analysis of the corn stover to aviation biofuels supply chain. *Bio Fuels, Bio Products & Biorefining*, 9(2), 201-210. https://doi.org/10.1002/bbb.1536

[34] Bodell, L. (2022). Virgin Atlantic doesn't plan to return to London Gatwick this year. Retrieved from https://simpleflying.com/virgin-atlantic-no-plan-london-gatwick-return-2022/.

[35] Boeren, E. (2019). Understanding Sustainable Development Goal (SDG) 4 on "quality education" from micro, meso, and macro perspectives. *International Review of Education*, 65, 277–294. https://doi.org/10.1007/s11159-019-09772-7

[36] Bowman, M., & Simmons, G. (2011). *London's airports*. Barnsley, UK: Pen and Sword Aviation.

[37] Budd, L., & Budd, T. (2013) Environmental technology and the future of flight. In L. Budd, S. Griggs & D. Howarth (Eds.), *Sustainable aviation futures* (pp. 87-107). Bingley, UK: Emerald Group Publishing.

[38] Budd, L., & Ison, S. (2017). Airfield design, configuration and management. In. L. Budd & S. Ison (Eds.), *Air transport management: An international perspective* (pp. 41-60). Abingdon, UK: Routledge.

[39] Budd, L., & Ison, S. (2018). The airport industry. In. N. Halpern & A. Graham (Eds.), *The Routledge companion to air transport management* (pp. 48-59). Abingdon, UK: Routledge.

[40] Budd, T., Budd, L., & Ison, S. (2015). Environmentally sustainable practices at UK airports. *Transport*, 168(2), 116-123. https://doi.org/10.1680/tran.13.00076

[41] Bullough, J.D. (2012). *Issues with use of airfield LED light fixtures.* Airport Cooperative Research Program Synthesis 35. Washington, DC: Transportation Research Board.

[42] Calabrese, A., Costa, R., Gastaldi, M., Ghiron, N.L., & Montalvan, R.A.V. (2021). Implications for Sustainable Development Goals: A framework to assess company disclosure in sustainability reporting. *Journal of Cleaner Production*, 319, 128624. https://doi.org/10.1016/j.jclepro.2021.128624

[43] Capaz, R.S., de Medeiros, E.M., Falco, D.G., Seabra, J.E.A., Osseweijer, P., & Posada, J.A. (2020). Environmental trade-offs of renewable jet fuels in Brazil: Beyond the carbon footprint. *Science of The Total Environment*, 714, 136696. https://doi.org/10.1016/j.scitotenv.2020.136696

[44] Cardona, A., Piacentino, A., & Cardona, F. (2006). Energy saving in airports by trigeneration. Part I: Assessing economic and technical potential. *Applied Thermal Engineering*, 26(14-15), 1427-1436. https://doi.org/10.1016/j.applthermaleng.2006.01.019

[45] Cathles, L. M., Brown, L., Taam, M., & Hunter, A. (2012). The greenhouse-gas footprint of natural gas in shale formations. *Climatic Change*, 113: 525–535. https://doi.org/10.1007/s10584-011-0333-0

[46] Chourasia, A.S., Jha, K., & Dalei, N.N. (2021). Development and planning of sustainable airports. *Journal of Public Affairs*, 21(1), e2145. https://doi.org/10.1002/pa.2145

[47] Cortez, L.A.B. (2014). *Roadmap for sustainable aviation biofuels for Brazil: A flightpath to aviation biofuels in Brazil*. Sao Paulo, Brazil: Blucher.

[48] Craig, T. (2021). SAF makes Gatwick debut. Retrieved from https://www.airportsinternational.com/article/saf-makes-gatwick-debut.

[49] Culberson, S.D. (2011) Environmental impacts of airports. In N.J. Ashford, S.A. Mumayiz & P.H. Wright (Eds.), *Airport engineering: Planning, design, and development of 21st century airports* (pp. 704-738) (4th ed.). Hoboken, NJ: John Wiley & Sons.

[50] Danjuma Mambo, A., EftekharI, M., & Steffen, T. (2015). Evaluation of indoor environment system performance for airport buildings. *International Journal of Sustainable and Green Energy*, 4(3), 73-84.

[51] Davis, C.E., & Davis, E. (2020). *Managerial accounting* (4th ed.). Hoboken, NJ: John Wiley & Sons.

[52] Derrington, M.L. (2019). *Qualitative longitudinal methods: Researching implementation and change*. Thousand Oaks, CA: SAGE Publications.

[53] de Rubeis, T., Nardi, I., Paoletti, D., Di Leonardo, A., Ambrosini, D., Poli, R., & Sfarra, S. (2016). Multi-year consumption analysis and innovative energy perspectives: The case study of Leonardo da Vinci International Airport of Rome. *Energy Conversion and Management*, 128, 261-272. https://doi.org/10.1016/j.enconman.2016.09.076

[54] Diakaki, C., Grigoroudis, E., Kabelis, N., Kolokotsa, D., Kalaitzakis, K., & Stavrakakis, G. (2010). A Multi-Objective Decision Model for the improvement of energy efficiency in buildings. *Energy*, 35(12), 5483-5496. https://doi.org/10.1016/j.energy.2010.05.012

[55] Dimitriou, D., & Voskaki, A. (2012). Airports' environmental impacts: Results from the evaluation of sixteen international airports. *In Proceedings of the 1st International Aviation Management Conference, IAMC – 2012, Dubai, UAE, 18 – 20 November 2012* (pp. 61-66).

[56] Dimitriou, D., Voskaki, A., & Sartzetaki, M. (2014). Airports environmental management: Results from the evaluation of European airports environmental plans. International. *Journal of Information Systems and Supply Chain Management*, 7(1), 1-14.

[57] Dodd, T., Orlitzky, M., & Nelson, T. (2018). What stalls a renewable energy industry? Industry outlook of the aviation biofuels industry in Australia, Germany, and the USA. *Energy Policy*, 123, 92-103. https://doi.org/10.1016/j.enpol.2018.08.048

[58] Doganis, R. (2005). *The airport business*. Abingdon, UK: Routledge.

[59] Dube, K., Nhamo, G., & Chikodzi, D. (2021). COVID-19 pandemic and prospects for recovery of the global aviation industry. *Journal of Air Transport Management*, 92, 102022. https://doi.org/10.1016/j.jairtraman.2021.102022

[60] Eden, P.E. (2017). *The world's most powerful civilian aircraft*. New York, NY: The Rosen Group.

[61] Eid, A., Saleh, M., Barakat, M., & Obrecht, M. (2022). Airport sustainability awareness: A theoretical framework. *Sustainability*, 14(19), 11921. https://doi.org/10.3390/su141911921.

[62] El Zowalaty, M.E., Young, S.G., & Järhult, J.E. (2020). Environmental impact of the COVID-19 pandemic – A lesson for the future. *Infection Ecology & Epidemiology*, 10(1), 1768023. https://doi.org/10.1080/20008686.2020.1768023

[63] Emeara, M. S., Abdelgawad, A.F.., & El Abagy, A.H. (2021). A novel renewable energy approach for Cairo International Airport "CIA" based on Building Information Modeling "BIM" with cost analysis. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 85(2), 80-106. https://doi.org/10.37934/arfmts.85.2.80106

[64] Fabeil, N. F, Pazim, K. H., & Langgat, J. (2020). The impact of Covid-19 pandemic crisis on micro-enterprises: Entrepreneurs' perspective on business continuity and recovery strategy. *Journal of Economics and Business*, 3(2), 837-844.

[65] Faramawy, S., Zaki, T., & Sakr, A.A.E. (2016). Natural gas origin, composition, and processing: A review. *Journal of Natural Gas Science and Engineering*, 34, 34-54. https://doi.org/10.1016/j.jngse.2016.06.030

[66] Ferrulli, P. (2016). Green airport design evaluation (GrADE) – Methods and tools improving infrastructure planning. *Transportation Research Procedia*, 14, 3781-3790. https://doi.org/10.1016/j.trpro.2016.05.463

[67] Fesanghary, M., Asadi, S., & Geem, Z.W. (2012). Design of low-emission and energy-efficient residential buildings using a Multi-Objective Optimization Algorithm. *Building and Environment*, 49, 245-250. https://doi.org/10.1016/j.buildenv.2011.09.030

[68] Flottau, J. (2023). Wing-spar crack repairs slow down Airbus A380 return to service. *Aviation Week & Space Technology*, 184(25), 19.

[69] Fossi, E., & Esposito, M.A. (2015). "Green" terminals: The Italian state of the art: Qualitative overview of the current situation in core network airports. *CSE City Safety Energy*, 1, 58-66.

[70] Freyssinier, J.P. (2014). The long-term performance of LEDs. *International. Airport Review*, 18, 38–41.

[71] Gao, Y. (2022). Benchmarking the recovery of air travel demands for US airports during the COVID-19 pandemic. *Transportation Research Interdisciplinary Perspectives*, 13, 100570. https://doi.org/10.1016/j.trip.2022.100570

[72] Gatwick Airport Limited. (2014). Annual report and financial statements for the year ended 31 March 2014. Retrieved from https://www.gatwickairport.com/globalassets/documents/business_and_community/investor_relations/year_end_2014/gatwick_airport_limited_financial_statements_31march2014.pdf.

[73] Gatwick Airport Limited. (2016). Annual report and the consolidated and parent company financial statements for the year ended 31 March 2016. Retrieved from https://www.gatwickairport.com/globalassets/publicationfiles/business_and_community/all_public_publications/investor_relations/june-2016/ivy-holdco-limited-consolidated-financial-statements-31-march-2016.pdf.

[74] Gatwick Airport Limited. (2017). Decade of change 2016 performance report. Retrieved fromhttps://www.gatwickairport.com/globalassets/company/sustainability/reports/2016/decade-of-change-2016-report.pdf.

[75] Gatwick Airport Limited. (2018a). Annual report and the consolidated and parent company financial statements for the year ended 31 March 2018. Retrieved from https://www.gatwickairport.com/globalassets/documents/business_and_community/investor_relations/yearend-june2018/ivy-holdco-limited-consolidated-financial-statements-31-march-2018---final-signed.pdf.

[76] Gatwick Airport Limited. (2018b). Decade of change 2017 performance report. Retrieved from https://www.gatwickairport.com/globalassets/company/sustainability/reports/2017/decade-of-change-2017-report.pdf.

[77] Gatwick Airport Limited. (2019). Decade of change 2018 performance report. Retrieved from https://www.gatwickairport.com/globalassets/company/sustainability/reports/2019/2019-decade-of-change-report.pdf.

[78] Gatwick Airport Limited. (2020a). Annual report and the consolidated and parent company financial statements for the year ended 31 December 2020. Retrieved from https://www.gatwickairport.com/globalassets/business--community/investors/december-2020/ivy-holdco-limited-consolidated-financial-statements-december-2020.pdf.

[79] Gatwick Airport Limited. (2020b). Decade of change 2019 performance report. Retrieved from https://www.gatwickairport.com/globalassets/company/sustainability/reports/2019/2019-decade-of-change-report.pdf.

[80] Gatwick Airport Limited. (2021a). Decade of change 2020 performance report. Retrieved from https://www.gatwickairport.com/globalassets/company/sustainability/reports/2020/decade-of-change-2020-report.pdf.

[81] Gatwick Airport Limited. (2021b). Second decade of change to 2030. Sustainability Policy Retrieved from https://www.gatwickairport.com/globalassets/company/sustainability/reports/2021/decade-of-change-policy-to-2030.pdf.

[82] Gatwick Airport Limited. (2022a). Annual report and the consolidated and parent company financial statements for the year ended 31 December 2021. Retrieved from

https://www.gatwickairport.com/globalassets/company/investor/2021/ivy-holdco-limited-consolidated-financial-statements-31-december-2021.pdf.

[83] Gatwick Airport Limited. (2022b). Decade of change: 2021 performance summary. Retrieved from https://www.gatwickairport.com/globalassets/company/sustainability/reports/2021/decade-of-change-2021-report.pdf.

[84] Gatwick Airport Limited. (2023a). Gatwick key facts. Retrieved from https://www.gatwickairport.com/business-community/about-gatwick/company-information/gatwick-key-facts/.

[85] Gatwick Airport Limited. (2023b). Health, safety, and environment. Retrieved from https://www.gatwickairport.com/business-community/about-gatwick/company-information/how-we-operate/health-safety/.

[86] Gatwick Airport Limited. (2023c). Net zero direct emissions by 2040. Retrieved from https://www.gatwickairport.com/business-community/sustainability/topic/emissions/.

[87] González-Ruiz, J.D., Duque, E., & Restrepo, J. (2017). Green airport infrastructure in Colombia: Opportunities for public-private partnerships schemes. *Pertanika Journal of Science & Technology*, 25, 37 – 46.

[88] Graham, A. (2005). Airport benchmarking: A review of the current situation. *Benchmarking: An International Journal*, 12(2), 99-111. https://doi.org/10.1108/14635770510593059

[89] Graham, A. (2011). The objectives and outcomes of airport privatisation. *Research in Transportation Business & Management*, 1(1), 3-14. https://doi.org/10.1016/j.rtbm.2011.05.004

[90] Graham, A. (2018). *Managing airports: An international perspective* (5th ed.). Abingdon, UK: Routledge.

[91] Greer, F., Rakas, J., & Horvath, A. (2020). Airports and environmental sustainability: A comprehensive review. *Environmental Research Letters*, 15, 103007.

[92] Hafez, F.S., Sa'di, B., Safa-Gamal, M., Taufiq-Yap, Y.H, Alrifaey, M., Seyedmahmoudian, M., Stojcevski, A., Horan, B., & Mekhilef, S. (2023). Energy efficiency in sustainable buildings: A systematic review with taxonomy, challenges, motivations, methodological aspects, recommendations, and pathways for future research. *Energy Strategy Reviews*, 45, 101013. https://doi.org/10.1016/j.esr.2022.101013

[93] Hassett, M., & Paavilainen-Mäntymäki, E. (2013). Longitudinal research in organizations: An introduction. In M. Hasset & E. Paavilainen-Mäntymäki (Eds.), *Handbook of longitudinal research methods in organisation and business studies* (pp. 1-12). Cheltenham, UK: Edward Elgar Publishing.

[94] Hazel, R.A., Blais, J.D., Browne, T.J., & Benzon, D.M. (2011). *Resource guide to airport performance indicators*. Airport Cooperative Research Program Report 19A. Washington, DC: Transportation Research Board.

[95] Henryson, J., Håkansson, T., & Pyrko, J. (2000). Energy efficiency in buildings through information – Swedish perspective. *Energy Policy*, 28(3), 169-180. https://doi.org/10.1016/S0301-4215(00)00004-5

[96] Hitt, M.A., Ireland, R.D., & Hoskisson, R.E. (2020). *Strategic management: Concepts and cases: Competitiveness and globalization* (13th ed.). Boston, MA: Cengage.

[97] Holloway, S. (2016). *Straight and level: Practical airline economics* (3rd ed.). Abingdon, UK: Routledge.

[98] Hotle, S., & Mumbower, S. (2021). The impact of COVID-19 on domestic U.S. air travel operations and commercial airport service. *Transportation Research Interdisciplinary Perspectives*, 9, 100277. https://doi.org/10.1016/j.trip.2020.100277

[99] Iacus, M. S., Natale, F., Santamaria, C., Spyratos, S., & Vespe, M. (2020). Estimating and projecting air passenger traffic during the COVID-19 coronavirus outbreak and its socio-economic impact. *Safety Science*, 129, 104791. https://doi.org/10.1016/j.ssci.2020.104791

[100] International Airport Review. (2021a). Gatwick Airport publishes second Decade of Change sustainability policy. Retrieved from https://www.internationalairportreview.com/news/160584/gatwick-airport-sustainability-policy/.

[101] International Airport Review. (2021b). Sustainable aviation fuel introduced for the first time at London Gatwick. Retrieved from https://www.internationalairportreview.com/news/165632/sustainable-aviation-fuel-introduced-at-london-gatwick/.

[102] International Airport Review. (2023). London Gatwick Airport (LGW). Retrieved from https://www.internationalairportreview.com/airports/40668/london-gatwick-airport-lgw/.

[103] International Civil Aviation Organization. (2015). A focus on the production of renewable energy at the airport site. Retrieved from. https://www.icao.int/environmental-protection/Documents/Energy%20at%20Airports.pdf.

[104] Irvine, D., Budd, L.C.S., & Pitfield, D.E. (2015). A Monte-Carlo approach to estimating the effects of selected airport capacity options in London. *Journal of Air Transport Management*, 42, 1-9. https://doi.org/10.1016/j.jairtraman.2014.06.005

[105] Jackson, R. (2021). *Airbus A380*. Barnsley, UK: Pen & Sword Books.

[106] Jäger-Waldau, A., Szabó, M., Scarlat, N., & Monforti-Ferrario, F. (2011). Renewable electricity in Europe. *Renewable and Sustainable Energy Reviews*, 15(8), 3703-3716. https://doi.org/10.1016/j.rser.2011.07.015

[107] James, R. (2017). Gatwick Airport: Turning waste into energy. Retrieved from https://www.airport-technology.com/features/featuregatwick-turning-waste-to-energy-5711024/.

[108] Janić, M. (2011). *Greening airports: Advanced technology and operations*. London, UK: Springer Verlag London Limited.

[109] Karagkouni, A., & Dimitriou, D. (2022). Sustainability performance appraisal for airports serving tourist islands. *Sustainability*, 14(20), 13363. https://doi.org/10.3390/su142013363

[110] Kareem, F. M., Abbas Abd, A.M., & Zehawi, R.N. (2021). Utilize BIM technology for achieving sustainable passengers terminal in Baghdad International Airport. *Diyala Journal of Engineering Sciences*, 14(4), 62-78. https://doi.org/10.24237/djes.2021.14406

[111] Katila, P., Pierce Colfer, C.J., de Jong, W., Galloway, G., Pacheco, P. & Winkel, G. (2019). Introduction. In P. Katila., C.J. Pierce Colfer, W. de Jong., P. Pacheco & G. Winkel (Eds.), *Sustainable development goals* (pp. 1-16). Cambridge, UK: Cambridge University Press.

[112] Kazda, T., Caves, B., & Kamenický, M. (2015). Environmental control. In A. Kazda & R.E. Caves (Eds.), *Airport design and operation* (pp. 457-500) (3rd ed.). Bingley, UK: Emerald Group Publishing.

[113] Kemp, K. (2007). *Fight of the titans*. London, UK: Virgin Books Ltd.

[114] Kim, S.C., Shin, H.I., & Ahn, J. (2020). Energy performance analysis of airport terminal buildings by use of architectural, operational information and benchmark metrics. *Journal of Air Transport Management*, 83, 101762. https://doi.org/10.1016/j.jairtraman.2020.101762

[115] Korba, P., Koščáková, M., Főző, L., & Sekelová, I. (2022). Current state and possible challenges in the development of green airports. In *Proceedings of the New Trends in Civil Aviation (NTCA), Prague, Czech Republic, 26-27 October* (pp. 191-197). https://doi.org/10.23919/NTCA55899.2022.9934733

[116] Kumar, S., & Padture, N.P. (2018). Materials in the aircraft industry. In B. Kaufman & C.L. Briant (Eds.), *Metallurgical design and industry: Pre-history to the space age* (pp. 271-346). Cham, Switzerland: Springer International Publishing.

[117] Lamb, H.H. (2011). *Climate: Present, past and future. Volume 1: Fundamentals and climate now*. Abingdon, UK: Routledge.

[118] Lee, J.H., Cheng, I.C., Hua, H. & Wu, S.T. (2020). *Introduction to flat panel displays*. Hoboken, NJ: John Wiley & Sons.

[119] Lenkaitis, C. A. (2022). Integrating the United Nations' Sustainable Development Goals: Developing content for virtual exchanges. *Language Learning & Technology*, 26(1), 1–20.

[120] Leppävuori, J., Liimatainen, H., & Baumeister, S. (2022). Flying-related concerns among airline customers in Finland and Sweden during COVID-19. *Sustainability*, 14(17), 10768. https://doi.org/10.3390/su141710768

[121] Liaghat, D., Abbott, R., & Booth, J. (2011). Refurbishment of the Inter Terminal Shuttle, Gatwick Airport, UK. In *Proceedings of 13th International Conference on Automated People Movers and Transit Systems, May 22-25, 2011, Paris, France*. Washington, DC: American Society of Civil Engineers.

[122] Liang, F. Y., Ryvak, M., Sayeed, S., & Zhao, N. (2012). The role of natural gas as a primary fuel in the near future, including comparisons of acquisition, transmission and waste handling costs of as with competitive alternatives. *Chemistry Central Journal*, 6 (Supplement 1), S4. https://doi.org/10.1186/1752-153X-6-S1-S4

[123] Liu, X., Zhang, T., Liu, X., Li, L., Lin, L., & Jiang, Y. (2021). Energy saving potential for space heating in Chinese airport terminals: The impact of air infiltration. *Energy*, 215(Part B), 119175. https://doi.org/10.1016/j.energy.2020.119175

[124] Lyons Hardcastle, J. (2017). DHL, Gatwick Airport open first waste-to-energy plant for airline waste. Retrieved from https://www.environmentalleader.com/2017/03/dhl-gatwick-airport-open-first-waste-energy-plant-airline-waste/.

[125] Malik, M. (2022). Why London dominates the world's busiest airline markets. Retrieved from https://www.key.aero/article/why-london-dominates-worlds-busiest-airline-markets.

[126] Mann, J. (2022). Gatwick intends to boost regional economy by creating AEZ. Retrieved from https://www.airport-technology.com/analysis/gatwick-intends-to-boost-regional-economy-by-creating-aez/.

[127] Manuel, R. (2016). Gatwick building first airport waste plant of its kind as it leads the way in recycling. Retrieved from https://www.internationalairportreview.com/news/24471/gatwick-airport-waste-recycling/.

[128] Marsch, G. (2016). Composites consolidate in commercial aviation. *Reinforced Plastics*, 60(5), 302-305. https://doi.org/10.1016/j.repl.2016.08.002

[129] Mat Dawi, N., Namazi, H., Hweang, H.J., Ismail, S., Maresova, P., & Krejcar, O. (2021). Attitude towards protective behavior engagement during COVID-19 pandemic in Malaysia: The role of E-Government and social media. *Frontiers in Public Health*, 9, 609716. https://doi.org/10.3389/fpubh.2021.609716

[130] Ministry of Transport. (2017). Beyond the horizon: The future of UK aviation. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/636625/aviation-strategy-call-for-evidence.pdf.

[131] Miola, A., & Schiltz, F. (2019). Measuring sustainable development goals performance: How to monitor policy action in the 2030 Agenda implementation? *Ecological Economics*, 164, 106373. https://doi.org/10.1016/j.ecolecon.2019.106373

[132] Mumbower, S. (2022). Airline market exit after a shock event: Insights from the COVID-19 pandemic. *Transportation Research Interdisciplinary Perspectives*, 14, 100621. https://doi.org/10.1016/j.trip.2022.100621

[133] Munguia, N., Esquer, J., Guzman, H., Herrera, J., Gutierrez-Ruelas, J., & Velazquez, L. (2020). Energy efficiency in public buildings: A step toward the UN 2030 Agenda for Sustainable Development. *Sustainability*, 12(3), 1212. https://doi.org/10.3390/su12031212.

[134] Nam, V.H. (2019). Green sustainable airports: The deployment of renewable energy at Vietnam Airports. Is that feasible? *Journal of Mechanical Engineering Research and Developments*, 42(5), 61-65.

[135] Neale, B. (2018). *What is qualitative longitudinal research?* London, UK: Bloomsbury Publishing.

[136] O'Leary, Z. (2004). *The essential guide to doing research*. London, UK: SAGE Publications.

[137] Ortega Alba, S., & Manana, M. (2016). Energy research in airports: A review. *Energies*, 9(5), 349. https://doi.org/10.3390/en9050349

[138] Ortego Alba, S.O., & Manana, M. (2017). Characterization and analysis of energy demand patterns in airports. *Energies*, 10(1), 119. https://doi.org/10.3390/en10010119

[139] Orukpe, P. E., Onianwa, C.T. Abuh, A., & Aderanti, A.K. (2020). Reliability assessment of power distribution system in the Nigerian aviation industry. *The Journal of Engineering, Science and Computing*, II(II), 37-54.

[140] Otley, T. (2021). London Gatwick introduces first sustainable aviation fuel (SAF) for flights. Retrieved from https://www.businesstraveller.com/business-travel/2021/10/20/london-gatwick-introduces-first-sustainable-aviation-fuel-saf-for-flights/.

[141] Papagiannakis, R.G., Rakopoulos, C.D.., Hountalas, D.T., & Rakopoulos, D.C. (2010). Emission characteristics of high speed, dual fuel, compression ignition engine operating in a wide range of natural gas/diesel fuel proportions. *Fuel*, 89(7), 1397-1406. https://doi.org/10.1016/j.fuel.2009.11.001

[142] Pearson, J. (2022). Southend summers: London's 6th airport welcomes 1st passenger flight since October. Retrieved from https://simpleflying.com/london-southend-first-passenger-flight-2022/.

[143] Pels, E., Njegovan, N., & Behrens, C. (2009). Low-cost airlines and airport competition. *Transportation Research Part E: Logistics and Transportation Review*, 45(2), 335-344. https://doi.org/10.1016/j.tre.2008.09.005

[144] Pilavachi, P. A., Stephanidis, S.D.., Pappas, V.A.., & Afgan, N.H. (2009). Multi-criteria evaluation of hydrogen and natural gas fuelled power plant technologies. *Applied Thermal Energy*, 29(11-12), 2228-2234. https://doi.org/10.1016/j.applthermaleng.2008.11.014

[145] Prada, M., Prada, I.F.., Cristea, M., Popescu., Constantin Bungău, D.E., Aleya, L.., & Bungău, C.C. (2020). New solutions to reduce greenhouse gas emissions through energy efficiency of buildings of special importance – Hospitals. *Science of The Total Environment*, 718, 137446. https://doi.org/10.1016/j.scitotenv.2020.137446

[146] Preston, K. (2015). Sustainability initiatives helping airports address climate change. *International Airport Review*, 19(5), 16-19.

[147] Radomska, M., Chernyak, L., & Samsoniuk, O. (2018). The improvement of energy-saving performance at Ukrainian airports. In T.H. Karakoç, C. Ozgur Colpan & Y. Şöhret (Eds.), *Advances in sustainable aviation* (pp. 189-203). Cham, Switzerland: Springer International Publishing.

[148] Remenyi, D, Williams, B, Money, A., & Swartz, E A. (2010). *Doing research in business and management: An introduction to process and method*. London, UK: SAGE Publications.

[149] Roland, J. (2018). *How LEDs work.* Minneapolis, MN: Lerner Publishing Group.

[150] Rossi Dal Pozzo, F. (2015). *EU legal framework for safeguarding air passenger rights*. Cham, Switzerland: Springer International Publishing.

[151] Saayman, M. (2012). *An introduction to sport tourism and event management*. Bloemfontein, South Africa: Sun Press.

[152] Sajed Sadati, S.M., Cetin, K., Ceylan. H., Sassani, A., & Kim, S. (2018). Energy and thermal performance evaluation of an automated snow and ice removal system at airports using numerical modeling and field measurements. *Sustainable Cities and Society*, 43, 238-250. https://doi.org/10.1016/j.scs.2018.08.021

[153] Scholz, I., & Brandi, C. (2017). Implementing the 2030 Agenda for Sustainable Development: Achievements and limitations of the G20 Presidency in 2017. *Global Summitry*, 3(2), 156–175, https://doi.org/10.1093/global/guy003

[154] Scott, J. (2014). *A dictionary of sociology* (4th ed.). Oxford, UK: Oxford University Press.

[155] Scott, J., & Marshall G. (2009). *A dictionary of sociology* (3rd ed.). Oxford, UK: Oxford University Press.

[156] Simons, G.M. (2014). *Airbus A380: A history*. Barnsley, UK: Pen & Sword Books.

[157] Sovacool, B.K. (2010). A critical evaluation of nuclear power and renewable electricity in Asia. *Journal of Contemporary Asia*, 40(3), 369-400. https://doi.org/10.1080/00472331003798350

[158] Speight, J. G. (2019). *Natural gas: A basic handbook* (2nd ed.). Cambridge, UK: Gulf Professional Publishing.

[159] Sreejaya, K.V., Mubarak, K., & Al-Haddabi, A. (2020). Feasibility studies of solar energy as an alternative energy resource for Muscat International Airport. *INTI Journal*, 51, 1-6.

[160] Staples, M.D., Malina, R., Suresh, P., Hileman, J.I., & Barrett, S.R.H. (2014). Aviation CO_2 emissions reductions from the use of alternative jet fuels. *Energy Policy*, 114, 342-354. https://doi.org/10.1016/j.enpol.2017.12.007

[161] Stasinopoulos, P., Smith, M.H., Hargroves, K.C., & Desha, C. (2009). *Whole system design: An integrated approach to sustainable engineering*. London, UK: Earthscan Publications.

[162] Steele, K.S., Weber, M.J., Boyle, E.A.E., Hunt, M.C., Lobaton-Sulabo. A.S., Cundith, C., Hiebert, Y.H., Abrolat, K.A., Attey, J.M., Clark, S.D., Johnson, D.E., & Roenbaugh, T.L. (2016). Shelf life of fresh meat products under LED or fluorescent lighting. *Meat Science*, 117, 75-84. https://doi.org/10.1016/j.meatsci.2016.02.032

[163] Su, Y., Zhang, P., & Su, Y. (2015). An overview of biofuels policies and industrialization in the major biofuel producing countries. *Renewable and Sustainable Energy Reviews*, 50, 991-1003. https://doi.org/10.1016/j.rser.2015.04.032

[164] Sumathi, N., Phanendra, M.G.V.S., & Teja, K.G. (2018). Green airports - Solution to stop pollution! *International Journal of Latest Technology in Engineering, Management & Applied Science*, VII(IV), 78-85.

[165] Taber, C., & Steele, B. A. (2020). Impact of HVLS fans on airplane hangar air destratification. *ASHRAE Journal*, 62(4), 26-32.

[166] Taber, K.S. (2014). *Classroom based research and evidence-based practice: An introduction*. London, UK: SAGE Publications.

[167] Tang, H., Yu, J., Lin, B., Geng, Y., Wang, Z., Chen, X., Yang, L., Lin, T., & Xiao, F. (2023). Airport terminal passenger forecast under the impact of COVID-19 outbreaks: A case study from China. *Journal of Building Engineering*, 65, 105740. https://doi.org/10.1016/j.jobe.2022.105740

[168] Teodorović, D., & Janić, M. (2017). *Transportation engineering: Theory, practice, and modeling*. Oxford, UK: Butterworth-Heinemann.

[169] The Met Office. (2021). 2021: The UK's weather in review. Retrieved from https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2021/2021-a-year-in-weather-a-review.

[170] Thomas, C., & Hooper, P. (2013). Sustainable development and environmental capacity of airports. In N. J. Ashford., H.P. Martin Stanton., C.A. Moore., P. Coutu & J.R. Beasley. *Airport operations* (pp. 553-578) (3rd ed). New York, NY: McGraw-Hill.

[171] United States Environmental Protection Agency. (2022). Local renewable energy benefits and resources. Retrieved from https://www.epa.gov/statelocalenergy/local-renewable-energy-benefits-and-resources.

[172] Ussinova, A., Laplace, I., & Roucolle, C. (2018). An analysis of the impact of larger aircraft (A-380) on flight frequency. *Energy Efficiency*, 11: 701–712. https://doi.org/10.1007/s12053-017-9591-7

[173] Uysal, M. P., & Ziya Sogut, M. (2017). An integrated research for architecture-based energy management in sustainable airports. *Energy*, 140(Part 2), 1387-1397. https://doi.org/10.1016/j.energy.2017.05.199

[174] Vermeeren, C.A.J.R. (2003). An historic overview of the development of fibre metal laminates. *Applied Composite Materials*, 10, 189–205. https://doi.org/10.1023/A:1025533701806

[175] Walker, A. (2016). Gatwick hails world-first airport waste plant to boost recycling. Retrieved from http://www.infrastructure-intelligence.com/article/sep-2016/gatwick-hails-world-first-airport-waste-plant-boost-recycling.

[176] Woodford, G. (2013). In with the asphalt plant new. *World Highways/Routes du Monde*, 22(2), 31-35.

[177] Woodley, C. (2014). *Gatwick airport: The first fifty years*. Stroud, UK: The History Press.

[178] Yıldız, Ö. F., Yılmaz, M., & Çelik, A. (2021). Energy analysis of cold climate region airports: A case study for airport terminal in Erzurum, Turkey. *International Journal of Sustainable Aviation*, 7(1), 66-92. https://doi.org/10.1504/IJSA.2021.115343

[179] Yildiz, O.F., Yilmaz, M. & Çelik, A. (2022). Reduction of energy consumption and CO_2 emissions of HVAC system in airport terminal buildings. *Building and Environment*, 208, 108632. https://doi.org/10.1016/j.buildenv.2021.108632

[180] Yin, R.K. (2018). *Case study research and applications* (6th ed.). Thousand Oaks, CA: SAGE Publications.

[181] Zhao, X., Doering, O.C., & Tyner, W.C. (2015). The economic competitiveness and emissions of battery electric vehicles in China. *Applied Energy*, 156, 666-675. https://doi.org/10.1016/j.apenergy.2015.07.063

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Effect of organic amendments on *Aloe vera* growth in nursery in Daloa, Côte d'Ivoire

N'goran Koffi Désiré*, Tonessia Dolou Charlotte, Soumahin Eric Francis, Zoh Olivia Dominique, Sey Junias, Akaffou Doffou Selastique

Agricultural Production Improvement Laboratory, UFR-Agroforestry, University Jean Lorougnon Guédé BP 150 Daloa, Ivory Coast
*Corresponding Author

Received: 02 Feb 2023; Received in revised form: 02 Mar 2023; Accepted: 08 Mar 2023; Available online: 15 Mar 2023

Abstract— *In the face of climate change, the optimization of crop diversification policy in Côte d'Ivoire must go through research and promotion of crops of interest that require little water, including Aloe vera. However, in view of its slow growth in nursery, the improvement of growth substrate fertility by the supply of nutrients is necessary. Thus, this study aims at assessing the effects of six organic matter formulations on Aloe vera growth in nursery. To this end, a completely randomized block experimental design comprising six treatments and three replications was carried out. The amendments tested were cow dung, chicken droppings, charcoal, banana tree stems and ripe plantain and dessert bananas. The results showed substrate pH variability (6.67 to 7.87) depending on the amendments. Leaf emergence speed increased with cow dung from the 80th day after planting. Similarly, the highest number of leaves was obtained with cow dung (9.33 leaves). With 22.89 cm in average length and 1.65 cm in average width, the leaves generated with cow dung were also the longest and widest. This study showed that cow dung promotes rapid Aloe vera growth in nursery.*

Keywords— ***Climate change, Crop diversification, Aloe vera, Nursery, Organic matter***

I. INTRODUCTION

Côte d'Ivoire has based its economy since its independence on agriculture. This agriculture is dominated by cash crops such as coffee, cocoa, oil palm, cotton and rubber (Sangaré *et al*., 2009). Alongside these cash crops, there are food crops such as bananas. With an annual yield estimated at 1.6 million tons (Nindjin *et al*., 2003), it ranks third in terms of food production. It is an important source of income, employment and export earnings (Foure & Tezenas, 2000). Moreover, food crops contribute to local and regional economic development, ensuring regular income for producers.

However, the rapid growth of the Ivorian population, which rose from 2630000 in 1950 to 21295000 in 2015 (Kouakou *et al*., 2018) has a significant impact on agriculture. Indeed, this population growth has led to strong anthropogenic pressure on arable land and a strong reduction in the area occupied by forests. This situation has been exacerbated in recent years by insufficient and irregular rainfall, subjecting crops to water stress, which seriously limits their growth as well as plant productivity (Zerrad *et al*., 2008). Consequently, farmers are faced with a drop in their agricultural yield and therefore in their income. Faced with this observation, the optimization of crop diversification policy through research and the promotion of crops of interest and requiring little water is necessary. *Aloe vera*, which appears to be an interesting alternative, fits in this perspective.

Indeed, *Aloe vera* is a succulent plant that can grow with low or irregular water availability (Svjetlana *et al*., 2020). Moreover, the presence of bitter anthraquinones and other polyphenolic components makes the plant unattractive to pests and pathogens (Gharib, 2021). *Aloe vera* is mainly cultivated for its leaves from which juice and gel are extracted, which give rise to the development of products with diversified uses to such an extent that the plant has now

become a marketing strategy (Onyinyechi *et al*., 2021). The main producing countries are Mexico, Venezuela and the Dominican Republic. In this regard, the American continent alone produces 60% of *Aloe vera* gel sold in the world, while the remaining 40% comes from Asia and Australia (Michayewicz, 2013). In these countries, Aloe vera is grown to meet the ever-increasing international demand. According to IMF estimates, the *Aloe vera* market could bring in more than $3.3 billion dollars by 2026 (Anonymous 1, 2022). For Africa and other developing countries, this could therefore become a major financial windfall.

In West Africa, Nigeria is the leading *Aloe vera* producer. However, its yield is intended for the local market (Michayewicz, 2013). In Côte d'Ivoire, *Aloe vera* is an unknown plant that is mainly grown as an ornamental plant on degraded soils. Its cultivation is preferably done vegetatively because of the rapid growth of suckers compared to propagation through seeds. These can be cut from the mother plant when they reach 15-20 cm in length, and can be cultivated in nursery in the first year (Michayewicz, 2013). However, growth in nursery lasts a year or more due to the slow growth of this plant which can give vigorous plants to be transplanted to the field. Thus, any attempt to promote this plant must think about improving growth substrate fertility by providing nutrients to boost its cultivation.

To date, it is difficult to find works devoted to the search for standard amendments for a sustainable and large-scale *Aloe vera* yield. The hypothesis we put forward is that the contribution of organic matter to the soil would positively influence *Aloe vera* growth parameters. Thus this study, which was carried out in Daloa in west central Côte d'Ivoire, aims at assessing the effects of six organic matter formulations on *Aloe vera* growth in nursery. The organic matter used in this study were composed of plant and animal waste from the Daloa region.

II. MATERIAL AND METHODS

Study site

This study was conducted on an experimental plot at the University Jean Lorougnon Guédé (UJLoG) located in the department of Daloa (West central Côte d'Ivoire). It is bounded by the West longitudes 6.48° and 6.41° and the North latitudes 6.91° and 6.84° (Adjiri *et al*., 2018). The climate of this region is of the subequatorial Attiean type (Adjiri *et al*., 2020) with two seasons, namely a dry season and a rainy season. The dry season extends over four months (November to February). As for the rainy season, it lasts eight months and extends from March to October. The wettest months are April, August and September when an average of 103.58 mm of rain is recorded each year. Furthermore, the average annual temperature is 26.3°C and the months of November and May are the driest with average temperatures of 26.2 and 27.9°C, respectively (Dro *et al*., 2020). The soils in this area are generally ferralitic, moderately leached on firm land and sandy hydromorphic (Zro *et al*., 2018).

Methodology

Trial set up

The trial was set up in December 2020 and lasted four (04) months. The plant material used in this study consisted of *Aloe vera* suckers with a size between 15 and 20 cm (Michayewicz, 2013). These all-comer suckers were collected from different districts of Daloa near homes.

The organic amendments tested included:

- Cow dung (1);
- Chicken droppings (2);
- Charcoal (3);
- Banana tree stems or banana stipes (4);
- Ripe plantain (5);
- Ripe dessert banana (6);

The soil used as substrate was collected from the experimental plot of UJLoG. The organic matter tested were mixed with soil in 15-cm high pots with a surface area of 0.0176 m^2.

For each pot the height was divided into three (03) of which 2/3 were filled with soil and 1/3 with the amendment except for the pots containing the bananas. Indeed, at this point, the pots were completely filled with soil and then holes were made in each banana which, subsequently, were buried in the ground at the rate of one banana per pot. In each pot, the suckers were buried so that only the roots were covered with the substrate except for dessert bananas and plantains where the suckers were buried in the holes made inside them and then covered with substrate. The control was made up of a pot filled entirely with soil collected from the experimental plot. The Experimental Design was a completely randomized block with 3 replications (Fig. 1). Plant monitoring consisted of watering as needed when the surface of the substrate was dry. Also, regular cleaning was carried out in order to avoid any competition of weeds with *Aloe vera* plants.

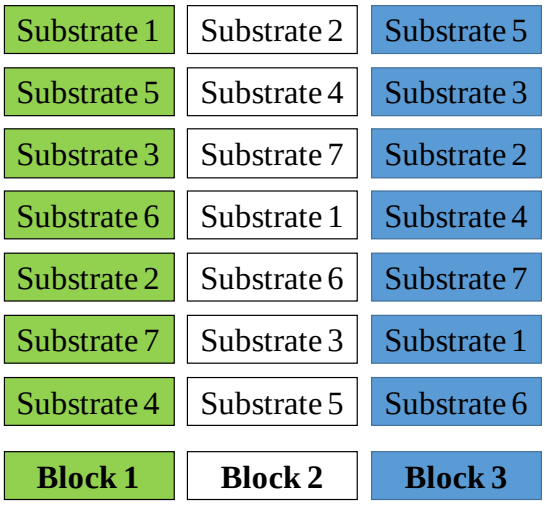


Fig 1: Experimental design

Substrate 1: Control; Substrate 2: Soil + cow dung; Substrate 3: Soil + chicken droppings; Substrate 4: Soil + charcoal; Substrate 5: Soil + banana stipes; Substrate 6: Soil + ripe plantain; Substrate 7: Soil + ripe dessert banana.

Parameters measured

The observations focused on substrate growth parameters and pH monitoring. Substrate pH, determined by the electrometric method with a pH meter (Alla *et al*., 2018) was measured every 20 days. The probe was pushed, after cleaning with a cloth, into the substrate about 10 cm followed by the reading one (01) minute later. This operation was repeated three times at different locations of the substrate contained in each pot in order to calculate the average for result reliability.

The growth parameters concerned leaf emergence speed, the number of emerged leaves, leaf length and width over time. Thus, a leaf was considered new when its length reached 4 cm (Yosser, 2012). The length of the new generated leaves as well as their width were taken every 20 days using a graduated ruler.

Statistical analysis of data

The data collected was subjected to statistical tests using Statistica 7.1 software. An analysis of variance made it possible to assess the effects of amendments on *Aloe vera* sucker growth. The hypothesis of equality of averages was assessed at α risk = 5%. If this last hypothesis was rejected, the Newman-Keuls multiple comparison test (at α risk threshold = 5%) made it possible to classify the averages into homogeneous groups.

III. RESULTS AND DISCUSSION

3.1. Results

3.1.1. pH of the different substrates

The measured pHs varied from 6.67 to 7.87 and are shown in Table 1 and Fig. 2. The pH values showed a significant difference ($P<0.05$) regarding substrates.

Compared to the pH of the control which was 7.87 and which represented the starting pH of the substrates, the input of amendments led to a drop in the pH of the substrates. A very significant reduction was obtained with cow dung, ripe plantain, chicken droppings and charcoal amendments. However, these pH remained basic with the exception of the substrate amended with charcoal powder which was acidic (6.67).

Table 1: Average pHs of the studied substrates

	S 1	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**P**
Average pH	7.87^{a}	7.36^{b}	7.59^{ab}	6.67^{c}	7.69^{ab}	7.49^{b}	7.73^{ab}	0.00

The averages on the same line followed by different letters are significantly different at 5% threshold.

S1: reference**; S2**: Soil + cow dung; **S3**: Soil + chicken droppings; **S4**: Soil + charcoal; **S5**: Soil + banana stipes; **S6**: Soil + ripe banana plantain; **S7**: Soil + ripe dessert banana; **P**: Probability

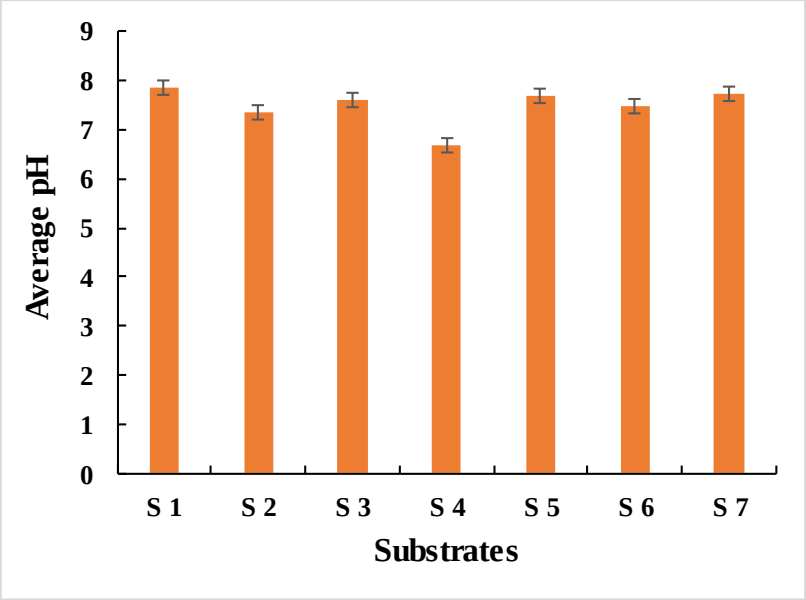


Fig. 2 : Average pHs depending on the substrates

S 1: Control**; S 2:** Soil + cow dung**; S 3:** Soil + chicken droppings**; S 4**: Soil + charcoal**; S 5:** Soil + banana stipes; **S 6:** Soil + ripe plantain**; S 7:** Soil + ripe dessert banana

3.1.2. Leaf emergence speed

Leaf emergence speed followed the same evolution regardless of the type of substrate (Fig. 3). The analysis of variance of the data shows that the amendments used did not significantly influence (P > 0.05) new (Table 2). However, Figure 3 shows a slight increase in leaf emergence speed from the 80th day after planting on substrate 2 (cow dung) and from the 100th day after planting on the substrate amended with chicken droppings (substrate 3).

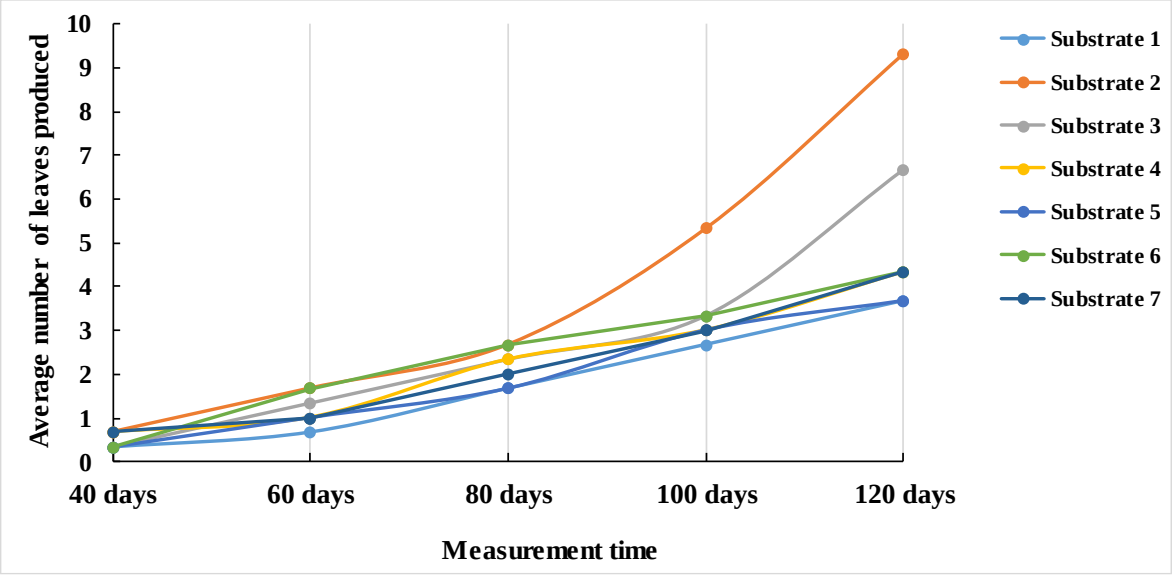


Fig. 3 : Evolution of the average number of leaves generated on the substrates depending on time

Table 2: Average number of leaves generated on the substrates

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	P
40 days	0.33[a]	0.67[a]	0.33[a]	0.67[a]	0.33[a]	0.33[a]	0.67[a]	0.93
60 days	0.67[a]	1.67[a]	1.33[a]	1.00[a]	1.00[a]	1.67[a]	1.00[a]	0.33
80 days	1.67[a]	2.67[a]	2.33[a]	2.33[a]	1.67[a]	2.67[a]	2.00[a]	0.34
100 days	2.67[a]	5.33[a]	3.33[a]	3.00[a]	3.00[a]	3.33[a]	3.00[a]	0.17
120 days	3.67[a]	9.33[a]	6.67[a]	4.33[a]	3.67[a]	4.33[a]	4.33[a]	0.17

The averages on the same line followed by different letters are significantly different at 5% threshold.

S1: reference; **S2**: Soil + cow dung; **S3**: Soil + chicken droppings; **S4**: Soil + charcoal; **S5**: Soil + banana stipes; **S6**: Soil + ripe banana plantain; **S7**: Soil + ripe dessert banana; **P**: Probability

3.1.3. Number of emerged leaves

The number of emerged leaves on the different substrates is illustrated by Fig. 4. Organic fertilizers increased the number of emerged leaves except banana tree stems which generated a number (3.67 leaves) identical to that of the control (3. 67 leaves). The highest number of leaves was obtained on substrates 2 (9.33 leaves) - cow dung-based - and 3 (6.67 leaves) - chicken dropping-based -, respectively. However, statistical analysis revealed no significant difference (P > 0.05).

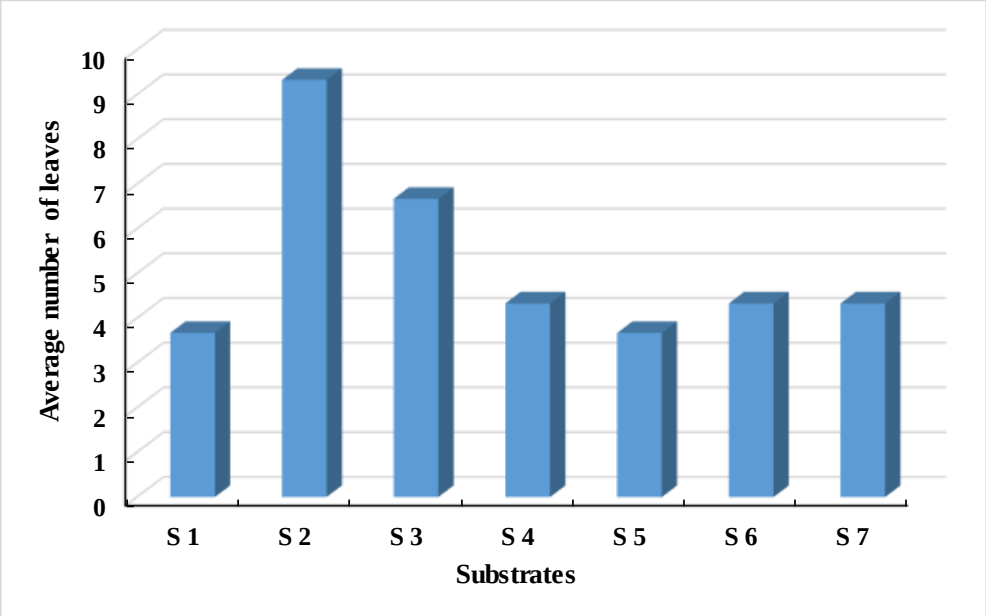


Fig. 4 : Number of leaves generated depending on the substrates

S 1: Control**; S 2:** Soil + cow dung**; S 3:** Soil + chicken droppings**; S 4**: Soil + charcoal**; S 5:** Soil + banana stipes; **S 6:** Soil + ripe plantain**; S 7:** Soil + ripe dessert banana

3.1.4. Effect of amendments on the length of new generated leaves

Fig. 5 shows that the average length of generated leaves on amendeded substrates increased with time. However, the leaves generated on the amended substrates were longer than those generated on the non-amended control. Thus, significant differences (P<0.05) were observed from the 80th day (Table 3I). Substrate 2, with cow dung, was the one that produced the longest leaves from the 40th day after planting (8.50 cm) to the 120th day (22.89 cm). It was followed by the one with chicken droppings even if on the 120th day after planting no significant difference was observed between substrates 2, 3 and 4. The same was true for substrates 1,5,7 where no significant difference was

observed although the average lengths of generated leaves on substrates 5 and 7 were greater than those of the leaves generated on the control from the 100th day.

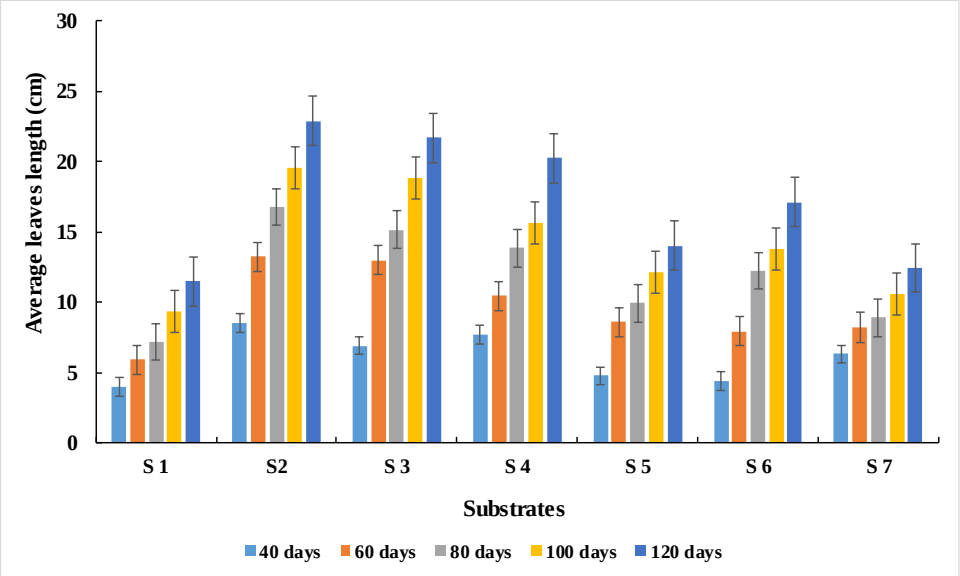


***Fig. 5** : Evolution of the average length of leaves generated on the substrates depending on time*

S1: Control; S2: Soil + cow dung; S3: Soil + chicken droppings; S4: Soil + charcoal; S5: Soil + banana stipes; S6: Soil + ripe plantain; S7: Soil + ripe dessert banana

Table 3: Average length of leaves generated on substrates

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	P
40 days	4.00^{a}	8.50^{a}	6.90^{a}	7.70^{a}	4.75^{a}	4.40^{a}	6.30^{a}	0.38
60 days	5.90^{a}	13.25^{a}	13.00^{a}	10,45^{a}	8.60^{a}	7.90^{a}	8.20^{a}	0.37
80 days	7.16^{c}	16.78^{a}	15.16^{ab}	13.84^{abc}	9.92^{abc}	12.22^{abc}	8.88^{bc}	0.00
100 days	9.38^{b}	19.60^{a}	18.83^{a}	15.66^{ab}	12.08^{b}	13.79^{ab}	10.53^{b}	0.00
120 days	11.49^{b}	22.89^{a}	21.71^{a}	20.24^{a}	14.00^{b}	17.12^{ab}	12.43^{b}	0.00

The averages on the same line followed by different letters are significantly different at 5% threshold.

S1: reference; **S2**: Soil + cow dung; **S3**: Soil + chicken droppings; **S4**: Soil + charcoal; **S5**: Soil + banana stipes; **S6**: Soil + ripe banana plantain; **S7**: Soil + ripe dessert banana; **P**: Probability

3.1.5. Effect of Amendments on center width of new generated leaves

Fig. 7 shows the average width of *Aloe vera* leaves of measured on the different substrates. Significant differences ($P < 0.05$) between the substrates were observed on the 80th day after planting (Table 4). The amended substrates all favored good leaf width growth compared to the control. The substrates amended with cow dung and chicken droppings induced better *Aloe vera* leaf width growth. However, cow dung promotes leaf width growth better than chicken droppings. Indeed, the highest average width was obtained with cow dung (1.34 cm). On the 100th day after planting, cow dung and chicken droppings generated the largest leaves with averages of 1.43 cm and 1.39 cm, respectively. After 120 days of planting, the widest leaves were still those obtained on substrates amended with cow dung (1.65 cm) and chicken droppings (1.61 cm). The lowest averages were obtained with the control substrate even if between the 100th and 120th day after planting, the leaves obtained on substrate 5 had the same average width as those obtained on the control.

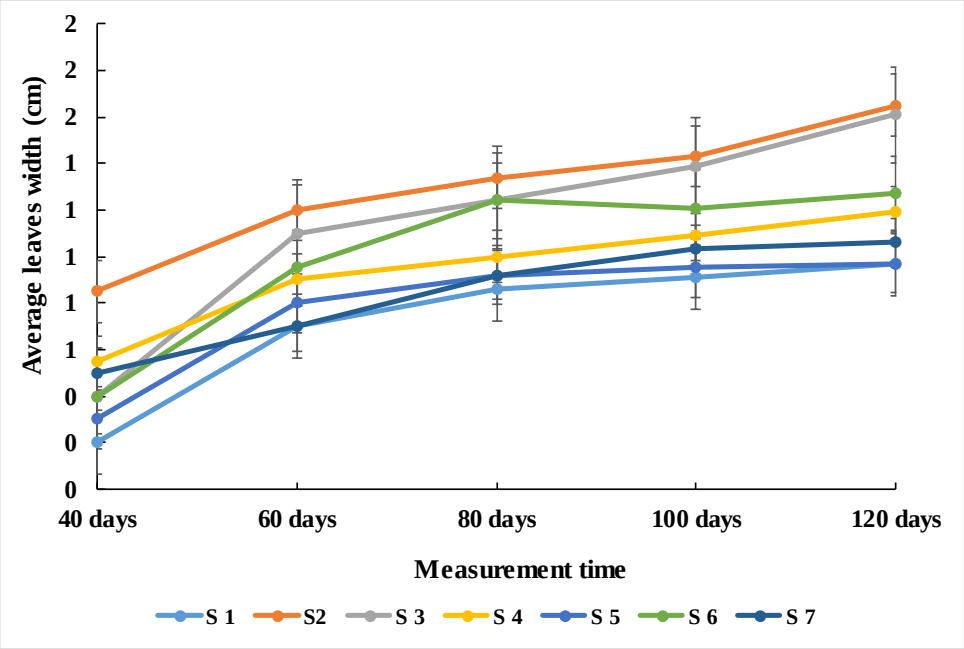


Fig 6: Evolution of the average width of the leaves generated on the substrates depending on time

S1: reference; S2: Soil + cow dung; S3: Soil + chicken droppings; S4: Soil + charcoal; S5: Soil + banana stipes; S6: Soil + ripe banana plantain; S7: Soil + ripe dessert banana

Table 4: Average width of the leaves generated on substrates

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	P
40 days	0.20^{a}	0.85^{a}	0.40^{a}	0.55^{a}	0.30^{a}	0.40^{a}	0.50^{a}	0.68
60 days	0.70^{a}	1.20^{a}	1.10^{a}	0.90^{a}	0.80^{a}	0.95^{a}	0.70^{a}	0.06
80 days	0.86^{b}	1.34^{a}	1.24^{ab}	1.00^{ab}	0.92^{ab}	1.24^{ab}	0.92^{ab}	0.01
100 days	0.91^{b}	1.43^{a}	1.39^{a}	1.09^{ab}	0.95^{b}	1.21^{ab}	1.03^{b}	0.02
120 days	0.97^{b}	1.65^{a}	1.61^{a}	1.19^{b}	0.97^{b}	1.27^{b}	1.06^{b}	0.00

The averages on the same line followed by different letters are significantly different at 5% threshold.

S1: reference; **S2**: Soil + cow dung; **S3**: Soil + chicken droppings; **S4**: Soil + charcoal; **S5**: Soil + banana stipes; **S6**: Soil + ripe banana plantain; **S7**: Soil + ripe dessert banana; **P**: Probability

3.2. Discussion

The pH of *Aloe vera* growth substrates evolved differently depending on the types of amendment ranging from 7.87 to 6.67. The organic amendments supplied therefore did not have the same influence on the modification of soil pH. The variability of pH takes into account the nature of organic amendments (Koulibaly, 2011). Charcoal input resulted in an acidic pH while other inputs kept the soil at a basic pH. This result is in contradiction with the results which tend to show that charcoal, due to its adsorbent properties, tends to increase soil pH (Bio, 2016). We could explain our results by the quality of charcoal used or the management of the crop. For example, poorly controlled irrigation can lead to excessive drainage, loss of bases and Ca^{2+} at depth, resulting in acidification of the surface (Koulibaly, 2011). However, the variation in pH was not an obstacle to the cultivation of aloe in nurseries. These results are in agreement with some authors who have shown that *Aloe vera* is generally cultivated on soils whose pH varies between 6.0 and 7.20 and can even tolerate high pHs (Anonymous 2, 2022; Gharib, 2021).

Leaf generating speed and total number of generated leaves, although improved by the input of organic fertilizers, were not statistically different from one substrate to another before 80 days after sowing. One could conclude that the examination of the comparative rhythms of emergence of *Aloe vera* leaves is first of a genetic order. As

a result, it provides information both on the size of the leaf system and on the number of leaves up to the adult stage of the plant (Vincourt, 1984). However, these genetic characteristics can be influenced by the cultivation environment. Indeed, at 80 and 100 days after planting, it was noted the intensification of leaf emergence on the substrates amended with cow dung and chicken droppings, respectively. In fact, these organic constituents have, in the meantime, been mineralized to be made available to the plant for its development (Segnou *et al*., 2012; Etter, 2017).

The amendments supplied have relatively improved *Aloe vera* leaf growth in length and width. According to Djéké *et al*., (2011) and Useni *et al*., (2013), the decomposition of organic fertilizers raises the levels of soil nutrients available to plants. These results would therefore result from a favorable action of the nitrogen and humus contained in these organic amendments, in particular cow dung and chicken droppings (Dembele, 2014). Indeed, according to Eleiwa *et al*. (2012), plant vegetative growth is positively correlated with nutrient absorption, in particular nitrogen which plays an important role in the increase in leaf area index and generation as well as photosynthetic activity. In addition, the results obtained in plants that received chicken droppings could be explained by the essential role that assimilable phosphorus, released into the soil by this manure, plays in growth and development, as well as in plant metabolism and energy transport (Ouedraogo *et al*., 2014). Similarly, according to Kouassi *et al*. (2017), charcoal contributes to nitrogen immobilization. In fact, adding charcoal to heavily weakened tropical soils improves their physical, chemical and biological properties. As a result, these soils can acquire good cation exchange capacities (CEC) and better abilities to retain and recycle nutrients over long cultivation periods. These results would therefore be attributable to this capacity possessed by charcoal. Through the effects due to banana, it seems that nitrogen assimilation by plants is favored by the strong presence of potassium and phosphorus in banana peel, as thought by Leikam *et al*., (1983). According to them, adequate phosphorus and potassium nutrition can increase the crop's growth response to nitrogen. The results obtained, in connection with substrate 5, show a low quantity of nitrogen in banana tree stems, which would justify the weak growth of the plants having evolved on this substrate compared to other fertilizers. Indeed, nitrogen is the most important nutrient for good growth of *Aloe vera* plants (Michayewicz, 2013). This observation is confirmed by Harry *et al*. (2011) who claim that the concentrations of total nitrogenous matter in banana tree stems are low and close to a straw.

IV. CONCLUSION

Cow dung, chicken droppings, charcoal, banana stipes, ripe plantain, and ripe dessert banana were used to determine and compare their effects on *Aloe vera* sucker growth in nursery. The results show that the pH of the substrates depends on the type of amendment supplied. This pH varied from 6.67 to 7.87. Regarding growth parameters, thanks to its richness in nitrogen, cow dung intensified leaf emergence speed. Moreover, with 9.33 leaves generated, 2.89 cm average leaf length and 1.65 cm average leaf width, it favored the rapid growth of *Aloe vera* suckers. Thus, for the establishment of an *Aloe vera* nursery, the use of cow dung could be recommended to promote good and rapid growth of suckers.

REFERENCES

[1] Adjiri, O., Assoma, T.V., Soro, G., Aka, N., Bengaly, I. and Soro, N. (2020). Evaluation of the suitability of natural spring waters for agriculture using hydrochemical techniques: the case of the departments of Daloa and Zoukougbeu, Ivory Coast. *Africa Science*, 16 (1): 204-217.

[2] Adjiri, O., Kouamé, V., Niangoran, C.K., Soro G. and Biémi, J. (2018). Toxic waste dumping in Ivory Coast: following the effectiveness of the clean-up operation based on residual pollution indicators. *Environment, Risks & Health*, 2 (17): 147-154.

[3] Alla, K.T., Bomisso, E.L., Ouattara, G. and Dick, A.E. (2018). Effects of plantain peel by-product fertilization on agromorphological parameters of the F1 Eggplant variety kalenda (Solanum melongena) in Bingerville locality, Ivory Coast. *Journal of Animal & Plant Sciences*. Vol.38, Issue 3: 6292-6306.

[4] Anonymous 1 (2022). Mexico big producer of the beauty scrunchie [online]. https://www.actulatino.com/2021/08/16/l-aloe-vera-the-mexico-big-producer-of-scrunchie-beauty/ (Consulted on 03/09/2022).

[5] [5] Anonymous 2 (2022). What type of soil for Aloe vera? [online]. https://plantsguide.com/what-type-of-soil-for-aloe-vera/ (consulted on 25/01/2023).

[6] Bio, S. (2016). Growing differently: local examples of agro-ecological techniques. 21 p.

[7] Dembele, A. (2014). Response of maize (*Zea mays* L.) to compost or manure on soils amended with fragmented twigs of *Piliostigma reticulatum* (D.C.) Hochst. DEA thesis. University of Polytechnic of Bobo-Dioulasso. Burkina Faso, 64 p.

[8] Djéké, D.M., Angui, K.T.P. and Kouadio, Y.J. (2011). Decomposition of cocoa shells in ferralitic soils of the Oumé area, west-central Ivory Coast: effects on soil chemical characteristics. *Biotechnology Agronomy Society and Environment*. 15 (1), 109 - 117.

[9] Dro, B., N'goran, K.D., Coulibaly, S., Salla, M., Amon, A.D.E and Kouassi, K.H (2020). Floristic Diversity of the Lianas of the Forest Classified as Bouaflé, Centre West of

Ivory Coast. *European Scientific Journal*. Edition Vol.16, No.27 ISSN: 1857 - 7881.

[10] Eleiwa, M.E., Brahim, S.A. and Mohamed, M.F. (2012). Combined effect of NPK levels and foliar nutritional compounds on growth and yield parameters of potato plants (*Solanum tuberosum* L.) *African Journal of Microbiology Research*, 6 (24) : 5100-5109.

[11] Etter, A. (2017). Organic fertilizers: yield and quality. Review UFA 10/ 2017, 2 p.

[12] Foure, E. and Tezenas, D.M. (2000). Banana production: a major economic challenge for food security. *Newsletter of the regional cooperation for the development of horticultural products in Africa*, 1 (8) : 23-28.

[13] Gharib, K. and Ben, Z.S. (2021). Investigations on Antimicrobial, Antifungal and Antiviral Properties of *Aloe vera*. Master thesis, University Brothers Mentouri Constantine 1, 48p.

[14] Kouakou, A.C.A., Coulibaly, B., Kaba D., Anoh, K.P and Courtin, F. (2018). Settlement dynamics and landscape modification in the Marahoué National Park (Ivory Coast). *TROPICULTURA*, 36(2): 206-216.

[15] Koulibaly, B. (2011). Characterization of soil acidification and fertility management of cotton agrosystems in Burkina. Thesis at the University of Ouagadougou Option Applied Sciences Speciality: Agro-pedology. 183 p.

[16] Leikam, D.F., Murphy, L.S., Kissel, D.E., Whitney, D.A. and Mserh, H.C. (1983). Effect of nitrogen and phosphorus chorus application and nitrogen source in winter wheat grand yield and leaf tissue phosphorus. *Soil. SCI. AMG*: 530-535.

[17] Michayewicz, N. (2013). Aloe vera, a medicinal plant traditionally and widely used for thousands of years, with numerous therapeutic properties. Miracle plant? Doctoral thesis, University of Lorraine, France, 148p.

[18] Nindjin, K.A.G., Agbo, N.G. & Otokore, O.D. (2003). Varieties of yams (*Dioscorea spp*) found on markets in Ivory Coast and their culinary preference Post-harvest, 32 p.

[19] Onyinyechi, C., Amobi, A.A., Cynthia, E., Chineye, L., Nneka, M.U.C., Simeon, O., Chidimma, C., Kelechi, M.O.F. and Chukwuebuka, O. (2021). In vivo study of antiplasmodium and histological activity of *Garcinia kola* and *Aloe vera* extracts against Falciparum malaria. *Journal of Medicinal Plants Research*, 15 (5) : 18-195.

[20] Ouédraogo, J., Nacro, H.B., Ouédraogo, E., Youl, S. and Sedogo, M. (2014). Improving phosphorus availability through soil macrofauna management: case of a lixisol in the semi-arid zone of Burkina Faso. *Int. J. Biol. Chem. Sci*. 8(4): 1838-1846.

[21] Sangare, A., *Koffi, E.M., Akamou, F.M. & Fall, C.A. (2009).* National Report on the State of Plant Genetic Resources for Food and Agriculture. Republic of Ivory Coast. Ministry of Agriculture. The State of Plant Genetic Resources for Food and Agriculture: Second National Report. 63 p.

[22] Segnou, j., Akoa, A., Youmbi, E. and Njoya, J. (2012). Effect of mineral and organic fertilization on fruit yield of chilli (*Capsicum annuum* l.; solanaceae) in lowland forest zone in Cameroon. 10 p.

[23] Svjetlana, Z., Parađiković, N., Davidović, J., Gidas, E. and Vujošević, A. (2020). The effect of water extract of *Aloe vera* (L.) burm.f. on germination and growth of scarlet sage; *Proceedings of the XI International Scientific Agricultural Symposium Agrosym* , 12 (7) : 262-267.

[24] Useni, S.Y., Chukiyabo, K.M., Tshomba, K.J., Muyambo, M.E., Kapalanga, K.P., Ntumba, N.F., Kasangij, A.K.P., Kyungu, K., Baboy, L.L., Nyembo, K.L. and Mpundu, M.M. (2013). Use of recycled human waste for increasing maize (Zea mays L.) production on a ferralsol in southeastern DR Congo. *Journal Applied Biosciences*. 66: 5070 - 5081.

[25] Vincourt, P. (1984). Relationships between leaves appearance rhythm, total number of leaves and flowering precocity in maize. *Agronomy*, 4 (8), pp.795-800.

[26] Yosser, B.Z. (2012). Behaviour of Aloe vera planted on two different textured soils and subjected to saline treatment. End of study project. Mograne High School of Agriculture, 49 p.

[27] Zerrad, W., Maataoui, B.S., Hilali, S., El Antri, S. and Hmyene, A. (2008). Comparative study of biochemical mechanisms of resistance to water stress in two varieties of hard wheat. *Lebanese Science Journal*, 9(2). 27-36.

[28] Zro, B.F.G, Soro, D. and Abobi, D.H.A (2018). Comparative analysis of the effects of two organic amendments on the organo-mineral status and productivity of a sandy soil. *Journal of Applied Biosciences* 124: 12416 - 12423.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Farmers' Perception of agroforestry in the Bambou–Mingali forest massif (Congo)

Gilles Freddy Mialoundama Bakouetila[1,*], Budeh Wickler Nzobadila Kindiela[2], François Mankessi[1,3], Ildevert Madel Mounkala Mabanza[4], Ségolen Lutterah Missengué Scherell [1]

[1.]National School of Agronomy and Forestry, Marien Ngouabi University, Congo
[2.]Laboratory of Cropping Systems and Soil Sciences, National Institute for Agronomic Research (IRA), Congo
[3.]National Afforestation and Reforestation Program (PRO NAR), Ministry of Forest Economy, Congo
[4.]Reforestation National Service (SNR), Ministry of Forest Economy, Congo
*Corresponding author

Received: 01 Feb 2023; Received in revised form: 01 Mar 2023; Accepted: 10 Mar 2023; Available online: 19 Mar 2023

Abstract— *Agroforestry offers an opportunity to enhance the value of poor ferralitic savannah soils in the Republic of Congo. The aim of the study was to analyze farmers' perceptions of agroforestry in the Bambou–Mingali artificial forest massif. A survey was conducted among 42 farmers who had signed an exploitation contract with the National Reforestation Service (SNR). The study revealed that most of the farmers involved in agroforestry on reforested state-owned plots were adults (83%) and had received education (100%). Agri-silviculture is practiced on these plots. The SNR is responsible for preparing the land for planting forest species (for example, Acacia, Eucalyptus, pines). Weeding was the only maintenance operation carried out by all farmers. Positive factors that may lead farmers to adopt agroforestry innovations in state reforested plots include free access to land, economies of scale in the establishment of food crops, and satisfaction with the yields obtained and income earned compared to savannah areas. Acacia was the most valued forest tree among farmers. Thus, the reforested plots are an opportunity to promote agroforestry for the benefit of smallholders.*

Keywords— ***Perception, agroforestry, socio-economic, forest massif, Congo***

I. INTRODUCTION

Congolese agriculture meets only 30% of the country's food needs (ECOM, 2005). The production system is based on shifting cultivation with cassava (*Manihot esculenta* Crantz) as the main crop. Cassava has a high capacity to adapt to different ecosystems and is the staple food of the Congolese (Massamba and Treche, 1995). The diagnostic assessment of this sector has shown that crop yields are low, averaging 11 t/ha (IFAD, 2008). These low yields can be attributed to low soil fertility, diseases caused by the spread of the African cassava mosaic virus, traditional low-input techniques, and the use of rudimentary tools, among other factors (Mabanza and Mahouka, 2001; Nzobadila Kindiela *et al.*, 2019).

Moreover, the soils of the Congo region are naturally poor, characterized by less exchangeable cations in the clay–humus complex and the acidity of the upper horizons (Djondo, 1994). Farmers cultivating food crops use slash-and-burn agriculture as the primary method of land preparation for cultivation. Slash-and-burn farming temporarily increases the availability of alkaline cations and, consequently the soil pH. Regardless of this positive impact, which is short-lived, this practice has many negative impacts on the soil, including volatilization of nutrients, destruction of organic matter, formation of a water repellent layer on the surface, and destruction of soil biology (Garcia-Oliva *et al.*, 1999; Okonkwo, 2010). In this context, agroforestry can be a sustainable alternative to slash-and-burn farming practices, and can be implemented with the aim of maintaining soil agricultural productivity at a

threshold deemed profitable. Agroforestry systems include both traditional and modern land use techniques where trees are associated with crops and/or livestock systems in agricultural settings. Trees contribute to several ecosystem processes, such as organic matter formation, nutrient recycling, erosion prevention, and water balance modification (Nasielski *et al.*, 2015; Carrier, 2018). Therefore, agroforestry systems offer forms of soil fertility improvement, food, and financial resources for local populations (Dupraz and Liagre, 2008; Jose, 2009).

In the Republic of Congo, the national reforestation policy is implemented by the National Afforestation and Reforestation Programme (ProNAR) and the National Reforestation Service (SNR). The SNR is a public service responsible for the establishment and management of state-owned plantations. In its prerogatives, this service has to its credit several state-owned areas at the national scale, including that of Bambou–Mingali located in the district of Igné, Department of Pool, 70 km north of Brazzaville. Within the framework of the management of the massifs, the national policy advocates partnerships between the public service and farmers/wood plantation industries. These partnerships aim to associate the cultivation of trees and food crops in plantations. The agroforestry initiative was launched by the SNR in the Bambou–Mingali forest massif in 2015. Several years after the launch of this initiative enhancing the value of state-owned plots through agroforestry, the results and effectiveness of this agroforestry system remain poorly understood. As a good understanding of farmers' perception is a prerequisite for sustainable land management initiatives, as reported by Valdivia *et al.* (2012) and Adedayo and Oluronke (2014), this study aimed to analyze farmers' perceptions of the socio-economic benefits of the agroforestry system under the socio-environmental conditions of Bambou–Mingali.

II. METHODOLOGY

Study area

The study was conducted in the Bambou–Mingali forest massif, in the sub-prefecture of Igné, in the urban community of Igné as well as in the villages bordering this massif (Figure 1). The village of Bambou–Mingali is located at a distance of approximately 60 km from Brazzaville on the Mbé Plateau. An important forest massif that comprises approximately 1100 ha in the state land domain of 2100 ha is located nearby and secured by the P_{RO}NAR. Several forest species are planted in rows in this area, with variable densities for each species. These include clones of the hybrid *Eucalyptus urophylla* × *Eucalyptus grandis*, *Eucalyptus PF1*, *Pinus caribaea*), *Millettia laurentii*, *Acacia auriculiformis*, and *Acacia mangium*. Access to the site for farmers is subject to the signing of a memorandum of understanding between them and the SNR. All farmers are required to maintain the land in an acceptable state of cleanliness to enable proper growth of the trees at the site. The farmers conduct periodic maintenance of the young plants and crops and the public service or the industrialists are responsible for land preparation operations (ploughing, harrowing, squaring, staking, hole digging, and planting)

The climate of the study area is humid tropical (Samba-Kimbata, 1978). The average annual temperatures vary between 23 °C and 26 °C. Seasons alternate as follows: short dry season (January, rainfall decreases), first rainy season (February to mid-May, with a peak in April), long dry season (mid-May to mid-September) and second rainy season (October to December). The interannual rainfall variability between 1980 and 2014 was approximately 1,364 mm (Mengho, 2017). The soils in the study area are ferralitic, impoverished, and highly desaturated from the ochre sands of the Teke Plateau. They are characterized by sandy texture and low organic matter content, with a low reserve of exchangeable bases. The cation exchange complex is dominated by aluminum (46%), calcium (20%), and magnesium (9%) (Souchere and Bosseno, 1974; Djondo, 1994). The habitat comprises a herbaceous savannah with the following dominant species: *Hyparrhenia diplandra* Stapf., *Crotalaria retusa* L., *Hymenocardia acida* Tul., and *Annona senegalensis* Pers. (Descoing, 1975; Makany, 1976). Following land reclamation, the dominant species were *Digitaria horizontalis* Willd. and *Imperata cylindrica* (L.) P. Beauv.

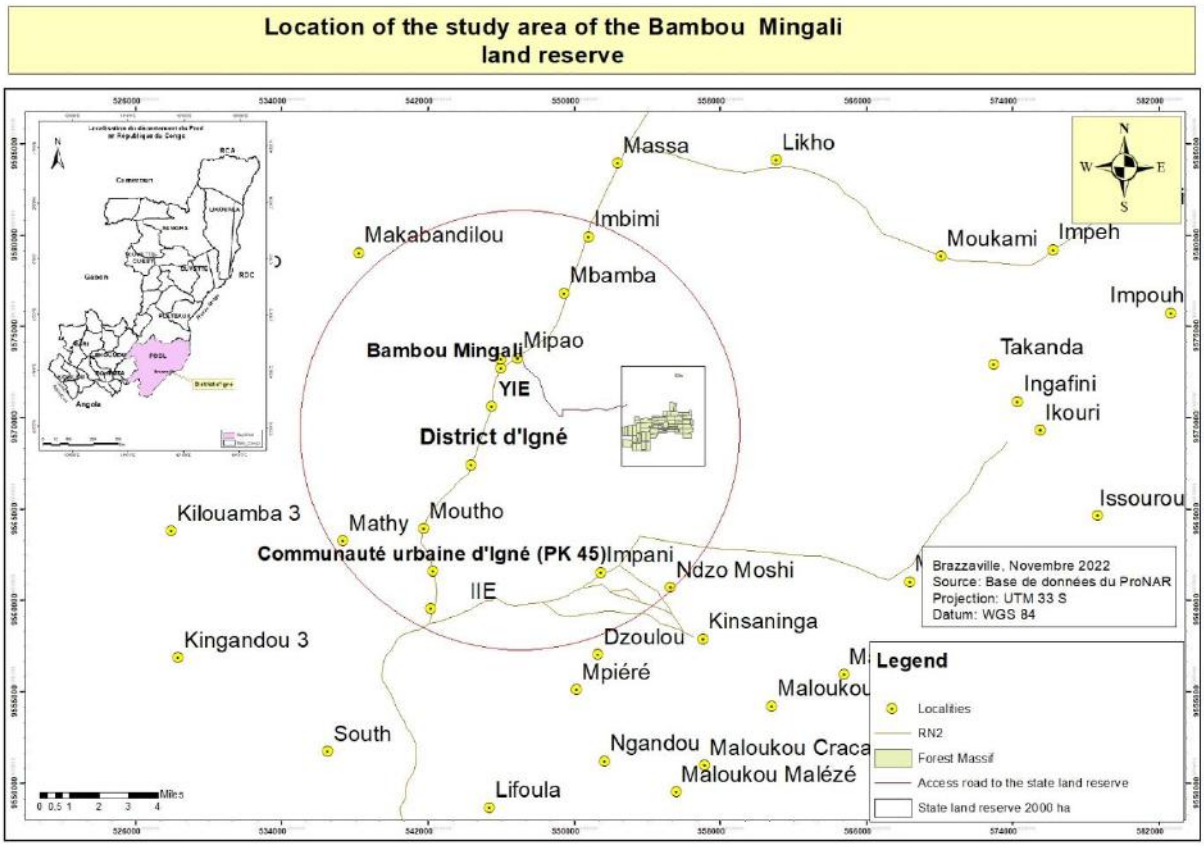


Fig.1. Location of the study area

Sampling and data collection

The study population consisted of farmers of the Bambou–Mingali forest massif. As the list of agroforestry farmers in this forest massif was available, the sample was constituted on the basis of probability sampling, by drawing lots. The selected farmers were contacted by telephone and an appointment was made to conduct the individual interview using a survey questionnaire. A total of 42 farmers were selected from the 50 farmers who had signed the contract with the SNR forestry station represented by its head of unit, resulting in a sampling rate of 84%. The interviews were supplemented with open discussions, individual interviews with resource persons via an interview guide, and documented information. The latter focused on documentation related to agroforestry and knowledge of the study area. The data collection tools (survey questionnaire and interview guide) included information on farmer profiles, the characterization of the production system, and perception of the benefits of agroforestry; these tools were validated during a pre-survey. The formal individual interviews were conducted either at the farmers' residence or at the farm site. However, free discussions were held in places where people could use the land, in this case in bars.

Data processing and analysis

Data were analyzed using Sphinx software version 5.1.0.7. The database constituted through data entry was checked for consistency and conformity between the data collected and those entered. The data collected in the field were subjected to descriptive statistical analysis, thus determining the numbers and frequencies (%) of the response modes of the variables studied. The chi-square test was used to test the significance of the responses for qualitative variables. Excel 2016 software was used to graphically represent the results.

The qualitative data from the open discussions, literature review, and resource person interviews were subjected to content analysis to extract the information essential to the study objectives.

III. RESULTS

Description of the Bambou–Mingali agroforestry system

Access to the inter-rows of forest plots in the massif for the cultivation of food crops is subject to the signing of a work protocol between the station chief and the farmer, who may be the farmer or a person belonging to another category. The terms of the contract stipulate that "the SNR authorizes the farmer to plant cassava cuttings or other food crops in the young plantations." However, the farmer is obliged not to destroy the young plants during the planting of cassava

cuttings or other food crops, and the same applies to weeding operations aimed at keeping the plots clean throughout the crop cycle. This is a "win-win" public-private partnership agreement, as the SNR is exempted from the cost of maintaining the plot and the farmers are given free access to an area of between 0.5 and 5 ha. If the plot is not maintained, the SNR conducts mechanical maintenance of the plot, which implies that it destroys everything in the rows using a machine, leaving only the forest species, and then withdraws the farmer's access to the plot.

Table 1 presents a description of the Bambou–Mingali agroforestry system. The results show that the agroforestry system practiced here was the only one practiced in these state plots. Cassava was the main crop cultivated by farmers, accounting for 79% ($P < 0.05$). It represents the staple food of this region as well as the main product marketed after processing (cassava pods, cassava bread, or chikwangue). Approximately half of the farmers (55%) managed agroforestry plantations of less than one hectare ($P < 0.05$). However, 31% of the farmers cultivated areas between 1 and 2 ha. Very few cultural maintenance operations were conducted within these agroforestry plots. Weeding was the main maintenance operation conducted by almost all farmers, 95% ($P < 0.05$). The use of basal and maintenance fertilization and the use of plant protection products for better crop protection was rare ($P < 0.05$). Moreover, very few farmers (7%) used crop rotation ($P < 0.05$).

Table 1. Characteristics of the Bambou–Mingali agroforestry system

Variables	Responses	Frequency (%)	Significance
Cultivation system used	Agri-silviculture	100	Constant
	Other	0	
Key crops of the farm	Cassava	79	P < 0.05
	Vegetables	15	
	Corn	6	
Area farmed (ha)	< 1 ha	55	P < 0.05
	1-2 ha	31	
	> 2 ha	14	
Cultivation operations conducted	Weeding	95	P < 0.05
	Weeding and fertilization	5	
	Other	0	
Use of fertilizers	No	95	P < 0.05
	Yes	5	
Use of plant protection products	No	100	P < 0.05
	Yes	0	
Practice of crop rotation	No	93	P < 0.05
	Yes	7	

Socio-economic importance of the Bambou–Mingali agroforestry system

The practice of agroforestry in the Bambou–Mingali forest massif mobilized both women and men, in proportions of 45% and 55%, respectively ($P > 0.05$). Young people (17%) were less involved compared to adults (83%). Thus, the proportion of adults that participated in the system was approximately five times greater than that of youth ($P < 0.05$). The schooling rate of farmers was 100%, with a predominance of farmers with a secondary level 2ème degree (31%) ($P < 0.05$). Agriculture and trade were the two main activities the surveyed farmers participated in, with proportions of 45% and 31%, respectively.

The survey results also showed that more than half of the farmers (60%) had less than 5 years of agroforestry experience ($P < 0.05$). However, 24% of the farmers surveyed claimed to have between 6 and 10 years of agroforestry experience (Table 2). In contrast, a marginal proportion of farmers had a rich agroforestry experience exceeding 11 years. Half of the respondents resided in the urban community of Igné ($P < 0.05$). Other respondents lived in the rural communities of Bambou–Mingali (19%), Yié (19%), and Moutoh (12%).

Table 2. Profile of farmers in the Bambou–Mingali forest massif

Variables	Responses	Frequency (%)	Significance
Type	Female	45	P > 0.05
	Male	55	
Age range (years)	Young ≤ 35	17	P < 0.05
	Adult ≥ 36	83	
Level of education	Primary	29	P > 0.05
	Secondary 1er degree (middle school)	24	
	Secondary 2ème degree (high school)	31	
	University	17	
Main activity	Agriculture	45	P < 0.05
	Trade	31	
	Other activities	21	
Length of time in agroforestry experience	≤ 5 years	60	P < 0.05
	6-10	24	
	≥ 11 years	17	
Location of respondent's residence	Urban Community of Igné	50	P < 0.05
	Bambou–Mingali	19	
	Yié	19	
	Moutoh	12	

The results of the survey showed that marketing and self-consumption were the two objectives of establishing farms in the Bambou–Mingali forest massif. Notably, a large majority of farmers (86%) were involved in commercial, market-oriented farming (P < 0.05). Free access to land within the forest massif was the main determinant of the establishment of agricultural plantations in this massif (72%) (P < 0.05). However, proximity to the place of residence (19%) and the search for fertile land (9%) were also among the other factors contributing to the cultivation of food crops within the forest plots (Table 3).

Table 3. Motivations for agroforestry practice in the artificial forest

Variables	Responses	Frequency (%)	Significance
Objectives of the operation	Auto consumption	14	P < 0.05
	Marketing	86	
Motivations for the establishment of plantations in the forest	Free access to land	72	P < 0.05
	Soil fertility	9	
	Proximity of the place of residence	19	

Analysis of the consolidated operating cost for the cultivation of one hectare of cassava in plots located inside and outside the forest under SNR management showed that the SNR's contributed approximately 45% to the production cost of cassava cultivation. Indeed, farmers who cultivated cassava on plots prepared by the SNR minimized expenses related to access to land and soil preparation operations (stump removal, stump collection, ploughing, and harrowing). These costs amount to 180,000 FCFA for one hectare of cassava (Table 4). This category of farmer incurred a production cost of 216,500 FCFA and made a turnover of 500,000 FCFA after selling 60 bags of cassava. At the end of the production cycle, they had a net commercial margin of 283,500 FCFA. However, farmers

who cultivated cassava outside the forest massif incurred higher production costs. These production costs amounted to 396,500 FCFA, i.e., a difference of 180,000 FCFA, thus reflecting the satisfaction of the farmers in partnership with the SNR.

Table 4. Consolidated operating cost for cassava cultivation in Bambou–Mingali

Operation	Bambou–Mingali Forest Massif		Outside the forest massif - Savannah	
	Expenses (FCFA)	Product (FCFA)	Expenses (FCFA)	Product (FCFA)
Expenses (A)				
Purchase of the machete	4 000		4 000	
Purchase of the hoe	3 500		3 500	
Purchase of the peel	4 000		4 000	
Land rental	0		30 000	
Stump removal	0		50 000	
Pickup	0		10 000	
Ploughing	0		45 000	
Spraying	0		45 000	
Buy cuttings	10 000		10 000	
Cutting of cuttings	5 000		5 000	
Transport	10 000		10 000	
Planting	30 000		30 000	
Weeding	120 000		120 000	
Harvest	30 000		30 000	
Total load	**216 500**		**396 500**	
Turnover - Cassava sales (B)		500 000		500 000
Net sales margin (B-A)		**283 500**		**103 500**

The socio-economic importance of agroforestry within this massif is justified by the satisfaction of the majority of farmers surveyed (88%). Indeed, 81% of the respondents were satisfied with the income generated through agroforestry within this forest massif ($P < 0.05$). A marginal proportion of farmers (7%) were highly satisfied with the income generated. However, 12% of farmers remain dissatisfied with the income generated; these mostly included farmers cultivating in *Eucalyptus* plots.

Perception of the benefits of the state agroforestry system and the most suitable forest species

Table 5 shows the perception of farmers in Bambou–Mingali forest massif regarding the benefits of trees within the farm and the most suitable forest species for cultivation in association with food crops. The analysis of Table 5 shows that leaf collection was the main benefit perceived by the farmers (57%) ($P < 0.05$). These leaves are used to fertilize the soil and also serve as natural remedies. For example, *Eucalyptus* leaves are harvested for the treatment of respiratory tract diseases (bronchitis, flu) and ENT diseases (sinusitis). The ecosystem services provided by trees integrated into farming also concern the improvement of soil fertility for certain forest species of the family Fabaceae (*Acacia* spp.), which affects crop yields and farmers' income. Harvesting of wood, caterpillars and mushrooms are also ecosystem services provided by the agroforestry system through the trees. During September and October, when the rains begin, some farmers reported harvesting mushrooms from their agroforestry farms.

The results also indicate that *Acacia* is the most preferred tree in agroforestry in the study area. More than half of the farmers included in the survey held this view (69%) ($P < 0.05$). In terms of preference, *Acacia* was followed by pine and *Millettia*, at 14% and 12%, respectively. *Eucalyptus*

was the least preferred tree in agroforestry, with 5% of the respondents showing a preference for it.

Of the farmers interviewed, 79% thought that cassava yields in the Bambou–Mingali massif were higher than those in the savannah zone ($P < 0.05$). Only 21% disagreed with this view. This category of farmers cultivated food crops in the *Eucalyptus* plots.

Table 5. Perceived benefits of the agroforestry system in state-owned plots

Variables	Responses	Frequency (%)	Significance
Advantage of trees in the farm	Collection of leaves	57	$P < 0.05$
	Improvement of soil fertility	19	
	Firewood	18	
	Mushroom harvesting	6	
Best woody species for agroforestry	*Acacia mangium* Willd./*Acacia auriculiformis* A. Cunn. ex Benth.	69	$P < 0.05$
	Pinus spp.	14	
	Millettia laurentii De Wild.	12	
	Eucalyptus spp.	5	

Acacia and pine were the two most preferred forest trees in the agroforestry system. Most farmers (90%) preferred to grow cassava with *Acacia* ($P < 0.05$). The same was true for maize (*Zea mays* L.) cultivation; 70% of the farmers preferred to cultivate with *Acacia* (Figure 2). However, for groundnut (*Arachis hypogaea* L.) cultivation, more than half of the farmers preferred to cultivate it in association with young pine trees ($P < 0.05$). Therefore, the promotion of agroforestry should focus more on *Acacia* to enhance the value of the savannah areas, which are less appreciated by farmers.

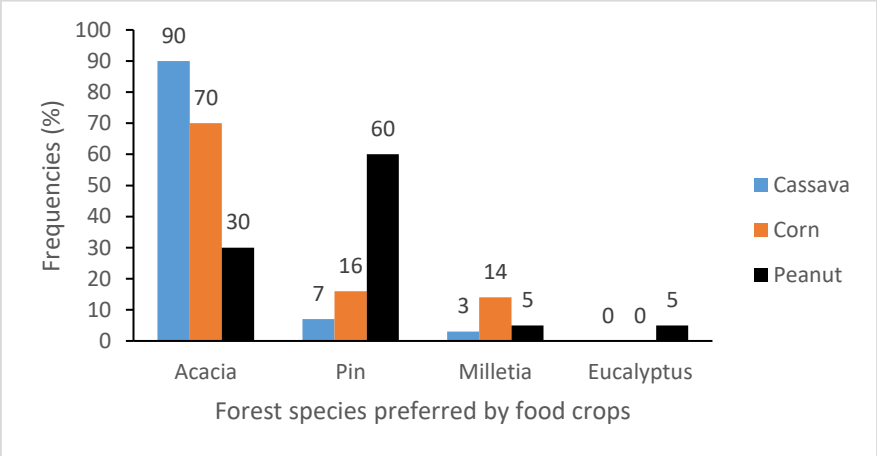


Fig.2. Farmers' perception of the preference for forest species cultivated in association with food crops

IV. DISCUSSION

Characteristics of the Bambou–Mingali agroforestry system

Only one agroforestry system, the agri-silviculture cultivation system, was practiced by farmers in the plots located in the Bambou–Mingali forest massif. Agricultural production was achieved using technical itineraries and archaic means of production that were not very efficient. With respect to crop maintenance operations, few interventions were conducted, and weeding was the most common intervention. The cut weeds were stirred up and left on the ground to restore exported nutritive elements through decomposition.

In the Bambou–Mingali forest massif, cassava was the preferred crop, and was planted both as a monoculture and in association with trees. Previous studies have shown that the traditional agricultural system integrates a range of crops with differing phonologies to ensure optimal production that is staggered in time. Crop association provides production security by minimizing risks and

maximizing land and labor use (Jayne *et al.*, 2010). National agricultural production basins are characterized by low crop diversity, including cassava cultivation areas. Furthermore, several studies in rural areas note that crops are often grown in association with others (maize, vegetables, groundnuts, etc.), but rarely as monocultures (ECOM, 2005). Only cassava is cultivated through monoculture; however, this is often observed in areas where cultivation of other crops is challenging owing to extremely poor soils.

The area utilized for agricultural purposes in the Bambou–Mingali Forest is mostly less than one hectare. Very few farmers practice cultivation in >2 ha of land; this can be explained by a various factors, including the difficulty in obtaining quality cuttings and tractors for land preparation and low soil fertility. Congolese agriculture is poorly mechanized and therefore highly dependent on labor. Moreover, cassava cultivation benefits from little investment, despite constraints such as field maintenance. In many agricultural production basins in Congo, family farms range between 0.5 and 1 ha (ECOM, 2005; CERAPE-SOFRECO, 2012). Larger areas are sown by producers with greater financial and human resources, as they can bear the higher production and marketing costs.

Mineral fertilization of cassava is significantly rare, and only 2 respondents out of the 42 surveyed applied NPK fertilizer for food crops. The distribution circuit for agricultural inputs is disorganized, resulting in low availability and high cost. In addition, the agricultural extension services responsible for disseminating good agricultural practices are deficient. It has been observed that the supply of organic matter is also non-existent in the area. This observation is shared by CERAPE-SOFRECO (2012) who found that the use of fertilizers remains marginal, and is limited to peri-urban areas. As cassava is a hardy crop, its cultivation requires only basic land preparation and few maintenance cultivation operations (El-Sharkawy, 2004). Several studies have shown the importance of fertilizers in maintaining soil quality. Schroth *et al.* (2001) also showed that fertilization is less frequent in agroforestry.

The use of phytosanitary treatments was non-existent in the study area. For the farmers surveyed, cassava plants in the field were rarely affected by crop diseases and pests. However, it should be noted that cassava is a hardy crop, growing quite well in most environments, and farmers are generally unaware of the symptoms of cassava diseases. Moreover, several farmers perceive that cassava that is attacked by pests or diseased is still productive. Thus, the model of agriculture practiced in the Bambou–Mingali forest massif is the same as that of almost all Congolese food production basins, strongly dominated by the individual or family village agricultural model, using rudimentary tools and techniques and not resorting to chemical inputs, especially fertilizers and pesticides (CERAPE-SOFRECO, 2012).

To a certain extent, farmers tend to grow varieties that are adapted to the environment (Elias *et al.*, 2004). This observation was also shared by CERAPE-SOFRECO (2012) who found that the use of pesticides in the Congolese rural environment remains marginal, and is limited to the peri-urban areas of the country, where market gardening activity remains important. Very few farmers in the agroforestry massif exploit the entire domain granted by the SNR by implementing crop rotations. However, fallowing is a constant feature of production systems in rural areas (Floret *et al.*, 1993).

Socio-economic importance of the Bambou–Mingali agroforestry system

The farmers of the Bambou–Mingali forest massif comprised both men (55%) and women (45%). Farmers in the age range of 36–44 years (45%) were the most involved in the agroforestry plantations of Bambou–Mingali. Almost similar results were also reported by the RGA (2017), wherein 74% of the heads of adult agricultural households and those in this category in the age range of 36–49 years were the most dynamic in the Congolese agricultural sector (38%). The high level of participation of this category of farmers remains an asset for the extension of agroforestry practices. Many studies report that age can be a determining factor in the adoption of a new technique (Adedayo and Oluronke, 2014). Regarding the age of agroforestry implementation, a majority of the farmers interviewed claimed to have practiced agroforestry for less than 5 years. The high proportion of farmers with less than 5 years of experience is owing to the fact that the SNR has only allowed farmers to cultivate in the massif for 5 years. However, those with more than 5 years' experience had already practiced the system elsewhere, in the surrounding forest blocks or in other localities.

All farmers included in the survey were educated. However, over half (55%) of them received secondary education, with a predominance of those with a secondary 2ème degree (31%). Nearly one-fifth of the respondents (17%) had a university degree. This can be explained by the proximity of the surrounding localities to the city of Brazzaville, the political capital, where the education offered is highly diverse. Moreover, the urban community of Igné includes school infrastructure, including a public high school. It is obvious that the development of agroforestry techniques and innovations requires a minimum of training and technical supervision. Results of previous studies have shown that the level of education plays a role in learning

new agricultural techniques and facilitates their adoption (Valdivia *et al.*, 2012; Adedayo and Oluronke, 2014).

The main activity of 45% of the farmers in the Bambou–Mingali Forest was agriculture. Other farmers used agriculture as a secondary or tertiary activity. This second category of farmers were primarily engaged in trade, vehicle driving, and handicrafts; this category also included government officials. The high involvement of farmers who do not farm as their main activity can be explained by the fact that households are highly dynamic in rural areas and can implement several monetization strategies simultaneously (Jayne *et al.*, 2010).

Most of the farmers (86%) surveyed conducted agricultural activities with the aim of marketing their products; a small portion of the production was devoted for self-consumption. As agriculture is the main income-generating activity for the inhabitants of this area, the cultivation of food crops is not only for self-consumption but also has serious economic importance. The integration of the local economy into a wider trade zone has been achieved through the National Road No. 2, which provides trade opportunities between the surrounding localities and the city of Brazzaville, where the demand for food products remains very high.

Farmers were highly satisfied with the income generated from agroforestry production compared to that generated from farms in the savannah zone. This satisfaction of the respondents was owing to the fact that farmers growing cassava on SNR plots saved expenses related to access to land and soil preparation operations. Increasing productivity within production systems is a requirement for economic development and poverty alleviation. This positive perception of farmers in Bambou–-Mingali forest range corroborates the work of Mercer (2004) and Bengali (2018), who argue that endogenous determinants affect farmers' perception. A majority of the respondents believed that this SNR initiative of agroforestry could enhance the value of wasteland and reduce the distances traveled in search of forest patches. In this context, the Société des Plantations Forestières Batéké Brazzaville (SPF2B), whose main objective is charcoal production, has integrated agroforestry into its production model by setting up a community development program. This program aims to encourage local communities to grow food crops (such as cassava, groundnuts, and maize) in the spaces between the *Acacia auriculiformis* A. Cunn. Ex Benth trees planted. All land preparation operations in the areas allocated to local communities in the Igné district of Congo are carried out by the SPF2B company prior to the allocation of land portions.

Benefits of the state agroforestry system and perception of the most suitable forest species

Free access to land was the main driving farmers' preference for the Bambou–Mingali state forest for conducting farming activities. To a lesser extent, they also cited the proximity of the site to their place of residence. The benefits cited by farmers owing to the presence of trees on their farms were soil fertilization and the availability of plant materials for traditional medicine. Collection of firewood and mushroom harvesting were among the less cited reasons. Similar to our findings, Jose (2009) showed that agroforestry parks are significant sources of wood and non-wood products that are indispensable to the population.

Most farmers found that crop yields were higher in the SNR agroforestry site than those outside the site. They also found that crop yields obtained in the *Acacia* plots were significantly better compared to plots with other forest species. *Eucalyptus* was the least preferred forest tree in association with crops. The relatively high crop yields in the *Acacia* plots can be explained by the fact that *Acacia* is genus belonging to the legume family Fabaceae and thus restores soil fertility. Indeed, leguminous plants are atmospheric nitrogen-fixing plants that transform nitrogen from the air into nitrogenous compounds in symbiosis with certain types of bacteria, thus improving soil fertility.

The consequences of a tree-crop association are variable depending on the associated species and the site studied (pedoclimatic conditions). Nevertheless, it would positively affect agricultural production owing to the discontinuous arrangement of trees, which would result in an increase in soil and air humidity, soil fertility, as well as a slowing of winds (Jose, 2009; Schroth *et al.*, 2001; Nasielski *et al.*, 2015). In contrast, the presence of trees sometimes adversely affects crop development (Carrier, 2018). The study by Akouehou *et al.* (2011) in Benin showed that the Taungya agroforestry system based on *Acacia auriculiformis* restored agricultural land and allowed farmers to have an additional and diversified gain of food products to support their needs. Dupraz and Liagre (2008) reported several advantages of agroforestry, including agronomic advantages (such as creation of microclimates in the plots, vertical development of the root system, nitrogen fixation for legumes) and economic advantages through income diversification. Consequently, the promotion of agroforestry based on forest species in state-owned plots provides an opportunity to enhance the value of savannah areas and a strategy for sustainable agricultural development that benefits family and commercial farming.

V. CONCLUSION

This study contributes towards a better understanding of farmers' perception of agroforestry in the Bambou–Mingali forest massif. The study revealed that the farmers in this

forest massif included both men (55%) and women (45%), 83% of whom were adults; the youth did not participate in farming to a considerable extent. The agri-silviculture system was the main cropping system practiced in this region. Cassava was the main crop grown in these forest plots, and other food crops (for example, maize and groundnuts) were sometimes cultivated along with cassava. Overall, the areas cultivated covered <2 ha (86%). Land preparation operations were generally managed by the SNR when the forest species were installed, which constituted an economy of scale for the farmers. Weeding was the main crop maintenance operation, and it also remained one of the "sine qua non" conditions for the utilization of state-owned plots of this forest massif by farmers. Very few farmers used fertilization (organic and mineral) and phytosanitary products. The survey also revealed that farmers perceived several advantages of agroforestry, including free access to land, economy of scale in setting up the farm, and satisfaction with crop yields and income compared to savannah areas. *Acacia* was the most valued forest tree.

The agroforestry experience of the Bambou–Mingali forest can serve as an example for the development of other forest areas. It enables the reconciliation of environmental and food concerns by developing uncultivated land for agriculture while reducing the distances traveled in search of forest patches. Promotion of forest species of the Fabaceae family, such as *Acacia*, is therefore necessary in the reforestation policy of state-owned plots. Future research should examine the sustainability of the agroforestry systems implemented and conduct in-depth studies of tree and food crop interactions to determine the best innovations to be popularized.

REFERENCES

[1] Adedayo, A.G, & Oluronke, S. 2014. Farmers' Perception and Adoption of Agroforestry Practices in Osun State, Nigeria. Forest Research, 3:127-132.

[2] Akouehou, S.G., Agbahungba, A.G, Houndehin, J., Mensah, G.A, & Sinsin, B.A. 2011. Socioeconomic performance of the Acacia auriculiformis agroforestry system in Lama in southern Benin. International Journal of Biological and Chemical Sciences, 5(3):1039-1046.

[3] Bengali, M.M. 2018. Perceptions of agroforestry by the peasants of the mixed group of Bissiga, in the Central Plateau region, in Burkina Faso. Master's thesis. University of Quebec, Canada,.

[4] Carrier, M. 2018. Ecological interactions in intercropping agroforestry systems. Master's thesis in biology, University of Quebec.

[5] CERAPE-SOFRECO, 2012. Agricultural Sector Study, Republic of Congo. Agricultural Sector Development Plan, National PDSA. Brazzaville, Congo.

[6] Descoing, B. 1975. Phytogeographic sketch of the Congo. Congo Atlas. ORSTOM, Paris, France.

[7] Djondo, M.Y. 1994. Ion exchange properties of ferrallitic clayey soils of the Niari Valley and sandy soils of the Mbé-Batéké plateau. Doctoral thesis, University of Paris XII-Val de Marne, France.

[8] Dupraz, C., F. 2008. Liagre. Agroforestry: trees and crops. 2nd edition. Editions France Agricole, Paris, France.

[9] ECOM, 2006. Profile of poverty in the Congo. Congolese household survey for the assessment of poverty in 2005. Ministry of Planning, Territorial Development and Economic Integration, CNSEE (2006). Final analysis report, Brazzaville, 2005.

[10] Elias, M., Muhlen, G.S, McKey, D., Roa A.C, & Tohme, J. 2004. Genetic diversity of traditional South American landraces of cassava (*Manihot esculenta* Crantz): an analysis using microsatellites. Economic Botany, 58: 242-256.

[11] El-Sharkawy, M.A. 2004. Cassava biology and physiology. Plant Molecular Biology, 56:481-501.

[12] Floret, C., Pontanier, R., & Serpantié, G. 1993. Fallowing in tropical Africa. File MAB 16. UNESCO, Paris, France.

[13] Garcia-Oliva, F., Sanford, R.L, & Kelly, E. 1999. Effects of slash-and-burn management on soil aggregate organic C and N in a tropical deciduous forest. Geoderma, 88, 1–12.

[14] IFAD, 2008. Study on the marketing potential of cassava-derived products on CEMAC markets. Regional Initiative for Cassava Production and Marketing (IRPCM), 2008.

[15] Jayne, T.S, Mather, D., & Mghenyi, E. 2010. Principal challenges confronting smallholder agriculture in sub-Saharan Africa. World Development, 38(10), 1384-1398.

[16] Jose, S. 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry systems, 76(1), 1-10.

[17] Mabanza, J., & Mahouka, J. 2001. Production of decontaminated cassava cultivars (*Manihot esculenta* Crantz) in competition with weeds. Cahiers Agricultures, 10(1):41-53.

[18] Makany, L. 1976. Vegetation of the Téké plateaus (Congo). Faculty of Sciences, Orsay; Thesis Sciences, Paris, France.

[19] Massamba, J., & Treche S. 1995. Consumption of cassava in the Congo. In: Cassava Food Processing. T. Agbor Egbe, A. Brauman, D. Griffon, S. Trèche (eds), ORSTOM editions, 85-92.

[20] Mengho, B.M. 2017. Geography of the Congo. 21st Century African Library Collection. Editions L'Harmattan.

[21] Mercer, D.E. 2004. Adoption of agroforestry innovations in the tropics: A review. Agroforestry Systems, 61:311-328.

[22] Nasielski, J., Furze, J.R, Tan, J., Bargaz, A., Thevathasan, N.V, & Isaac, M.E. 2015. Agroforestry promotes soybean yield stability and N2-fixation under water stress. Agronomy for Sustainable Development, 35(4): 1541-1549.

[23] Nzobadila Kindiela, B., Mialoundama Bakouetila, G.F, Yebas, L., Makosso, S., Bita A.M., & Attibayéba, 2019. Impact of fragmented rameal wood of *Bridelia ferruginea* and *Acacia mangium* on the growth and production of cassava on ferralitic soil in Congo. Journal of Animal and Plant Sciences, 40(2):6636-6647.

[24] Okonkwo, C.I. 2010. Effect of Burning and Cultivation on Soil Properties and Microbial Population of Four Different Land Use Systems in Abakaliki. Research Journal of Agriculture and Biological Sciences, 6 (6): 1007-1014.
[25] RGA, 2017. Statistical tables of the General Census of Agriculture (RGA 2014-2017). Project UTF/PRC/014/PRC. General Census of Agriculture and CountrySTAT. Ministry of Agriculture, Livestock and Fisheries (Republic of Congo) and Food and Agriculture Organization of the United Nations (FAO).
[26] Samba-Kimbata, M.J. 1978. The Bas-Congolese climate. 3rd cycle doctoral thesis, University of Dijon, France.
[27] Schroth, G., Lehmann, J., Rodrigues, M.R.L., Barros, E., & Macêdo. J.L.V. 2001. Plant soil interactions in multistrata agroforestry in the humid tropics. Agroforestry Systems, 53: 85-102.
[28] Souchere, P., & Bosseno, R. 1974. Pedological study of three plots located around the villages of Odziba, Imbama and Mbé (Plateau de Mbé). ORSTOM, Brazzaville, Congo.
[29] Valdivia, C., Barbieri, C., & Gold, MA. 2012. Between Forestry and Farming: Policy and Environmental Implications of the Barriers to Agroforestry Adoption. Canadian Journal of Agricultural Economies, 60(2): 155 - 175.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Beef cattle farming potential in the coconut plantation companies lands in South Minahasa Regency, Indonesia

Tilly D. F. Lumy, Richard E. M. F. Osak* and Stevy P. Pangemanan

Faculty of Animal Husbandry, University of Sam Ratulangi, Manado-95115, Indonesia
*Correspondence Author

Received: 02 Feb 2023; Received in revised form: 07 Mar 2023; Accepted: 15 Mar 2023; Available online: 25 Mar 2023

Abstract— *This study aims to determine the carrying capacity and profitability of developing beef cattle farming in the coconut land hold by coconut plantation companies. The research was conducted using a survey method on tenant farmers of coconut land that are managed by plantation companies, both state company and private companies holding land use rights (HGU) for coconut plantations. Data that are observed and measured in the field based on the results of interviews with respondents, as well as secondary data from related agencies. The analytical methods used are carrying capacity and profit predicted analysis. The results of the study were concluded as follows: (1) Potential carrying capacity of forage for cattle in coconut plantation company land has an average of 5.28 AU (Animal Unit) of cattles, while on average ownership of cattle only 2.06 AU of cattles each tenant farmer in coconut land that are managed by plantation companies, so that the number of cattle ownerships can still be increased by about 3.22 AU. Tenant farmers of coconut plantation companies land have the potential for the availability of forage on cultivated coconut land owned by coconut plantation companies, so that they can still increase the number of cattle kept.*

Keywords— ***Beef cattle, cattle ownerships, Cultivation Rights.***

I. INTRODUCTION

Indonesia has several potential resources, including natural resources to develop location-specific beef cattle farming. One of the resources for the development of forage is the coconut plantation area, which can be managed with the coconut-beef cattle integrated farming system (coco-beef IFS).

North Sulawesi Province determines coconut as one of the leading and potential commodities, and nationally, the province accounts for around 9% of production national coconut, but coconut's contribution to revenue area is still low (Yusuf et al., 2020). The area of coconut plantation land for both smallholder plantations and plantation companies in North Sulawesi is around 270 thousand hectares (Marbun, 2014). North Sulawesi has a state-owned plantation company (BUMN) namely PTP Nusantara XIV (or PTPN XIV) and several privately owned plantation companies that hold land use rights (HGU) for coconut plantations.

Most of the coconut land areas are cultivated in monoculture, even though they have the potential for integration with beef cattle (Polakitan, 2012, Osak et al., 2018 and Osak et al., 2020) for planting various kinds of superior forage. Quantity and quality of forage in the tropics fluctuates especially during the dry season resulting in a decrease in the level of productivity of cattle with low levels of growth (Osak et al., 2020). For this reason, it is necessary to research the carrying capacity and profitality of beef cattle farming in the coconut plantation companies land in South Minahasa which is very potential to increase the population of cattle in the context of food security from beef cattle.

The research aims to obtain the following results: (1) the potential for the development of forage crops in coconut fields belonging to coconut plantation companies;

and (2) profitability or potential profit from developing beef cattle farming in coconut areas controlled by coconut plantation companies in South Minahasa.

II. MATERIALS AND METHOD

This research was conducted on sharecroppers on coconut plantation companies in North Sulawesi Province, Indonesia where the regency that had the largest coconut plantation area and the largest population of cattle was selected, namely South Minahasa Regency.

The data used are primary data from sharecroppers who raise cattle on land areas under the control of coconut plantation companies that have Cultivation Rights (HGU). The economic valuation method uses primary data, namely data obtained from direct observation in the field, using in-depth interviews with respondents based on questionnaires that have been prepared according to the objective of the study (Hidayatullah, *et al*., 2011). Data were analyzed using Microsoft Excel.

III. RESULT AND DISCUSSION

The potential carrying capacity of coconut land is studied based on carrying capacity in coconut land for cattle, namely the maximum number of animal units (AU) of cattle that can be supported or served by feed resources in an area of coconut land. Forage feed is one of the important factors in efforts to maintain and increase the productivity of cattle. In addition to having a big influence on livestock productivity, feed is also the biggest cost in raising livestock. The main driver was feed, which may account for 60%-70% of total livestock production costs (Becker, 2008). Therefore, the quality and availability (stocking) must be continuously available so that it can meet the basic needs of life, production and reproduction. The adequacy of the availability of fodder for cattle that is kept is a quite serious challenge in the development of livestock in Indonesia. An indication of a shortage of feed supply is the low level of cattle production, both in terms of population and production, so that beef and feeder imports are still dominant.

The availability of forage sources as the main feed for cattle ruminants has recently been increasingly limited. This is due to reduced land for forage production due to the conversion of land use for food purposes and residential areas. In North Sulawesi, cut and carry superior forages were not commonly used, whereas in this area only natural pasture vegetation was used, of which only about 30% was edible for livestock. Cow (Kaligis and C. Sumolang, 1991, Kaligis et al 1996). For this reason, the effectiveness of alternative land use for forage crops needs to be increased, where one of the alternative lands is coconut plantation land.

Table 1. Capacity and potential for raising cattle in coconut plantations by sample villages

No	Sample Village Name	Average grazing area (ha/farmer)	Average Cattle Animal Unit (AU)	Average Capacity (AU/Year)	Average Development Potential (AU)
1.	Pungkol Village Tatapaan Subdistrict	0,76	2,19	4,08	1,89
2.	Ongkaw Village Sinonsayang Subdistrict	0,61	1,58	6,32	4,74
3.	Blongko Village Sinonsayang Subdistrict	0,64	2,19	3,80	1,61
4.	Tiniawangko Village Sinonsayang Subdistrict	0,67	2,30	6,93	4,63
	Average	0,67	2,06	5,28	3,22

The capacity to accommodate cattle in the coconut area and the availability of forage forage used by cattle breeders in coconut plantation company land can be seen in Table 1, which shows that overall the sample cattle breeders have an average of only 2.06 AU of beef cattle, while the average On average, it has a capacity to accommodate 5.28 AU of beef cattle on coconut land.

This showed that coconut land tenant farmers have the potential to provide forage forage under coconut trees land owned by coconut plantation companies, so that they can still increase the number of cattle units kept by

around 3.22 AU of beef cattle or an increase of about 56.31 percent. These results indicated that the sample tenant farmers of coconut land that are managed by plantation companies have the potential to provide forage in the cultivated coconut land owned by the coconut plantation companies, so that they can still increase the number of cattle units kept.

This potential will be further increased through the introduction of superior shade-tolerant forage plants under coconut trees such as dwarf elephant grass and the legume Indigofera sp. will increase the carrying capacity and production of cattle. Carrying capacity of natural pasture, including coconut plantations in North Sulawesi, was only 1-2 AU (animal unit) per hectare, whereas with the introduction of innovative superior feed crops it could reach greater than 20 AU (Paat and Taulu, 2012) so it has the potential to increase around 15.88 AU of beef cattle or an increase of about 770.87 percent, if land use in coconut plantations is increased by planting a variety of superior forages, both grass and legumes that are shade tolerant, such as elephant grass cv. Mot. and ruzi (Brachiaria ruziziensis) and the legume Indigofera sp. (Osak et al., 2022).

The potential for increasing the capacity to accommodate beef cattle will increase the population and production of cattle as a food source of animal protein which is needed by the consumer community, and increase the income of farmer-breeder households and the economy.

IV. CONCLUSION

1) The average ownership of beef cattle by tenant farmers or cultivators on the lands of coconut plantation companies is 2.06 AU, while the holding capacity of cattle on their cultivated land can reach 5.28 AU so that the number can still increase by around 3.22 AU Beef cattle are grazed on coconut plantation company land, and predicted that potential around 15.88 AU of beef cattle or an increase of about 770.87 percent, if land use in coconut plantations is increased by planting a variety of superior forages, both grass and legumes that are shade tolerant
2) The potential for the development of cattle on coconut plantations will be further increased, if through the introduction of superior forage crops that are shade tolerant under coconut trees such as elephant grass cv. Mot. and ruzi (Brachiaria ruziziensis) and the legume Indigofera sp.. akan meningkatkan kapasitas tampung dan produksi ternak sapi.

ACKNOWLEDGEMENT

We thank the Rector of Sam Ratulangi University, for the RTUU Research Grant in 2020 which has funded the research that produced this paper.

REFERENCES

[1] Becker, G.S., 2008. Livestock Feed Costs: Concerns and Options. https://www.everycrsreport.com/files/20080917_RS22908_c81d3f0c7d2765b880a80eac330168541b4c383e.pdf
[2] Hidayatullah, T., R.Y. Suryandari, A.C. Fitriyanto, dan I. Nahib, 2011. Balance mapping and economic valuation of small island resources. Geografia OnlineTM Malaysia Journal of Society and Space **7**(1):87-92.
[3] Kaligis, D.A., C.J. Sumolang, B.F. Mullen and W.W. Stur, 1996. Preliminary Evaluation of Grass-Legume Pastures under Coconuts in North Sulawesi. ACIAR Proceedings **64**:16-20.
[4] Kaligis, D. A and C. Sumolang, 1991. Forage Species For Coconut Plantation In North Sulawesi. In Forage for Plantation Crops. Ed. H. M. Shelton and W. W. Stur. ACIAR Proc. No.32.
[5] Marbun, J., 2014. Kebun Kelapa Sulut Terancam Alih Fungsi Lahan. http://www.republika.co.id/berita/nasional/daerah/14/03/19/n2nur6-kebun-kelapa-sulut-terancam-alih-fungsi-lahan diakses tanggal 25 Februari 2017.
[6] Osak, R.E.M.F., S.D. Anis and A. Rumambi, 2018. Productivity of dwarf elephant grass (Penisetum purpureum cv. Mott) and coconut (Cocos nucifera) in Coconut-Beef Cattle Integrated Farming System (Coco-Beef IFS) in South Minahasa, Indonesia. International Journal of Environment, Agriculture and Biotechnology (IJEAB) **3**(5):1874-1878.
[7] Osak, R.E.M.F., S.D. Anis and A. Rumambi, 2020. Replacement of Napier grass with legume tree foliage in the coconut-beef cattle integrated farming system (Coco-Beef IFS). Livestock Research for Rural Development 32 (1) Retrieved March 6, 2022, from http://www.lrrd.org/lrrd32/1/richa32014.html
[8] Osak, R.E.M.F., S.D. Anis and T.D.F. Lumy, 2022. Replacement of Napier grass with Increase the added value of cattle and coconut integration system farming (SISKA) through the application of the Three Strata Forage Livestock System (HMT-TS). National Competitive Basic Research Report (RD-KN). LPPM Unsrat, Manado.
[9] Paat, P.C. dan L.A. Taulu, 2012. Introduction OF Pennisetum purpureum Schum Cv. Mott In Sentra Cattle Production In North Sulawesi. Proceedings of the National Seminar on Animal Husbandry Technology "Building a Center of Excellence for the Development of the Livestock Industry Towards National Meat Self-Sufficiency" pp.384-392.
[10] Polakitan. D. 2012. Analysis of Integrated Farming of Plants and Goat Livestock in Coconut Plantation Areas in North Sulawesi. Pastura **2**(2):70-73.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Metabolic engineering of *Saccharomyces cerevisiae* for ethanol and butanol biofuel production

Salman Khan[1], Asif Hussain[2], Muhammad Iftikhar Hussain[3], Sahibzada Muhammad Aqeel[2], Samra Basharat[2], Arif Hussain[4], Waleed Al-Ansi[5], Abdulqader[2], Nie Yao[1]*

[1]Lab of brewing microbiology and applied enzymology, the Key Laboratory of Industrial Biotechnology of Ministry of Education, College of Biotechnology, Jiangnan University, Wuxi 214122, Jiangsu, People's Republic of China.
[2]The Key Laboratory of Industrial Biotechnology, Ministry of Education, College of Biotechnology, Jiangnan University, Wuxi 214122, Jiangsu, People's Republic of China.
[3]Key Laboratory of Carbohydrate Chemistry and Biotechnology, Ministry of Education, Jiangnan University, Wuxi 214122, China.
[4]National Engineering Research Center for Functional Food, College of Food Sciences, Jiangnan University, Wuxi 214122, Jiangsu, PR China.
[5]Department of Food Science and Nutrition, Faculty of Agriculture, Food and Environment, Sana'a University, Sana'a, Yemen
*Corresponding Author

Received: 05 Feb 2023; Received in revised form: 11 Mar 2023; Accepted: 17 Mar 2023; Available online: 25 Mar 2023

Abstract— *The production of biofuels through biological processes has garnered increasing attention due to their potential benefits over conventional fuels, including lower greenhouse gas emissions, higher energy output, and reduced-price fluctuations. However, the metabolic processes of primitive microorganisms used in biofuel production are not compatible with those of fossil fuels. To address this, scholars have employed metabolic engineering techniques to modify the metabolisms of various microorganisms, including S. cerevisiae, for enhanced biofuel production. Specifically, overexpression of enzymes involved in bioethanol and biobutanol production, knockouts of competing pathways, improvements in carbon flux and tolerance have been applied to maximize the potential of S. cerevisiae for bioethanol and biobutanol production. This review focuses on the current state of metabolic engineering of S. cerevisiae for the production of bioethanol from lignocellulose and biobutanol from all kind of substrates, along with the potential use of cell surface technology in this field.*

Keywords— ***strain robustness, biofuel, biomass, bio-butanol, knocked in, bio-ethanol, knocked out.***

I. INTRODUCTION

The organic substance butanol has the chemical formula C4H9OH and is a member of the hydrocarbon family. The four isomers of butanol are 2-butanol, 1-butanol, tert-butyl alcohol and isobutanol. The most naturally produced butanol by microorganisms is isobutanol, which is also known as biobutanol, along with 1-butanol. Moreover, Bioethanol (also known as ethyl alcohol), chemical formula for ethanol is C2H5OH, made by microbial fermentation. Since the combustion of alcohol produces heat energy. The majority of biofuel which come from lignocellulosic biomass or the sugars or starches produced by plants like corn, sugarcane, sweet sorghum, or sugarcane, and have been utilized as a fuel [1]. The possibility to replace fossil fuels with biofuels like bioethanol and biobutanol and reduce greenhouse gas emissions when used directly or blended with gasoline in vehicles [2].

The interest in fuel synthesis from biomass has increased as a result of the rising costs of fossil fuels. Biofuel or bio-renewable fuel are the terms used to describe this fuel. The three main categories of biofuel feedstocks are as follows: (1) biomass made up of lignocellulosic materials like grasses, straw, and wood. (2) feedstocks that contain sucrose, such as sweet sorghum, sugar beet, sugarcane, and fruits. (3) Starchy foods, such as sweet potatoes, corn, potatoes, rice, wheat, and milo [3]. The usage of biofuel

blends in automobiles can greatly cut down on the consumption of petroleum and emissions of greenhouse gases. Microorganisms are used in the fermentation process to make biofuels. In order to convert polysaccharides into monomeric form, the process's feedstocks must also undergo pretreatment because microorganisms are unable to consume sugars in complex forms [4]. In the US, Brazil, and a few EU member states, there are programs in place that support the large-scale production of biofuels. After the United States, Brazil is the greatest producer of bioethanol in the world and its largest exporter.

According to recent World Health Organization research, air pollution causes 3 million deaths annually. Scientists' interest in finding alternate forms of energy has increased as a result of the environment's negative effects and the diminishing supply of fossil fuels [5]. In this regard, a variety of alternative energy sources, such as wind, hydro, geothermal, and solar, are accessible. The solar energy sector is one of them. It is expanding quickly and is thought to be a good solution to prevent environmental and energy issues [6]. The production of lignocellulosic-based biofuels at the biorefinery is another factor that qualifies it as a source of sustainable energy [7]. Bioethanol and biobutanol have gained popularity over time, surpassing other biofuels, and are now acknowledged as reliable sources of renewable energy [8]. By replacing fossil fuels with these biofuels, issues including environmental damage, price volatility, and the depletion of fossil fuel reservoirs would be less of a concern. However, because these biofuel operations are currently only dependent on food materials, a conflict between the food and fuel industries has resulted, which is indirectly a factor that has raised the cost of food ingredients [8].

Nitrogen oxide (NOx), sulfur oxide (SOx) and carbon monoxide (CO) emissions are reduced and absent in biofuels, making it a more affordable option [9]. Bioethanol is distinguished by having a high octane number (102), expanded flammability thresholds, a quick spread of flame, and a high heat of vaporization. It lowers particulate matter (PM10) emissions from tailpipes, which lowers pollution in general. The most popular ratio for blending bioethanol with gasoline is E10, sometimes referred to as "gasohol," which is 10% bioethanol to 90% gasoline.[10].

Butanol is manufactured annually to the tune of 15 to 17 billion dollars worldwide. The butanol derivatives with the highest economic value include butyl glycol ether, butyl acetate, and plasticizers. It has numerous uses in the pharmaceutical industry as a solvent and as a diluent in brake fluid compositions. Butanol is less hydroscopic and corrosive than bio-ethanol because It is less volatile, has more energy, and is somewhat miscible with water [11]. A gasoline engine may run directly on butanol without any alterations or replacements because its properties are comparable to those of gasoline [12], With a 22% oxygen concentration, it is a cleaner-burning, fuel extender [13].

Researchers' efforts to increase bio-butanol and bio-ethanol production through by-product accumulation reduction, usage of a cheaper substrate, and enhancement of butanol producers' robustness to butanol and oxygen by using engineered *Saccharomyces cerevisiae* have been diverted by metabolic engineering. However, much work remains to be done in order to make the biological production of bio-butanol and bio-ethanol more compatible with the one from petrochemical processes. Herein, the authors concluded the metabolic tuning of *S. cerevisiae* for enhanced bioethanol and butanol production.

II. METABOLIC ENGINEERING OF *S. CEREVISIAE* FOR BIOETHANOL PRODUCTION

Since *Saccharomyces cerevisiae* can withstand high bioethanol concentrations and inhibitors produced during the fermentation process, it is the ideal microbe for the fermentation of lignocellulosic biomass to bioethanol [14]. The cellular system of *S. cerevisiae* has undergone substantial engineering in order to attain the full use of all possible carbon sources in the lignocellulosic biomass in order to convert lignocellulosic feedstocks into bioethanol cheaply. Recent improvements in metabolic engineering and synthetic biology have enhanced the productivity and output of lignocellulosic bioethanol produced by *S. cerevisiae* [15]. The main goals of metabolic engineering strategies are either detoxification of inhibitors or modulation of stress responses. The former goal is mostly accomplished by expressing enzymes that transform inhibitors into less harmful chemicals and/or by establishing a redox balance between the detoxification pathways and the oxidoreductase xylose consumption pathways [16].

Lignocellulosic biomass primarily comprises cellulose-hemicellulose complexes that are enclosed within a lignin matrix. The cellulose-hemicellulose fraction of this biomass is deemed to be a highly effective source for bioethanol production [17]. Cellulose represents a significant homopolysaccharide component within plant cell wall, exclusively composed of glucose monomers, a vital substrate in the generation of biofuels [18]. The co-expression of multiple cellulases has proven valuable in developing strains proficient of growth and bioethanol production from a variety of cellulosic feedstocks. In this study, three cellobiohydrolase (CBH) enzymes, specifically CBH1 (from *Aspergillus aculeatus*), and CBH2 (from *Trichoderma reesei*) were combined with beta-glucosidase

(from *A. aculeatus*) and endoglucanase (from *T. reesei*) in a sequential integration approach within the yeast genome via the integration method. The resulting strain, which secreted all three CBH enzymes in addition to BGL and EGL, demonstrated the highest bioethanol concentration of 28 g/L from corncob. These findings underscore the importance of CBH enzyme diversity in efficiently hydrolyzing complex biomass [19]. In recombinant expression systems, the optimization of surface display of heterologous enzymes can be achieved by controlling the copy number of integrated genes, utilizing marker-less integration design, or by modifiying the enzyme ratio for process optimization. A method called "cocktail delta integration" has been established to engineer yeast displaying multi-enzyme components. This technique involves the frequent transformation of equimolar concentration of cellulase expression cassettes, which are integrated in yeast chromosomes at the delta sites simultaneously. Transformants with the optimal cellulose-degrading activity can then be screened easily. This strategy was employed to engineer *S. cerevisiae* for the co-display of three cellulases: exoglucanase and endoglucanase from *T. reesei* while beta-glucosidase from *A. aculeatus*, with the aim of achieving higher PASC (phosphoric acid-swollen cellulose) degradation activity compared to conventional integration methods [20]. In order to enhance the efficiency of cellulose degradation, another study implemented delta integration to boost cellulase expression in haploid yeast strains. These strains were subsequently bred to create a diploid strain with increased cellulase expression. The findings revealed that the engineered diploid strain displayed a six-fold improvement in PASC degradation activity and produced 7.6 g/L of bioethanol, compared to its haploid strain. Notably, the diploid strain also demonstrated the ability to directly produce bioethanol from pre-treated rice straw without the use of any exogenous enzymes [21]. In recent scientific research, combinations of cellulases were displayed on *S. cerevisiae* to produce bioethanol directly from lignocellulosic biomass pre-treated with ionic liquid. The efficacy of this method was tested on bagasse treated with 1-butyl-3methylimidazolium acetate [Bmim][OAc], resulting in 0.8 g/L bioethanol production within 96 hours, comparable to its theoretical maximum (73.4%). However, the efficiency of the engineered yeast was found to be low towards hardwoods, as only 21.2% and 18.3% of the theoretical bioethanol yield were obtained after 72 hours of fermentation from cedar biomass and [Bmim][OAc]-treated eucalyptus, respectively [22]. Yang, Zhang, et al. improved *S. cerevisiae's* ability to use lignocellulosic biomass (crushed orange peel) by incorporating a promoter for the control of the glyceraldehyde-3-phosphate dehydrogenase gene into the organism's genome. The mutant strain's bioethanol conversion rate was 37.7 times greater than that of the wild-type strain [23].

Due to *S. cerevisiae's* inability to use hemicellulose sugars naturally due to the absence of pentose fermentation enzymes, xylose catabolizing genes from other microorganisms have been expressed heterologous [24]. In Sakamoto et al. study, endogenous xylulokinase (XKS), xylose reductase (XR), and xylitol dehydrogenase (XDH) from *Scheffersomyces stipitis* were expressed in the recombinant strain of *S. cerevisiae* to carry out simultaneous saccharification and fermentation (SSF) of rice straw hydrolysate made up of several hemicelluloses. Moreover, surface displays of the same strain were made with hemicellulose-degrading enzymes from *Aspergillus oryzae*, *Trichoderma reesei*, and *Aspergillus aculeatus*. After 72 hours of fermentation, the final modified strain generated an bioethanol titer of 8.2 g/L [25]. *S. cerevisiae* was genetically altered to use xylan by co-expressing a number of xylan-degrading and xylose-accumulating enzymes. To facilitate full conversion of xylan into xylose, the recombinant strain was specifically designed to express xylosidase (from *A. niger*) and endoxylanase (from *T. reesei*). The production of new xylulose kinase (xyl3) from *S. stipitis* and xylose isomerase (xylA) from Bacteroides thetaiotaomicron, which circumvented the cofactor requirement of the alternative xylose reductase (XR)-xylitol dehydrogenase (XDH) pathway, further accelerated the accumulation of xylose. The natural aldose-reductase gene (GRE3) was removed to reduce xylitol buildup. The new yeast strain produced more enzymes and thrived in an aerobic setting. When grown solely on xylose while oxygen was scarce, it generated 9 g/L of bioethanol [26].

Thermostable and inhibitor resistant strain of *S. cerevisiae* was modified to display hemicellulolytic enzymes on its surface and engineered to optimize xylose utilization pathways for hemicellulose degradation. The developed strain was able to convert hemicellulose hydrolysate from hydrothermally treated maize-cob feedstock into 11.1 g/L bioethanol [27]. In a study, metabolic engineering and adaptive evolution were combined to modify *S. cerevisiae* to consume xylose and arabinose alongside glucose simultaneously. The resulting strain was able to utilize 24% extra pentose sugar after 120 hours of fermentation on a mixed sugar medium [28]. Through a combination of CRISPR-Cas9-mediated rational and evolutionary engineering, a highly efficient strain of *S. cerevisiae* capable of fermenting xylose was created. That strain, called XUSE, used an isomerase-based process to convert xylose into bioethanol with a yield of 0.43 g/g, and was able to simultaneously ferment glucose and xylose without significant glucose inhibition [29]. To further improve bioethanol yield, the high osmolarity glycerol pathway was

also engineered [30]. Although a mutant SFA1 in *S.* cerevisiae has achieved the highest bioethanol yield from lignocellulosic hydrolysates at 0.492 g/g total sugars [31]. The fermentation rates of xylose remain suboptimal, typically 20-35% smaller than those of glucose, which restricts overall bioethanol productivity in lignocellulosic fermentation. Additionally, as the hydrolysates become more concentrated to reach economically feasible bioethanol production with titers of 40-50 g/L, inhibitor concentration also increases, further impeding the functioning of the modified strains. Thus, the challenge remains to develop a robust *S. cerevisiae* platform capable of efficiently producing lignocellulosic bioethanol while tolerating high inhibitor concentrations [15]

Table 1: Metabolic engineering of Saccharomyces cerevisiae to produce bioethanol from lignocellulosic biomass

Purpose	Modifications	Productivity	References
Improving xylose catabolism	△PHO13, TAL1	About 3.4 times rise in xylose utilization rate	[32]
Acetate utilization	gndA	13% higher bioethanol yield on glucose	[33]
Improving bioethanol production capacity	PHO4	About 4 times higher bioethanol yield	[34]
S. cerevisiae	Δssk1Δsmp1	6% higher bioethanol yield	[30]
Improving inhibitor tolerances	RTC3, ANB1	10% higher bioethanol yield from xylose	[35]
Carbon loss minimization	cfxP1, XKS1, XYL1, mXYL1 and XYL2	1.33 times higher bioethanol yield	[36]
Acetate utilization	*Adh*E	6% higher bioethanol yield from xylose	[37]
S. cerevisiae	SeACS, adhE	14.8% higher bioethanol	[38]
Extracellular secretion of cellulases	Integration of cellulases from different sources within the yeast genome	bioethanol concentration of 28 g/L	[19]
Improve expression of cellulases	integration of sestc expression cassette	37.7 times higher (7.53 g/L) bioethanol	[23]
Surface display	hemicellulose-degrading enzymes from different sources	8.2 g/L of Bioethanol	[25]
Improving xylan degradation	Co-expression of xylan-degrading and xylose-accumulating enzymes	9 g/L of bioethanol	[26]
hemicellulose degradation	Display of hemicellulolytic enzymes on surface and optimization of xylose assimilation	11.1 g/L bioethanol	[27]

III. METABOLIC ENGINEERING OF *S.CEREVISIAE* FOR BIO BUTANOL PRODUCTION

S. cerevisiae, a type of yeast that possesses a natural ability to use the 2-ketoisovalerate synthesis pathway, sometimes referred to as the valine pathway, is a method for producing isobutanol from glucose. This process results in the creation of 2-ketoisovalerate, an intermediary substance in the biosynthesis of valine. Aldehyde dehydrogenase is used in the Ehrlich pathway, however, to transform 2-ketoisovalerate, a by-product of valine biosynthesis, into isobutanol. In essence, the Ehrlich route in *S. cerevisiae* uses 2-ketoisovalerate as a precursor molecule to produce isobutanol [39, 40]. Despite the possibility of producing 1-butanol using *S. cerevisiae*, little has been done to completely understand its cellular metabolism. However, two potential routes for 1-butanol biosynthesis in *S. cerevisiae* have been discovered: the first includes using the amino acid absorption pathway, while the second involves

either separately or in combination with the first, expressing heterologous clostridial 1-butanol biosynthetic pathways. [41, 42].

S. cerevisiae is considered to be the most extensively studied eukaryotic organism, and is recognized as a highly proficient producer of bio-butanol[43]. The levels of butanol production achieved through yeast fermentation are significantly lower compared to those achieved through the fermentation processes of *Clostridium* and *E. coli* bacteria. There are various advantages to using S. cerevisiae to manufacture butanol, including its ability to withstand low pH levels and inhibitors [44]. Additionally, *S. cerevisiae* is widely regarded as the most resilient microorganism when it comes to tolerance to butanol[45]. *S. cerevisiae* is the most suitable cellular organism for integration into existing industrial infrastructure as a cell factory. Numerous investigations necessitate experimentation on yeast to generate isomers of butanol, namely isobutanol and 1-butanol, that can be compared to those produced by *E. coli* and *Clostridium* species. As a result, researchers have attempted metabolic engineering of *S. cerevisiae* to make it a viable contender for industrial-level butanol synthesis. Similar to *E. coli* and *Clostridium species*, *S. cerevisiae* may synthesize butanol. various metabolic approaches have been applied to *S. cerevisiae* for production of two main isomers of butanol such as Iso-butanol and 1-butanol [40].

3.1 Biological isobutanol production by engineered *S.cerevisiae*

Isobutanol is a liquid having organic nature with no color that is combustible. Which is one of butanol isomers. Isobutanol have been considered and employed as a fuel alternative and solvent in certain industries [46]. In a pioneering study, the isobutanol synthesis in *S. cerevisiae* was verified by elevating the expression of enzymes named as *Ilv*5, Ilv2 and Ilv3, which encode acetohydroxyacid reductoisomerase, dihydroxy acid dehydratase, and acetolactate synthase, respectively) using glucose as a substrate, about 3.86 mg/l yield of isobutanol was achieved [47]. This study was the first to report on isobutanol production using *S. cerevisiae*. The results show that among various tested *Kiv*Ds and alcohol dehydrogenases, *Adh*6 along with *Kiv*Ds from *Lactococcus lactis* are the most effective enzymes in catalyzing α-ketoisovalerate to isobutanol. By increasing the expression of *L. lactis Kiv*D, *Adh*6 and *Ilv*2 in a *pdc*1 knocked out yeast strain, isobutanol titers of approximately 6.6 mg/l were achieved [48]. The *Pdc*1 coding pyruvate Decarboxylase, *Ilv*2, and Alcohol Dehydrogenase 6 (*Adh*6) enzymes controlling the conversion of pyruvate into acetaldehyde, acetolactate and NADPH-alcohol respectively. Subsequently, acetaldehyde is transformed into acetate via the action of *Ald*6 (Acetaldehyde Dehydrogenase 6) enzyme.

*L. lactis Kiv*Ds Overexpression in cytosol was evaluated for its potential to increase isobutanol production [47]. The in vitro specificity of *Kiv*D was found to be the highest and led to an increase in synthesis of isobutanol to 20.0 mg/L from 15.0 mg/L when co-overexpressed with *Ilv*5, *Ilv*3, and *Ilv*2 and exploiting glucose as a single carbon source [49]. Nevertheless, Brat and his team found that the presence of an active mitochondrial valine synthetic route prevented further increases in the isobutanol titer when all of the enzymes in the valine biosynthesis pathway were overexpressed in the cytosol [50]. The researchers successfully expressed *Ilv*5, *Ilv*3, and *Ilv*2 in the cytosol without the addition of N-terminal amino sequences. They further assessed the activity of several *L. lactis Kiv*D and Aro10 (ketoisovalerate decarboxylase) in a *Pdc*-minus strain. The maximum activity was observed with both Aro10 and *Adh*2. As a result, co-expression of the Aro10, *Adh*2, *Ilv*5, *Ilv*3, and *Ilv*2 pathways in an *Ilv*1 (threonine ammonia-lyase) deleted strain resulted in an isobutanol synthesis of 630 mg/L.

In order to create a cytosolic artificial isobutanol route in *S. cerevisiae*, the enzymes *Ilv*5p, *Ilv*3p, and *Ilv*2p were expressed along with *Adh* and *Kiv*D. This improved isobutanol production [50, 51]. To increase the isobutanol titer, different techniques were used, such as correcting cofactor imbalances and downregulating competing routes. In addition, a cytosolic route was established by upregulating natural mitochondrial valine pathway enzymes. To do this, shortened genes (*Ilv*5c, *Ilv*3c, and *Ilv*2c) lacking mitochondrial targeting regions were overexpressed. It was discovered that upregulating the transhydrogenase shunt and removing the *lpd*1 gene yielded a titer of up to 1.62 g/liter when the strain was overexpressing *kiv*D and *Adh*6. [52]. The overexpression of *Adh*6, Aro10, *Ilv*3, *Ilv*5, *Ilv*2, *Adh*2, and *L. lactis Kiv*D enzymes in their native compartment, in combination with the downregulation of enzymes such as Bat1, *pd*1 and *Ald*6, has been reported to frequently improve isobutanol production [52, 53]. All these approaches were applied to an *lpd*1 downregulated strain, JHY465, which resulted in a further overexpression of *Adh*2 and Aro10 in the mitochondrial through fusing COX4-MLS (N-terminal mitochondrial localization signal) [54]. The final isobutanol production as a result was 330.9 mg/L. After inactivating the enzymes acetaldehyde dehydrogenase (*Ald*6), *Adh*1, *Ilv*1, amino-acid aminotransferase (*Bat*1), and *leu*1 along with upregulating enzymes tangled in the valine biogenesis isobutanol pathway, the D452-2 strain yielded in isobutanol (662.0 mg/L) using glucose as source of carbon [55]. The deletion of (*bdh*1, *bdh*2 encoding NAD-dependent butanediol dehydrogenase), acetolactate synthase (*ilv*2), *leu*9 ketopantothenate hydroxymethyltransferase (ecm31),

*leu*4, *adh*1, acetaldehyde dehydrogenase (*ald*6), *gpd*1, *gpd*2, and *ilv*1 genes in a yeast strain named as CEN.PK113-7D increase its ability of isobutanol synthesis. CEN.PK113-7D accumulated about 2.1 g/L, when the competing metabolites synthesis pathway for 2,3-butanediol, leucine, isoleucine, pantothenate, ethanol, and glycerol from glucose has been knocked out [56].

Xylose was effectively converted into isobutanol in a groundbreaking study using yeast that had been metabolically altered. The yield was 0.16 mg/g and the concentration was 1.36 mg/L after overexpressing and upregulating the valine biosynthesis enzymes and the xylose isomerase enzyme from the yeast cytoplasm, both of which are found in *C. phytofermentans*. In terms of producing isobutanol industrially from renewable feedstocks, this constitutes a significant advancement [57]. Recently, a higher isobutanol titer of 3.10 g/L was attained by expressing the mitochondrial isobutanol pathways in yeast, uptake of xylose isomerase, and eradication of competitive isobutanol-producing routes by removing the enzymes held to account for their biogenesis, *Bat*1, *Ald*6, and Pho13 [58].

3.2 Biological production of 1-butanol by engineered *S.cerevisiae*

The clostridial 1-butanol route in *S. cerevisiae* produces acetyl-CoA, an intermediate. The transformation of acetyl-CoA to acetoacetyl-CoA is then catalyzed by ERG10, also known as native thiolase. Since many different biomolecules require acetoacetyl-CoA as a precursor, foreign genes must be expressed to create heterologous enzymes that can convert acetoacetyl-CoA into 1-butanol. [40]. In their first attempt, Steen and his team successfully produced 1-butanol in *S. cerevisiae* by expressing isoenzymes from multiple sources to construct the 1-butanol pathway. The ESY7 mutant strain that has natural thiolase (ERG10) and Hb-CoA dehydrogenase (*Hbd*) overexpressed on a high copy number produced the best yield. Galactose was converted into 1-butanol at a rate of 2.50 mg/L. [59]. The CEN.PK113-11C yeast strain containing a plasmid with *Adh*2, ERG10, *Acs*, *crt*, *hbd*, *Ald*6, and *ter* enzymes was metabolically modified to create a pathway for the biosynthesis of 1-butanol and boost carbon flux. Using glucose as the substrate, this resulted in the synthesis of 16.30 mg/l butanol [43]. This is a six and a half times increase than the previously generated butanol titer, which was 2.50 mg/L [59].

A recent discovery showed that a yeast strain W303-1A with a 1-butanol biosynthetic pathway produced butanol at a low rate when glucose was employed as the growth substrate [60]. Trans-enoyl CoA reductase enzyme was introduced to the butanol pathway to boost productivity after the Pdc1 and Pdc2 genes were deleted to decrease glycerol generation. After fermentation for 49 h, Butanol 2.0 mg/L was generated by the mutant strain. The highest butanol concentration reported 835.0 mg/L, resulting in a yield of about 42 mg/g, was by [61]. A genetically engineered yeast strain's clostridial aceto-acetyl-CoA pathway production of 1-butanol was negatively impacted by the lower cytosolic acetyl-CoA and Coenzyme-A levels [41]. The researchers noticed a substantial rise in the formation of 1-butanol up to 130 mg/L in an oxygen-free environment when they boosted the amounts of NADH, Coenzyme-A and acetyl-CoA. This was achieved by expressing adhE$^{A267T/E568K/R577S}$ genes, producing an improved form of acetyl-CoA that can acetylate both trans-2-enoyl-CoA reductase and acetaldehyde dehydrogenase in the presence of NAD+. Interestingly, The modified yeast strain produced the highest 1-butanol titer of 0.86 g/L under aerobic conditions due to the overexpression of pantothenate kinase and amine oxidase (Fms1) [41].

IV. CELL SURFACE TECHNOLOGY FOR BIOETHANOL PRODUCTION

In several bioethanol manufacturing processes, this technique has been used in place of the conventional procedure [71, 72]. Various membrane technologies, including membrane distillation (MD), pervaporation (PV), ultrafiltration (UF), nanofiltration (NF), and microfiltration (MF), were employed to produce bioethanol. Microalgae can be recovered by employing MF/UF. Pretreatment is required for second and third generation bioethanol in order to make the biomass's carbohydrates available for conversion. After pretreatment and before fermentation, the second potential membrane use is the purification and concentration of prehydrolyzates. Concentrating the sugar solution and removing fermentation inhibitors are capabilities of MD, NF, and RO. An NF process with UF has been investigated in conjunction with enzyme recovery and other value-added manufacturing. After fermentation, bioethanol with low concentration is delivered for pre-concentration and pervaporation. In order to execute continuous fermentation, pervaporation and fermentation have been merged. Yeast and fermentation inhibitors can be eliminated throughout the process by utilizing UF and NF to create a hybrid process [73].

V. CELL SURFACE TECHNOLOGY FOR BIOBUTANOL PRODUCTION

In order to extract butanol from fermentation broth, various separation methods are now used, including adsorption [62], liquid–liquid extraction [63], gas stripping [64], pervaporation [65], reverse osmosis and perstraction, [66] Because to its effectiveness and energy-saving features as

well as the fact that it has no negative effects on microorganisms, pervaporation (PV) is regarded as having the highest potential of all these separation techniques. Contrary to distillation, pervaporation is a more sophisticated and cost-effective method to separate the water and butanol later [67]. Some of the components in a feed solution can preferentially pass through a membrane surface as it is being passed over the membrane, concentrating as vapors in the permeate. This membrane process, known as pervaporation, can achieve molecular separation for liquid mixtures [68]. The difference in vapor pressure between feed solution and permeate vapor, which is normally maintained by supplying a vacuum on the downstream side, is what drives the pervaporation process.

The separating membrane serves as the process' central component. When selecting a pervaporation membrane for a given mixture, there are two key considerations that must be made: Separation factor and permeate flux, or the mass flow rate per unit membrane area (the membrane's permeate side component to feed side component ratio divided by the permeate side component to feed side component ratio). Based on a membrane's specific characteristics, such as its hydrophilicity and organophilicity, there are many distinct types of pervaporation membranes for varied uses. Two scenarios are often involved when using the method of producing biobutanol through pervaporation. The first involves recovering butanol from low-solvent fermentation broth, where organophilic membranes may be utilized to let solvents flow while keeping water in retentate [69]. The solvent in the retentate must be dehydrated while the hydrophilic membranes must preferentially extract water from the solution in order to dehydrate low-water-content butanol-water combinations. The design and manufacture of intelligent membrane Over the past few years, materials have attracted a lot of interest with the goal of enhancing butanol pervaporation separation's long-term stability and effectiveness. Moreover, a number of scientists have developed various fermentation-pervaporation integrated techniques for making biobutanol [70].

VI. TECHNO-ECONOMIC COST OF BIOETHANOL AND BIOBUTANOL

lignocellulose-based biofuels are essential for preserving agricultural land and reducing the negative effects of global traffic and transportation on the environment [74]. Bioethanol has sparked a lot of interest in recent years as a fuel extender or even as a standalone liquid fuel. Consequently, because of their affordability and high potential for availability, lignocellulosic materials are extremely appealing substrates for the synthesis of bioethanol [75]. It is estimated that it will cost somewhere between 0.13 and 0.81 US dollars to produce one liter of ethanol. The cost of the feedstock, which ranged from 30 to 90 US dollars per metric ton, is one of the key factors affecting the economic outcome. In order to lower the energy needed for the distillation process and other downstream processes, high ethanol yields and concentrations must be attained during fermentation. Making ethanol produced from lignocellulose competitive with ethanol produced from sugar and starch requires improved pretreatment techniques, improved enzymatic hydrolysis using less expensive enhanced fermentation systems, and more effective enzymes, all of which pose considerable scientific challenges. Another method to reduce ethanol production costs overall is process integration, either internally or externally with other plant types, such as heat and power plants [76].

Production of bio-butanol is continuing on a global scale as an alternative to petrochemical fuels. The cost to manufacture butanol from cooked rice is $1.24 per kilogram (Kg), as determined by the techno-chemical analysis of butanol [77]. Costs for liquid-liquid extraction and distillation of butanol from corn biomass, lignocellulose, and sugarcane were 0.74 dollars, 1.19 dollars, and 1.59 dollars per kg, respectively [78]. ABE fermentation utilizing maize as the feedstock is used to produce butanol commercially at the Jilin Cathy industries in China for a cost of $2000 USD per ton, or roughly 70% of the whole cost. Thus, utilizing non-food biomass as a top priority to lower process costs By 2020, it is predicted that there would be a global demand for bio-butanol and other bio-based fuels of over 248 billion US dollars due to its advantages over other biofuels [79]. Butanol and ethanol are currently heavily supplied by petrochemical companies to the worldwide market, which makes its price dependent on the price of crude oil.

VII. FUTURE REMARKS

S. cerevisiae metabolic engineering for biofuel production has made great strides in recent years. However, there are still a number of difficulties that need to be addressed before this technology can be fully commercialized. One of the primary obstacles is the high cost of lignocellulosic biomass pretreatment, which is necessary for efficient conversion of this material to biofuels. Future research should focus on developing cost-effective and sustainable pretreatment methods that can increase the economic feasibility of conversion of lignocellulosic biomass.

Another challenge is the low yields of biofuels obtained from *S. cerevisiae*, which limit the scalability of the process. The development of novel biosynthetic pathways, the modification of central carbon metabolism, and the

improvement of fermentation conditions are some of the metabolic engineering techniques that should be investigated in future studies to increase the generation of biofuels. Furthermore, another significant problem that requires attention is the host cell toxicity of biofuels. Future research should aim to develop more robust *S. cerevisiae* strains that can tolerate higher concentrations of biofuels as well as strategies to minimize the toxicity of biofuels during fermentation.

VIII. CONCLUSION

Metabolic engineering of *S. cerevisiae* for 4 and 2 carbon biofuel production holds great promise for the sustainable and cost-effective production of biofuels. By manipulating the yeast's metabolic pathways, researchers have been able to redirect carbon flux towards the production of these valuable biofuels. With the growing demand for renewable energy sources and the need to reduce our reliance on fossil fuels, this approach represents an exciting avenue for future research and development in the field of biofuels. Further optimization of the metabolic pathways and scaling up the production process will be essential to ensure the economic viability and commercial success of this technology.

ACKNOWLEDGEMENTS

The authors thank the CSC, School of International Education, and College of Biotechnology at Jiangnan University for financial support and the research opportunity.

REFERENCES

[1] Rocha-Meneses, L., et al., *Second-generation bioethanol production: A review of strategies for waste valorisation.* Agronomy Research, 2017. **15**(3): p. 830-847.

[2] Basics, E., *Clean cities, energy efficiency & renewable energy (EERE)*. 2015.

[3] Smith, A.M., *Prospects for increasing starch and sucrose yields for bioethanol production.* The Plant Journal, 2008. **54**(4): p. 546-558.

[4] Overend, R.P. and E. Chornet, *Fractionation of lignocellulosics by steam-aqueous pretreatments.* Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences, 1987. **321**(1561): p. 523-536.

[5] Mussatto, S., *A closer look at the developments and impact of biofuels in transport and environment; what are the next steps? Biofuel Res. J. 3, 331*. 2016.

[6] Matutes, K.C.B. and R.L. Besagas, *Bioethanol Production from Selected Species of Astera Plants by Simultaneous Saccharification and Fermentation using Dilute Acid and Alkaline Extraction Pretreatment Methods.* 2021.

[7] Salimi, E., et al., *The role of enzyme loading on starch and cellulose hydrolysis of food waste.* Waste and Biomass Valorization, 2019. **10**: p. 3753-3762.

[8] Ibrahim, M.F., S.W. Kim, and S. Abd-Aziz, *Advanced bioprocessing strategies for biobutanol production from biomass.* Renewable and Sustainable Energy Reviews, 2018. **91**: p. 1192-1204.

[9] Taherzadeh, M.J. and K. Karimi, *Enzymatic-based hydrolysis processes for ethanol from lignocellulosic materials: A review.* BioResources, 2007. **2**(4): p. 707-738.

[10] Balat, M. and H. Balat, *Recent trends in global production and utilization of bio-ethanol fuel.* Applied energy, 2009. **86**(11): p. 2273-2282.

[11] Dürre, P., *Biobutanol: an attractive biofuel.* Biotechnology Journal: Healthcare Nutrition Technology, 2007. **2**(12): p. 1525-1534.

[12] Lee, S.Y., et al., *Fermentative butanol production by Clostridia.* Biotechnology and bioengineering, 2008. **101**(2): p. 209-228.

[13] Qureshi, N., B.C. Saha, and M.A. Cotta, *Butanol production from wheat straw hydrolysate using Clostridium beijerinckii.* Bioprocess and biosystems engineering, 2007. **30**: p. 419-427.

[14] Adegboye, M.F., et al., *Bioprospecting of microbial strains for biofuel production: metabolic engineering, applications, and challenges.* Biotechnology for biofuels, 2021. **14**(1): p. 1-21.

[15] Ko, J.K., et al., *Recent advances and future directions in plant and yeast engineering to improve lignocellulosic biofuel production.* Renewable and Sustainable Energy Reviews, 2020. **134**: p. 110390.

[16] Cunha, J.T., et al., *Engineered Saccharomyces cerevisiae for lignocellulosic valorization: a review and perspectives on bioethanol production.* Bioengineered, 2020. **11**(1): p. 883-903.

[17] Favaro, L., T. Jansen, and W.H. van Zyl, *Exploring industrial and natural Saccharomyces cerevisiae strains for the bio-based economy from biomass: the case of bioethanol.* Critical reviews in biotechnology, 2019. **39**(6): p. 800-816.

[18] Jung, S.-J., S.-H. Kim, and I.-M. Chung, *Comparison of lignin, cellulose, and hemicellulose contents for biofuels utilization among 4 types of lignocellulosic crops.* Biomass and bioenergy, 2015. **83**: p. 322-327.

[19] Hong, J., et al., *Development of a cellulolytic Saccharomyces cerevisiae strain with enhanced cellobiohydrolase activity.* World Journal of Microbiology and Biotechnology, 2014. **30**(11): p. 2985-2993.

[20] Yamada, R., et al., *Cocktail δ-integration: a novel method to construct cellulolytic enzyme expression ratio-optimized yeast strains.* Microbial cell factories, 2010. **9**: p. 1-8.

[21] 21. Yamada, R., et al., *Direct ethanol production from cellulosic materials using a diploid strain of Saccharomyces cerevisiaewith optimized cellulase expression.* Biotechnology for Biofuels, 2011. **4**(1): p. 8.

[22] Yamada, R., et al., *Direct Ethanol Production from Ionic Liquid-Pretreated Lignocellulosic Biomass by Cellulase-Displaying Yeasts.* Applied Biochemistry and Biotechnology, 2017. **182**(1): p. 229-237.

[23] Yang, P., et al., *CRISPR-Cas9 Approach Constructing Cellulase sestc-Engineered Saccharomyces cerevisiae for the Production of Orange Peel Ethanol.* Frontiers in Microbiology, 2018. **9**.

[24] Adebami, G.E., et al., *Genetics and metabolic engineering of yeast strains for efficient ethanol production.* Journal of Food Process Engineering, 2022. **45**(7): p. e13798.

[25] Sakamoto, T., et al., *Direct ethanol production from hemicellulosic materials of rice straw by use of an engineered yeast strain codisplaying three types of hemicellulolytic enzymes on the surface of xylose-utilizing Saccharomyces cerevisiae cells.* Journal of Biotechnology, 2012. **158**(4): p. 203-210.

[26] Mert, M.J., et al., *Engineering of Saccharomyces cerevisiae to utilize xylan as a sole carbohydrate source by co-expression of an endoxylanase, xylosidase and a bacterial xylose isomerase.* Journal of Industrial Microbiology and Biotechnology, 2016. **43**(4): p. 431-440.

[27] Cunha, J.T., et al., *Consolidated bioprocessing of corn cob-derived hemicellulose: engineered industrial Saccharomyces cerevisiae as efficient whole cell biocatalysts.* Biotechnology for Biofuels, 2020. **13**(1): p. 138.

[28] Wang, C., et al., *Coutilization of D-Glucose, D-Xylose, and L-Arabinose in Saccharomyces cerevisiae by Coexpressing the Metabolic Pathways and Evolutionary Engineering.* BioMed Research International, 2017. **2017**: p. 5318232.

[29] Tran Nguyen Hoang, P., et al., *Genomic and phenotypic characterization of a refactored xylose-utilizing Saccharomyces cerevisiae strain for lignocellulosic biofuel production.* Biotechnology for biofuels, 2018. **11**(1): p. 1-13.

[30] Jagtap, R.S., et al., *Improving ethanol yields in sugarcane molasses fermentation by engineering the high osmolarity glycerol pathway while maintaining osmotolerance in Saccharomyces cerevisiae.* Applied Microbiology and Biotechnology, 2019. **103**(2): p. 1031-1042.

[31] Zhu, L., et al., *Overexpression of SFA1 in engineered Saccharomyces cerevisiae to increase xylose utilization and ethanol production from different lignocellulose hydrolysates.* Bioresource Technology, 2020. **313**: p. 123724.

[32] Xu, H., et al., *PHO13 deletion-induced transcriptional activation prevents sedoheptulose accumulation during xylose metabolism in engineered Saccharomyces cerevisiae.* Metabolic Engineering, 2016. **34**: p. 88-96.

[33] Papapetridis, I., et al., *Improving ethanol yield in acetate-reducing Saccharomyces cerevisiae by cofactor engineering of 6-phosphogluconate dehydrogenase and deletion of ALD6.* Microbial Cell Factories, 2016. **15**: p. 1-16.

[34] Wu, R., et al., *Enhanced ethanol production from sugarcane molasses by industrially engineered Saccharomyces cerevisiae via replacement of the PHO4 gene.* RSC Advances, 2020. **10**(4): p. 2267-2276.

[35] Hasunuma, T., T. Sakamoto, and A. Kondo, *Inverse metabolic engineering based on transient acclimation of yeast improves acid-containing xylose fermentation and tolerance to formic and acetic acids.* Applied Microbiology and Biotechnology, 2016. **100**(2): p. 1027-1038.

[36] Li, Y.-J., et al., *Engineered yeast with a CO2-fixation pathway to improve the bio-ethanol production from xylose-mixed sugars.* Scientific reports, 2017. **7**(1): p. 43875.

[37] Wei, N., et al., *Enhanced biofuel production through coupled acetic acid and xylose consumption by engineered yeast.* Nature communications, 2013. **4**(1): p. 2580.

[38] Zhang, G.-C., et al., *Optimization of an acetate reduction pathway for producing cellulosic ethanol by engineered yeast.* Biotechnology and Bioengineering, 2016. **113**(12): p. 2587-2596.

[39] Kuroda, K. and M. Ueda, *Cellular and molecular engineering of yeast Saccharomyces cerevisiae for advanced biobutanol production.* FEMS Microbiology Letters, 2016. **363**(3).

[40] Hussain, A., et al., *Advances in microbial metabolic engineering for the production of butanol isomers (isobutanol and 1-butanol) from a various biomass.* BioEnergy Research, 2022. **15**(4): p. 1854-1871.

[41] Schadeweg, V. and E. Boles, *n-Butanol production in Saccharomyces cerevisiae is limited by the availability of coenzyme A and cytosolic acetyl-CoA.* Biotechnology for Biofuels, 2016. **9**(1): p. 1-12.

[42] Liu, R., et al., *Metabolic engineering of fatty acyl-ACP reductase-dependent pathway to improve fatty alcohol production in Escherichia coli.* Metabolic engineering, 2014. **22**: p. 10-21.

[43] Krivoruchko, A., et al., *Improving biobutanol production in engineered Saccharomyces cerevisiae by manipulation of acetyl-CoA metabolism.* Journal of Industrial Microbiology and Biotechnology, 2013. **40**(9): p. 1051-1056.

[44] Hong, K.-K. and J. Nielsen, *Metabolic engineering of Saccharomyces cerevisiae: a key cell factory platform for future biorefineries.* Cellular and Molecular Life Sciences, 2012. **69**: p. 2671-2690.

[45] González-Ramos, D., et al., *Genome-scale analyses of butanol tolerance in Saccharomyces cerevisiae reveal an essential role of protein degradation.* Biotechnology for biofuels, 2013. **6**(1): p. 1-18.

[46] Hahn, H., et al., *Butanols//Ullmann's Encyclopedia of Industrial Chemistry.* Wiley.—2013.—DOI, 2010. **10**(14356007): p. a04_463.

[47] Chen, X., et al., *Increased isobutanol production in Saccharomyces cerevisiae by overexpression of genes in valine metabolism.* Biotechnology for biofuels, 2011. **4**(1): p. 1-12.

[48] Kondo, T., et al., *Genetic engineering to enhance the Ehrlich pathway and alter carbon flux for increased isobutanol production from glucose by Saccharomyces cerevisiae.* Journal of biotechnology, 2012. **159**(1-2): p. 32-37.

[49] Lee, W.-H., et al., *Isobutanol production in engineered Saccharomyces cerevisiae by overexpression of 2-ketoisovalerate decarboxylase and valine biosynthetic enzymes.* Bioprocess and biosystems engineering, 2012. **35**: p. 1467-1475.

[50] Brat, D., et al., *Cytosolic re-localization and optimization of valine synthesis and catabolism enables increased isobutanol production with the yeast Saccharomyces cerevisiae.* Biotechnology for biofuels, 2012. **5**: p. 1-16.

[51] Matsuda, F., et al., *Construction of an artificial pathway for isobutanol biosynthesis in the cytosol of Saccharomyces cerevisiae.* Bioscience, biotechnology, and biochemistry, 2012. **76**(11): p. 2139-2141.
[52] Matsuda, F., et al., *Increased isobutanol production in Saccharomyces cerevisiae by eliminating competing pathways and resolving cofactor imbalance.* Microbial cell factories, 2013. **12**(1): p. 1-11.
[53] Park, S.-H., S. Kim, and J.-S. Hahn, *Metabolic engineering of Saccharomyces cerevisiae for the production of isobutanol and 3-methyl-1-butanol.* Applied microbiology and biotechnology, 2014. **98**: p. 9139-9147.
[54] Park, S.-H., S. Kim, and J.-S. Hahn, *Improvement of isobutanol production in Saccharomyces cerevisiae by increasing mitochondrial import of pyruvate through mitochondrial pyruvate carrier.* Applied microbiology and biotechnology, 2016. **100**(17): p. 7591-7598.
[55] Lee, K.-M., et al., *Elimination of biosynthetic pathways for l-valine and l-isoleucine in mitochondria enhances isobutanol production in engineered Saccharomyces cerevisiae.* Bioresource technology, 2018. **268**: p. 271-277.
[56] Wess, J., M. Brinek, and E. Boles, *Improving isobutanol production with the yeast Saccharomyces cerevisiae by successively blocking competing metabolic pathways as well as ethanol and glycerol formation.* Biotechnology for biofuels, 2019. **12**(1): p. 1-15.
[57] Brat, D. and E. Boles, *Isobutanol production from D-xylose by recombinant Saccharomyces cerevisiae.* FEMS yeast research, 2013. **13**(2): p. 241-244.
[58] Zhang, Y., et al., *Xylose utilization stimulates mitochondrial production of isobutanol and 2-methyl-1-butanol in Saccharomyces cerevisiae.* Biotechnology for Biofuels, 2019. **12**: p. 1-15.
[59] Steen, E.J., et al., *Metabolic engineering of Saccharomyces cerevisiae for the production of n-butanol.* Microbial cell factories, 2008. **7**: p. 1-8.
[60] Sakuragi, H., et al., *Enhanced butanol production by eukaryotic Saccharomyces cerevisiae engineered to contain an improved pathway.* Bioscience, Biotechnology, and Biochemistry, 2015. **79**(2): p. 314-320.
[61] Shi, S., et al., *Metabolic engineering of a synergistic pathway for n-butanol production in Saccharomyces cerevisiae.* Scientific Reports, 2016. **6**(1): p. 25675.
[62] Ennis, B., N. Qureshi, and I. Maddox, *In-line toxic product removal during solvent production by continuous fermentation using immobilized Clostridium acetobutylicum.* Enzyme and microbial Technology, 1987. **9**(11): p. 672-675.
[63] Grobben, N.G., et al., *Production of acetone, butanol and ethanol (ABE) from potato wastes: fermentation with integrated membrane extraction.* Applied Microbiology and Biotechnology, 1993. **39**: p. 494-498.
[64] Ezeji, T., N. Qureshi, and H. Blaschek, *Acetone butanol ethanol (ABE) production from concentrated substrate: reduction in substrate inhibition by fed-batch technique and product inhibition by gas stripping.* Applied microbiology and biotechnology, 2004. **63**: p. 653-658.
[65] Van Hecke, W., et al., *Integrated bioprocess for long-term continuous cultivation of Clostridium acetobutylicum coupled to pervaporation with PDMS composite membranes.* Bioresource technology, 2012. **111**: p. 368-377.
[66] Garcia III, A., E.L. Iannotti, and J.L. Fischer, *Butanol fermentation liquor production and separation by reverse osmosis.* Biotechnology and bioengineering, 1986. **28**(6): p. 785-791.
[67] Qureshi, N. and T.C. Ezeji, *Butanol,'a superior biofuel'production from agricultural residues (renewable biomass): recent progress in technology.* Biofuels, Bioproducts and Biorefining: Innovation for a sustainable economy, 2008. **2**(4): p. 319-330.
[68] Feng, X. and R.Y. Huang, *Liquid separation by membrane pervaporation: a review.* Industrial & Engineering Chemistry Research, 1997. **36**(4): p. 1048-1066.
[69] Lipnizki, F., et al., *Organophilic pervaporation: prospects and performance.* Chemical Engineering Journal, 1999. **73**(2): p. 113-129.
[70] Chapman, P.D., et al., *Membranes for the dehydration of solvents by pervaporation.* Journal of Membrane Science, 2008. **318**(1-2): p. 5-37.
[71] Vane, L.M., *A review of pervaporation for product recovery from biomass fermentation processes.* Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology, 2005. **80**(6): p. 603-629.
[72] Rothman, H., R. Greenshields, and F. Rosillo Callé, *The alcohol economy: Fuel ethanol and the Brazilian experience*. 1983: Frances Pinter (Publishers).
[73] Wei, P., et al., *A review of membrane technology for bioethanol production.* Renewable and Sustainable Energy Reviews, 2014. **30**: p. 388-400.
[74] Dempfle, D., O. Kröcher, and M.H.-P. Studer, *Techno-economic assessment of bioethanol production from lignocellulose by consortium-based consolidated bioprocessing at industrial scale.* New biotechnology, 2021. **65**: p. 53-60.
[75] Piccolo, C. and F. Bezzo, *A techno-economic comparison between two technologies for bioethanol production from lignocellulose.* Biomass and bioenergy, 2009. **33**(3): p. 478-491.
[76] Rai, M., et al., *Emerging role of nanobiocatalysts in hydrolysis of lignocellulosic biomass leading to sustainable bioethanol production.* Catalysis Reviews, 2019. **61**(1): p. 1-26.
[77] Ozturk, A.B., et al., *Techno-economic analysis of a two-step fermentation process for bio-butanol production from cooked rice.* Sustainable Energy & Fuels, 2021. **5**(14): p. 3705-3718.
[78] Mailaram, S. and S.K. Maity, *Dual liquid–liquid extraction versus distillation for the production of bio-butanol from corn, sugarcane, and lignocellulose biomass: A techno-economic analysis using pinch technology.* Fuel, 2022. **312**: p. 122932.
[79] Xin, F., et al., *Biobutanol production from crystalline cellulose through consolidated bioprocessing.* Trends in biotechnology, 2019. **37**(2): p. 167-180.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Physicochemical, colorimetric properties and yield of bresaola from beef, Baladi-goat and Awassi-sheep in Lebanon

Bachir Abi-Salloum[1], Maguy Al-Nahum[1], Mohammed Rached[2], Ossama Dimassi[3*]

[1] Lebanese International University, Department of Nutrition and Food Science, Beirut, Lebanon
[2.] Lebanese International University, Department of Biomedical Sciences, Beirut, Lebanon
[3] American University of Europe, New York, USA
*Corresponding Author

Received: 11 Feb 2023; Received in revised form: 12 Mar 2023; Accepted: 20 Mar 2023; Available online: 25 Mar 2023

Abstract—*Yield, physicochemical and colorimetric characteristics of bresaola from Lebanese Baladi-goat and Awassi-sheep compared to that from beef is studied. For this purpose, defatted lean meat cuts from Beef, Baladi-goat and Awassi-sheep were collected, weighed and processed following the EU-approved guidelines for Bresaola della Valtellina. The bresaola from beef (BFB) had the significantly lowest moisture and fat content compared to Bresaola from Baladi-goat (BFG), with the values of Bresaola from Awassi-sheep (BFS) being significantly the highest. Furthermore, the protein and ash content of BFB was significantly the highest, followed by the values of BFG with content of BFS being the lowest. The pH value of BFB was significantly the lowest, while there was no difference between those of BFG and BFS. There was no significant difference in the water activities of BFB, BFG and BFS (0.848±0.002). As for the colorimetric characteristics, the ΔE value of BFB with BFG is 14.74±4.10, while that of BFB with BFS is 17.88±4.10, and that of BFG with BFS is 16.00±4.10 noting that the values did not differ significantly. The BFB and BFG Hue values did not differ significantly both being significantly larger than that of BFS. The BFB and BFG Chroma values were not significantly different while both being significantly different from that of BFS. Bresaola from raw meat (kg-Bresaola/kg-raw meat) value for beef was found to be significantly higher than that of goat, with value for sheep being significantly the highest. Consequently, the opposite was true for weight loss (%).*

Keywords— ***Bresaola, Beef, Baladi Goat, Awassi Sheep, Conversion values, Physicochemical, Colorimetric properties.***

I. INTRODUCTION

Bresaola originate from Italy and is guaranteed by Protected Geographical Indication (PGI) community trademark "Bresaola della Valtellina," and gained popularity in the national and international market [1]. It is a dry meat product, similar to other products such as Turkish and Armenian pasturma [2] [3] and other dry-cured beef [4]. Bresaola has low fat and calories contents, and high amount of protein, iron, vitamins and minerals [5], fitting the current consumers' who favor meat that is authentic, tasty, rich in protein and low in lipid, cholesterol and carbohydrates [6] [7].

Traditionally, Bresaola is made by curing cuts from the hind quarter (mostly *Semimembranosus*, *Semitendinosus* and *Quadriceps femoris* muscles) of cattle, horses, or donkeys [7]. The meat is defatted, then marinated with dry salt and natural flavors for at least 7 days then dried and cured -with seasoning- under adequate environmental conditions (temperature, relative humidity and air velocity) for a duration of at least 3 weeks [8] [9]. The Bresaola

quality depends on the initial properties of the meat and its treatment [9, 10] influencing nutritional and sensorial characteristics of Bresaola [1]. In the last years several studies highlighted the favorable nutritional profile of meat and meat products from alternative animal species such as buffalo, goat [7, 11] and game animals [12-14].

In Lebanon, around 92-95 % of goat breeders raise the local population of goats called "Baladi" and 99% of sheep farmers raise the Awassi breed [15, 16]. They are mainly raised in extensive systems with different levels of concentrate supplementations [15]. Furthermore, more than 6000 families are living from the income of goat herd products such as milk, meat and fur [16]. The Awassi sheep is also a multipurpose breed with a dominance of meat production. The goat kids and the sheep lambs are slaughtered at the mature age of around one year for a weight varying between 40 and 55 kg [15]. The production of dry cured meat products that are available throughout the year could be a tool to increase the value of goat and sheep meat.

The aim of the work was to evaluate yield, chemical parameters like proximate composition, pH and aw in the raw material of Baladi goat and Awassi sheep compared to the traditional source of bresaola meat i.e. beef cattle, and the corresponding cured fermented and dried products prepared from the same meats, using the processing scheme of 'bresaola' production. Furthermore, the colorimetric properties of the produced beef, goat and sheep Bresaola was elucidated.

II. MATERIALS AND METHODS

2.1 Meat and Bresaola

The beef, Baladi-goat and Awassi sheep top cut round meat were collected from certified local Lebanese-licensed abattoir who abide by the standard handling procedures. The top cut round meat was taken from the 3 bulls, 3 Baladi-goat and 3 Awassi-sheep hind areas. After trimming, defatting and taking samples of raw meat, the cuts were tumbled with a curing mixture (for 1kg of fresh meat: 25g of sodium chloride, 1.2g of Fructose corn syrup, 0.2g of sodium nitrite, 1g spices) turned and massaged every 3 days at a 70-80% RH for a total duration of 9 days at 2–3C. After 9 days after shaping step, rapping in a natural casing, tying with a food grade string and place it into a curing chamber, at 13C and 85%RH for 2 months, bresaola was produced.

2.2 Physicochemical properties

All raw and Bresaola samples were sent to the laboratories of the Industrial Research Institute, Lebanese University Campus Hadatt (Baabda) Lebanon, to study their physicochemical properties. The three samples of raw and bresaola meat were tested with three replications each. Each sample was assessed for theses parameters: Moisture content following drying Method (AOAC Official Method 950.46B)[17, 18]; Protein content following Kjeldahl method (AOAC Official Method 928.08)[19]; Fat content following Soxhlet extraction method (AOAC Official Method 960.39)[20]; Ash content following using the basic heating technique (550 C for 5 h) AOAC official method 920.15 [19]; pH was measured using a pH-meter Microcomputer based pH/conductivity/TDS/salinity and temperature pocket meter Model pH/EC80 (Jenco VisionP), with tip probe electrode at 25C; Water activity (aw), was measured using (TESTO650, Germany) with an accuracy of ±0.001 at 25C.

2.3 Colorimetric Properties

The color of Bresaola were determined using pantone color chart [21] which had the corresponding CIE L*a*b* values. Following the American Meat Science Association [22] these parameters were calculated:

i. Redness Ratio where Larger ratios of a*/b* indicate less discoloration [22]-[23]

Equation (1): Redness Ratio= a*/b*

ii. Chroma (C): larger values indicating more saturation of the principle hue of the sample [22]

Equation(2): C= (a*^2 + b*^2)^(0.5)

iii. Hue angle (HA): Larger values indicate less red. [22]

Equation(3): HA= {arctangent (b*/a*)}

iv. Delta E (ΔE): Total color change. It is used to assess the difference in color between bresaola from beef, Baladi-goat and Awassi-sheep [22]

Equation(4): ΔE= (ΔL*^2+ Δa*^2+ Δb*^2)^0.5

2.4 Yield attributes

The initial weight of meat cuts was recorded. Furthermore, the final weight of the bresaola produced was recorded. This has allowed the calculation of bresaola from meat cut (kg bresaola/ kg raw meat) (5). Furthermore, the percent weight lost during the process was calculated (6).

Equation(5): Bresaola produced= Bresaola weight / Initial weight

Equation(6): Weight loss= (Initial meat weight – Bresaola weight)*100 / Initial meat weight

2.5 Statistical analysis

All data were subjected to analysis of variance, using the GLM procedure of the SPSS statistical software (IBM SPSS statistics 21). The mathematical model included fixed effect due to animal species for bresaola. Significant differences were found if P is less than 0.05. Least Squares

means were evaluated to set the difference between the different parameters. Furthermore, the Pearson correlation was calculated between the CIE L*a*b*, colorimetric calculated attributes and the physicochemical properties of produced bresaola.

III. RESULTS

3.1 Physicochemical Properties

3.1.1. Physicochemical properties of raw meat

The moisture content of beef cuts did not differ significantly from that of Baladi-goats cuts, both being significantly higher from moisture content in Awassi-sheep cuts "Table 1". Concerning the fat content, beef cuts was found to have the significantly lowest value compared to that of Baladi-goat and Awassi-sheep cuts which did not differ significantly from each other "Table 1".

Table 1: Physicochemical properties of raw meat cuts

	beef	Baladi-goat	Awassi-sheep
	mean±S.E	mean±S.E.	mean±S.E.
M.[1] (%)	74.6[a]±0.3	73.8[a]±0.3	69.6[b]±0.3
Fat (%)	1.37[a]±0.09	3.80[b]±0.09	4.03[b]±0.09
Prt.[2] (%)	22.4[a]±0.3	20.7[b]±0.3	25.0[c]±0.3
Ash (%)	1.23[a]±0.06	1.17[a]±0.06	1.17[a]±0.06
pH	5.60 [a]±0.03	5.47 [b]±0.03	5.97 [c]±0.03
aw[3]	0.967[a]±0.004	0.940[a]±0.004	0.947[a]±0.004

Within rows, means with different letters are significantly different. 1: Moisture; 2: Protein; 3: Water activity;

The protein content and pH values, the values recorded of Awassi-sheep cuts were significantly the highest followed by that of beef cuts, with that of Baladi-goat cuts being the significantly lowest. Last but not the least, the pH and aw values of the beef, Baladi-goats and Awassi-sheep cuts showed no significant difference "Table 1".

3.1.2. Physicochemical properties of Bresaola

The moisture and fat content of bresaola from beef (BFB) were significantly the lowest, those recorded for bresaola from Awassi-sheep (BFS) were significantly the highest with those recorded for bresaola from Baladi-goats (BFG) in between "Table 2". The opposite was true for the protein and ash content, where the values for BFB were found to be significantly the highest, followed by the values of BFG with those values of BFS being significantly the lowest "Table 2". The pH values of BFG and BFG did not differ from each other with that of BFB being significantly lower "Table 2". Concerning the water activity (aw) value there was no significant difference recorded in this study for BFB, BFG and BFS "Table 2".

Table 2: Physicochemical properties of Bresaola

	BFB	BFG	BFS
	mean±S.E.	mean±S.E.	mean±S.E.
M.[1] (%)	33.73[a]±0.07	34.97[b]±0.07	37.17[c]±0.07
Fat (%)	2.73[a]±0.05	5.23[b]±0.05	7.73[c]±0.05
Prt.[2] (%)	55.2[a]±0.1	53.2[b]±0.1	48.6[c]±0.1
Ash (%)	7.77[a]±0.03	6.27[b]±0.03	6.07[c]±0.03
pH	5.53 [a]±0.04	6.00 [b]±0.04	5.93[b]±0.04
aw[3]	0.850[a]±0.002	0.847[a]±0.002	0.852[a]±0.002

Within rows, means with different letters are significantly different. 1: Moisture; 2: Protein; 3: Water activity; BFB: Bresaola from beef; BFG: Bresaola from Baladi-goat; BFS: Bresaola from Awassi-sheep

3.1.3. Colorimetric properties

All the L, a* and b* values were positive. The L value of BFB was significantly higher than those values of BFG and BFS, both being non-significantly different "Table 3". As for the a* value, it was significantly the highest for BFB compared to those of BFG and BFS which did not differ significantly from each other "Table 3". Furthermore, the b* values of the BFB, BFG and BFS did not differ significantly from each other "Table 3".

*Table 3: CIE-L*a*b* values of Bresaola*

	BFB	BFG	BFS
	mean±S.E.	mean±S.E.	mean±S.E.
L	47.25[a]±1.75	37.80[b]±1.75	41.17[b]±1.75
a*	49.91[a]±3.49	50.61[b]±3.49	65.44[b]±3.49
b*	35.17[a]±2.35	30.51[a]±2.35	33.40[a]±2.35

Within rows, means with different letters are significantly different. BFB: Bresaola from beef; BFG: Bresaola from Baladi-goat; BFS: Bresaola from Awassi-sheep

As for the colorimetric calculated values, it was found that the Redness Ratio (1) and Chroma values of BFB and BFG did not differ significantly from each other while BFS values were significantly the highest "Table 4".

Table 4: Redness Ratio (1), Chroma (C) and Hue Angle (HA) values for bresaola

	BFB	BFG	BFS
	mean±S.E.	mean±S.E.	mean±S.E.
Redness Ratio	1.44^{a}±0.13	1.68^{a}±0.13	1.96^{b}±0.13
C	61.3^{a}±3.4	59.1^{a}±3.4	73.30^{b}±3.4
HA	35.5^{a}±2.5	30.9^{ab}±2.5	23.4^{b}±2.5

Within rows, means with different letters are significantly different. BFB: Bresaola from beef; BFG: Bresaola from Baladi-goat; BFS: Bresaola from Awassi-sheep

Concerning the Hue angle value, there was no significant differences between the BFB and BFG while that of BFS was significantly the lowest "Table 4". As for the Delta E, the color difference between BFB and BFG is 14.7±4.1, while that between BFB and BFS is 17.9±4.1 and last but not least the color difference between BFG and BFS is 16.0±4.1.

3.1.4. Correlation between Colorimetric properties and physicochemical properties

The moisture, fat and protein content were not correlated with the brightness (L) value of the meat, while it was highly and positively correlated with the ash content and highly and negatively correlated with the pH value.

*Table 5: Pearson correlation between CIE-L*a*b* value and physicochemical properties of bresaola*

	Brightness L	Redness a*	Yellowness b*
Moisture	n.s.	0.772	n.s.
Fat	n.s.	0.731	n.s.
Protein	n.s.	-0.786	n.s.
Ash	0.743	n.s.	n.s.
pH	-0.761	n.s.	n.s.
aw	n.s.	n.s.	n.s.

n.s.: Not significant

The redness value (a*), on the other hand was positively and highly correlated with the moisture and fat content and highly and negatively correlated with the protein content.

3.1.5. Yield parameters of Bresaola

As for the bresaola produced from kg of raw meat, it was found that Awassi-sheep meat produced the significantly highest bresaola weight, followed by that of beef meat with that of Baladi-goat meat being significantly the lowest "Fig. 1".

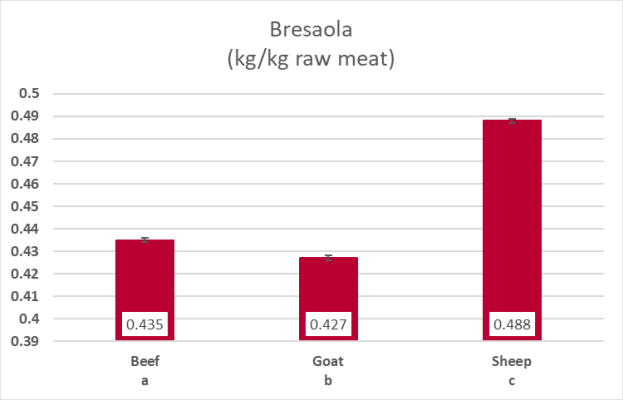


Fig.1 kg Bresaola from 1 kg raw meat
Different alphabetic letter indicate significant difference

Following the opposite tendency of bresaola weight produced, the weight loss during bresaola production was the lowest in BFS production, followed by that in BFB production with that in BFG production being the highest "Fig. 2".

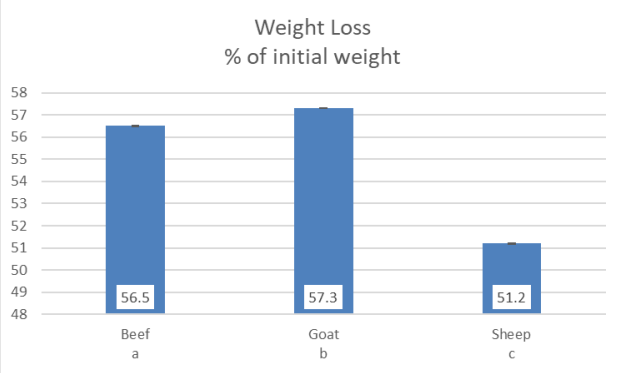


Figure 2 Percent weight loss during bresaola production
Different alphabetic letter indicate significant difference

IV. DISCUSSION

Animal species did affect significantly the physicochemical properties of Fresh meat and bresaola produced which is similar to the results found by Marino et, al. 20015[1], Zhang et al. 2015 [5] and Paleari *et. al.* 2003 [7]. The moisture content of fresh meat was highest in beef but turned to be lowest in the BFB produced. The opposite was true for Awassi-sheep raw meat, where it started to be the lowest and the moisture content was the highest in the BFS produced. This might be due to the higher fat content in Awassi-sheep meat compared to that of beef meat. This was different from the study in New-Zealand where bresaola done from lamb and mutton had the lowest fat content [5]. This difference might be attributed to the different species of sheep predominant in New-Zealand [24] which does not include the Awassi-sheep. The trend of fat content was the same in raw meat

and that of bresaola, where Beef and BFB had the lowest fat content followed by Baladi-goat and BFG with Awassi-sheep and BFS having the highest fat content. Concerning the protein content, it started by raw Awassi-sheep meat having the highest protein content but ended up by having the lowest one in the BFS. This might be explained by the fact mentioned by Zhang *et. al.* 2015 [5] who found that bresaola from mutton meat, when compared to bresaola from beef, veal, wagyu and lamb, had undergone the highest proteolysis rate leading to highest free amino acids content. As for the ash content, while there was no difference at the raw meat level, BFB had the highest ash content followed by BFG and then BFS. The increase of ash content is due to the salting stage, however the highest increase in beef ash content might be due to the lowest fat content which might have hindered salt penetration where the leaner the outer surface area the higher the penetration of salt [25]. As expected, the reductions in moisture content and increase in ash content resulted in a significant decrease in the aw of bresaola produced, around 0.851±0.002, compared to that of the fresh meat product, around 0.951±0.004. This reduction renders the bresaola produced relatively shelf stable even against *listeria monocytogenesis* [26, 27]. Concerning the pH there was no significant difference between the bresaola Bresaola produced, the values being within the acceptable range [9], keeping the product under the low acid food category [28].

Concerning the colorimetric properties of the BSB, BSG and BSF, there was significant difference among the different species which is in compliance with the literature [5, 29]. Starting with the brightness (L*) they were higher than those reported by Zhang *et. al.* 2015[5], ranging from 20 to 30, similar to those reported for young bulls[8] and commercial bresaola, around 40 [30]. This is although the moisture content of the produced Bresaola is similar to that recorded by Zhang *et. al.* 2015 [5] it has similar values to those recorded by the commercial bresaola. The BSB had the highest light reflectance, followed by that of BFS and BSG having the lowest value. The L value was correlated positively with the ash and negatively with the pH values. The redness value (a*) of BFB and BFG were similar to each other both being less red than the BFS. This might be due to the significantly highest moisture content which was reflected by high correlation between moisture content and a* value. This was not in accordance with Zhang *et. al.* 2015 [5] but this might be explained by the much lower moisture content recorded. The yellowness values of the BFB, BFG and BFS did not differ from each other which might explain the non-significant correlation was recorded between b* and the physicochemical properties. The calculated colorimetric values did differ significantly between BFB, BFG and BFS. The BFS had the highest Redness Ratio and HA values indicating least discoloration and more redness. This is in parallel to the a* values of BFN, BFG and BSB recorded and to the high change in color vales (ΔE) between BFN, BFG and BSB.

One of the most important attributes in any processing are the yield attributes. BFS had the highest yield and the least weight loss, despite starting with the highest moisture content. Weight loss of around 56 - 57% is a bit higher than the 34.1% to 40.5% recorded by Alabiso *et. al.* 2020 [10] who produced bresaola made from Cinisara cattle. The meat from Cinisara cattle had a starting moisture content from 74.5% to 76%, while we had the highest at 74.6% for beef, 73% for goat and 69.6% for sheep. Furthermore, the last stage of bresaola production, it which was kept at 13C and 85%RH for 2 months, compared to 12C and 72-75% RH for 1 month by Zhang *et. al.* 2015 [5], and to 10°C and 90% of RH for 1 month by Alabiso *et. al.* 2020 [10] might be the reason behind this variation.

V. CONCLUSION

Meat from Awassi-sheep and Baladi-goat can be used for bresaola production with their yield being higher than that observed in meat from beef. In addition to that, more studies should be done to monitor the effect of each stage and parameter on the end product. There was difference in the physicochemical properties and colorimetric properties between the beef, Baladi-goats and Awassi-sheep. More studies should be conducted to confirm some of the differences realized between the local breeds and those recorded by the literature. A sensory analysis should be conducted to assess the acceptability of BFG and BFS compared to BFB and the imported brands.

REFERENCES

[1] Marino, R., et al., Nutritional properties and consumer evaluation of donkey bresaola and salami: Comparison with conventional products. Meat Science, 2015. **101**: p. 19-24.

[2] Kaban, G., Changes in the composition of volatile compounds and in microbiological and physicochemical parameters during pastırma processing. Meat Science, 2009. **82**(1): p. 17-23.

[3] Oboturova, N., et al., Traditional foods of the North Caucasus region, in Nutritional and Health Aspects of Traditional and Ethnic Foods of Eastern Europe. 2022, Elsevier. p. 69-91.

[4] Heinz, G. and P. Hautzinger, Meat processing technology for small to medium scale producers. 2007.

[5] Zhang, R., Characterisation of bresaola products made from beef, veal, wagyu, mutton and lamb. 2015, Auckland University of Technology.

[6] Jiménez-Colmenero, F., J. Carballo, and S. Cofrades, Healthier meat and meat products: their role as functional foods. Meat science, 2001. **59**(1): p. 5-13.
[7] Paleari, M.A., et al., Cured products from different animal species. Meat science, 2003. **63**(4): p. 485-489.
[8] Braghieri, A., et al., Sensory properties affecting acceptability of "bresaola" from podolian young bulls. Journal of Sensory Studies, 2009. **24**(5): p. 677-697.
[9] De Palo, P. and A. Maggiolino, Bresaola, in Production of Traditional Mediterranean Meat Products. 2022, Springer. p. 105-110.
[10] Alabiso, M., et al., Effect of muscle type and animal category on fatty acid composition of bresaola made from meat of Cinisara cattle: preliminary investigation. CyTA-Journal of Food, 2020. **18**(1): p. 734-741.
[11] Madruga, M. and M. Bressan, Goat meats: Description, rational use, certification, processing and technological developments. Small Ruminant Research, 2011. **98**(1-3): p. 39-45.
[12] Hoffman, L.C. and E. Wiklund, Game and venison–meat for the modern consumer. Meat science, 2006. **74**(1): p. 197-208.
[13] Hoffman, L., The yield and nutritional value of meat from African ungulates, camelidae, rodents, ratites and reptiles. Meat science, 2008. **80**(1): p. 94-100.
[14] Van Schalkwyk, D., et al., Physico-chemical, microbiological, textural and sensory attributes of matured game salami produced from springbok (Antidorcas marsupialis), gemsbok (Oryx gazella), kudu (Tragelaphus strepsiceros) and zebra (Equus burchelli) harvested in Namibia. Meat Science, 2011. **88**(1): p. 36-44.
[15] Hosri, C., E. Tabet, and M. Nehme. Goat and sheep products value chain analysis in Lebanon. in Options Méditerranéennes: Series A: Mediterranean Seminars. 2016. CIHEAM Zaragoza, Spain.
[16] Mira, T., et al., GENETIC AND MORPHOLOGICAL CHARACTERIZATION OF LEBANESE MOUNTAIN LOCAL GOAT POPULATION. JAPS: Journal of Animal & Plant Sciences, 2021. **31**(2).
[17] AOAC., Method 950.46 B. Official methods of analysis, 1995. **2**: p. 39-1.
[18] Soderberg, D., Meat and Poultry and Meat and Poultry Products. Journal of AOAC International, 1994. **77**(1): p. 162-167.
[19] AOAC, Nitrogen in Meat, Kjeldahl Method. 928.08. Official methods of analysis, 2002.
[20] Chemists, A.o.O.A., AOAC official method 960.39. Fat (crude) or ether extract in meat. Final action, AOAC official methods of analysis 1995. 1995, Association of Official Analytical Chemists Arlington (VA).
[21] Chow, C.-F., *Biogenic amines-and sulfides-responsive gold nanoparticles for real-time visual detection of raw meat, fish, crustaceans, and preserved meat.* Food chemistry, 2020. **311**: p. 125908.
[22] Association, A.M.S., *AMSA Meat Color Measurement Guidelines: AMSA*. 2012: American Meat Science Association.
[23] Setser, C.S., *COLOR: REFLECTIONS AND TRANSMISSIONS 1 2*. Journal of Food Quality, 1984. **6**(3): p. 183-197.
[24] Dalton, D., T. Knight, and D. Johnson, *Lamb survival in sheep breeds on New Zealand hill country*. New Zealand journal of agricultural research, 1980. **23**(2): p. 167-173.
[25] Toldrá, F., *Dry-cured meat products*. 2008: John Wiley & Sons.
[26] Miraglia, V., et al., *Behaviour of Listeria monocytogenes in chunked or sliced seasoned Bresaola della Valtellina IGP*. Industrie Alimentari, 2009. **48**(496): p. 58-64.
[27] Dalzini, E., et al., *Growth potential of Listeria monocytogenes in sliced turkey bresaola packed in modified atmosphere.* Italian Journal of Food Safety, 2014. **3**(1).
[28] Nummer, B., Food Acidity and Safety. 2006.
[29] Teixeira, A., et al., Effect of salting and ripening on the physicochemical and sensory quality of goat and sheep cured legs. Meat Science, 2017. **134**: p. 163-169.
[30] Rød, S.K., et al., Cold atmospheric pressure plasma treatment of ready-to-eat meat: Inactivation of Listeria innocua and changes in product quality. Food microbiology, 2012. 30(1): p. 233-238.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

A Survey on Livestock Health Care Delivery System in Maharashtra of India

H P Aithal, S K Das* and K N Bhilegaonkar

Training and Education Centre (TEC), ICAR- Indian Veterinary Research Institute (IVRI),Shivajinagar, Pune – 411 005, Maharashtra, India

Received: 15 Feb 2023; Received in revised form: 10 Mar 2023; Accepted: 18 Mar 2023; Available online: 26 Mar 2023

Abstract— *Feedback of 250 Livestock Development Officers (LDO) of Maharashtra state was taken regarding the livestock health care delivery system in pre constructed format. The study revealed that 17.60 % LDO were looking after five and more than five dispensaries and23.20 % LDO were taking care of livestock from more than 20 villages. Many of the LDOs (56.80 %) were also involved in different extension works such as implementation of Gov. Schemes, survey work and cattle show etc., besides treatment of animals. Majority of the officers (72.40 %) visited farmer's house as and when farmers called. Moreover, 69.60 % LDO informed that they visited village for the treatment of livestock very often.Most of the officers informed about sufficient stock of vaccine (82.00 %), antibiotic (60.00 %), anthelmentis and analgesics (63.60 %), but 42.00 % LDO reported scarcity of vitamin and mineral mixture.In respect of disease outbreak / occurrence, LDO reported outbreak of 22 diseases in livestock and poultry. Most occurrence of disease was FMD in cattle (28.00 %), followed by PPR in goat (24.80 %) and HS in cattle (14.40%). 31.20 % respondents reported more than two weeks time was needed to get diagnostic report of disease from the testing laboratory.32.80 % LDO informed that they reported to the District Animal Husbandry Officer regarding outbreak / occurrence of disease.The officers revealed that the regular vaccination was carried out against FMD (97.20 %),HS (93.20 %) and BQ (92.00 %). 35.60 % respondents reported vaccine failure and cause of vaccine failure was found to be improper storage and transportation of vaccine (17.20 %) followed by untimely vaccination (10.80 %) and some even doubted about the quality of vaccine. 47.60 % LDO reported the sufficient availability of acaricide and 67.20 % respondents informed sufficient availability of anthelmintic in the animal health center.Artificial Insemination was preferred over natural service by farmers for breeding of livestock as reported by 83.60 % respondents.Conception rate in AI was reported to be 45.27 %, whereas number of AI / conception was reported to be 2.85. Reason for preference of AI by most of the farmers was easy availability (46.00 %) followed by better conception rate (43.60%).*

Keywords— ***Delivery System, Health Care, Livestock, Maharashtra, Survey***

I. INTRODUCTION

Livestock sector plays an important role in socio economic development of our country. The success of livestock industry depends on good health of the livestock. Maharashtra is rich source of livestock population. As per 20th Livestock Census (1) the bovine livestock population of Maharashtra is 19.50 million out of which cattle population is 13.90 million (7.22 % of national population) and buffaloes population is 5.60 million (5.10 % of national population). In Maharashtra goat population is 10.60 million, which is 7.12 % of National population. Livestock thus is an important integral part to the sustainability of economy of this state. So, information on the livestock health care delivery system in Maharashtrawill definitely help the State Animal Husbandry Department to identify the constrains and issue related to proper health care management of livestock of the state. This in turn would help to plan properly to monitor and undertake prevention and control measures of livestock diseases well in advance.

Moreover, all those information was lacking. Therefore this survey work was conducted as a part of extension work in the year 2018 - 19.

II. MATERIAL AND METHODS

A structured questionare was developed for collecting data from Livestock Development Officers (LDO) of Maharashtra on livestock health care delivery system in the state. Survey was done and information was collected in preconstructed proforma. The questionare was pretested and the information was collected from 250 Livestock Development Officers belonging to almost all the regions and districts of Maharashtra. The questionnaire included information on (i) responsibilities of the officers (the number of hospitals under their jurisdiction, number of villages to be covered with population of animals, responsibilities/duties assigned other than related to health care, etc.), (ii) animal treatment (common diseases, visit to villages, diagnosis of conditions, availability of drugs and vaccines, organization of outreach programmes and health camps etc.), (iii) disease surveillance and monitoring (common disease outbreaks, testing samples and facilities etc.), (iv) vaccination (common vaccinations, frequency, storage and transport of vaccines, vaccination failure etc.), (v) control of parasites (methods used for control, availability of acaricides, frequency of deworming, etc.), and (vi) animal production, reproduction and minor surgeries (feeding practice, breeding method, availability of AI straws, and minor surgeries such as dehorning, castration, branding, hoof trimming, dystocia and caesarean section etc. Afterwards data were analyzed statistically (5) using SPSS 10.5 version software.

III. RESULTS

The respondent Livestock Development Officers (LDOs) were belonging to 33 districts of Maharashtra. The maximum participants were from Nagpur (15) district followed by Nashik (14) and Raigarh (14) district. It was observed that 60.00 % LDO were holding charge of one hospital / dispensary, whereas 17.60 % were taking care of five and more than five dispensaries (Table – 1) indicating inadequate number of officers in certain areas. In terms of coverage of villages by the LDOs, 25.20 % informed that they were treating livestock of 6 – 10 villages, while 23.20 % LDO reported of taking care of livestock from more than 20 villages. Most of the LDO (30.00 %) reported that population of animal was 501-1000. However, 20.00 % LDO reported that animal population was < 500 and 19.20 % also reported that it was 5001-10000. When information was taken on different activities performed by the officials other than animal health care, it was observed that 56.80 % LDOs were involved in different extension works such as implementation of Gov. Schemes, survey work and cattle show etc. 30.00 % LDOs were engaged in tagging of cattle under INAPH (Information Network for animal productivity and health), insurance etc. 25.60 % LDO were taking care of fodder development.20.00 % LDO were involved in different miscellaneous works such as election duty, examination duty, *swacchataabhiyan*, *gramsabha* meeting, and farm management. 14.40 % officers were busy in livestock census.

Table - 1: Responsibilities of Officers

SL NO	Particular	Frequency	% based on number of respondents
1	**Number of Hospital**		
a	One	150	**60.00**
b	Two	23	9.20
c	Three	15	6.00
d	Four	8	3.20
e	Five and above	44	17.60
f	Not Reported	10	4.00
2	**Number of villages**		
a	1-5	49	19.60
b	6-10	63	**25.20**

c	11-15	47	18.80
d	16-20	21	8.40
e	Above 20	58	23.20
f	Not Reported	12	4.80
3	**Population of Animals**		
a	<500	50	20.00
b	501-1000	75	**30.00**
c	1001-2000	24	9.60
d	2001-5000	43	17.20
e	5001-10000	48	19.20
f	Not Reported	10	4.00
4	**Responsibilities other than related to livestock health**		
a	Fodder development	64	25.60
b	Extension work, implementation of Govt. Scheme,survey, cattle show	142	**56.80**
c	AI, Supply of semen & liquid nitrogen	27	10.80
d	Livestock census	36	14.40
e	INAPH tagging of cattle, insurance	75	30.00
f	Miscelleneous activitieseg. election duty, examination duty, swacchata abhiyan, gramsabha meeting, farm management etc.	50	20.00
g	Training	18	7.20
h	Castration	6	2.40
i	Distribution of chick, egg	3	1.20

The most common disease condition reported by LDOs was digestive disorder (Table – 2 A) followed by reproductive disorder and metabolic diseases. The reproductive disease was second most important which was due to mineral and vitamin deficiency. Parasitic and infectious diseases stood IV th and V th rank. It was observed from Table – 2B that 72.40 % LDO visited farmer's house as and when farmers called. Moreover, 69.60 % LDO informed that they visited villages for the treatment of livestock very often. When LDOs were asked about the diagnostic methods, it was reported that 58.80 % LDOs diagnosed cases by clinical examination and 39.60 % by clinical examination & laboratory test both. In case of visit of LDO to farmer, 83.20 % LDO informed that response of farmers to their visit was favourable. 86.80 % LDO reported that they organize animal health camp quarterly. Table– 2C indicated stock of medicine in the dispensary. Most of the livestock development officers informed about sufficient stock of vaccine (82.00 %), antibiotic (60.00 %), anthelmentis and analgesics (63.60 %), but 42.00 % LDO reported scarcity of vitamin and mineral mixture.

Table – 2A: Common disease conditions:-

SL No	Particular	Mean	Ranking
a	Infectious	3.00	V
b	Parasitic	2.99	IV

c	Metabolic	2.89	III
d	Digestive	**2.34**	**I**
e	Reproductive	2.83	II
f	Others	4.93	VI

Table – 2B: Information on visit of LDO to farmer's house, disease diagnosis and health camp organisation

SL No	Particular	N.O. respondents	% of respondents
1.	**When will you visit a farmer / village?**		
a	As and when farmer calls	181	**72.40**
b	Periodically for regular health check	66	26.40
c	As per directive of the superior	26	10.40
d	Any other	20	8.00
2.	**How often you visit a village for treatment?**		
a	Very Often (every day / alternate day)	174	**69.60**
b	Often (weekly / fortnightly)	45	18.00
c	Sometimes (monthly / two months)	14	5.60
d	Rarely	14	5.60
	Not reported	3	1.20
3	**How will you diagnose a clinical case?**		
a	Clinical examination	147	**58.80**
b	Laboratory test	17	6.80
c	Both	99	39.60
d	Others	2	0.80
4	**How Often organise animal health camp?**		
a	Quarterly	217	**86.80**
b	Half Yearly	10	4.00
c	Yearly	6	2.40
d	Rarely	**7**	2.80
	Not reported	10	4.00
5	**Response of farmer for your visit**		
a	Favourable	208	**83.20**
b	Not so favourable	27	10.80
c	Unfavourable	1	0.40
	Not reported	14	5.60

Table – 2 C: Availability of vaccine and medicine in the hospital

SL No	Particular	Yes		No		Not Reported	
		N.O. resp	%of resp.	N.O. resp	%of resp.	N.O. resp	%of resp.
a.	Vaccime	205	82.00	17	6.80	28	11.20
b.	Antibiotic	150	60.00	52	20.80	48	19.20
c.	Analgesics	159	63.60	49	19.60	42	16.80
d.	Anthelmentics	159	63.60	50	20.00	41	16.40
e.	Min. & Vit.	97	38.80	105	42.00	48	19.20

In respect of disease outbreak / occurrence of diseases during past few years, LDO reported outbreak / occurrence of 22 diseases in livestock and poultry (Table – 3). 28.00 % respondent informed occurrence of Foot and Mouth Disease (FMD) in cattle, followed by PPR (Pesti des Petits Ruminitis) in goat (24.80 %) and Hemorrhagic Septicemias (HS) in cattle (14.40%). In the present study no outbreak of anthrax and swine fever was reported. 50.80 % LDO informed that they would able to know about outbreak of disease through farmer and 52.80 % reported through routine visit of field. Most frequently collected material for outbreak investigation by the officers was faecal samples (70.00 %), followed by blood (68.80 %) and urine (20.40%). Majority of the officers (about 53%) reported that they generally get lab test results within 2 weeks. On query about the reporting system of the outbreaks, the officers responded that they report to higher authorities in the department about the occurrence outbreak. Finally almost all LDO (90.80 %) informed that they undertook follow up visit of outbreak area.

Table - 3: Disease surveillance and monitoring:-

SL No	Particular	Frequency	% based on number of respondents
1	**Disease Outbreak**		
a	Foot and Mouth Disease	**70**	**28.00**
b	Haemorrhagic Septicemia	36	14.40
c	Black Quarter	35	14.00
d	Trypanosomiasis	4	1.60
e	Thilereosis	4	1.60
f	Babesiosis	3	1.20
g	Three Days Sickness	2	0.80
h	Tick Fever	2	0.80
i	Brucellosis	1	0.40
j	Glanders	1	0.40
k	Poisoning	4	1.60
l	Rabies	1	0.40
m	Pesti des Petits Ruminants	62	24.80
n	Enterotoxemia	12	4.80
o	Contagious Ecthyma	2	0.80
p	Goat Pox	4	1.60
q	Sheep Pox	5	2.00

r	Blue Tongue	1	0.40
s	Contagious Caprine Pleuro Pneumonia	2	0.80
t	Botulism	5	2.00
u	Ranikhet Disease	9	3.60
v	Fowl Pox	5	2.00
2	**How will you come to know about disease outbreak?**		
a	Through farmer	127	50.80
b	Through livestock supervisor	34	13.60
c	Through superior	4	1.60
d	Through routine visit	**132**	**52.80**
3	**What samples you generally collect for testing?**		
a	Fecal	**175**	**70.00**
b	Blood	172	68.80
c	Urine	51	20.40
d	Tissue	37	14.80
e	Any other	12	4.80
4	**How much time it will take to get test report?**		
a	< 1 d	19	7.60
b	2 - 3 d	41	16.40
c	4 - 7 d	30	12.00
d	1 - 2 w	43	17.20
e	> 2 w	**78**	**31.20**
	Not Reported	39	15.60
5	**To whom you report the occurrence of infectious diseases?**		
a	Higher authority	39	15.60
b	LDO (E)	21	8.40
c	ACAH	48	19.20
d	DAHO	**82**	**32.80**
e	DCAH	12	4.80
f	RJCAH / JCAH	32	12.80
g	Dean, Veterinary College	1	0.40
	Not Reported	15	6.00
6	**Do you undertake follow up visit?**		
a	Yes	**227**	**90.80**
b	No	8	3.20
	Not Reported	15	6.00

The results of Table – 4 A revealed that FMD vaccination was done by 97.20 % officers regularly, which was followed by HS (93.20 %) and BQ vaccination (92.00 %). In goat 91.60 % officers reported about PPR vaccination and 86.40

% reported about ET vaccination. Respondent per cent in case of other vaccines were poor. The vaccination frequency followed by officers for different diseases is depicted in Table – 4B, which indicates that officers, in majority of the cases, were following optimum vaccination schedule. It was observed from Table – 4 (C) that 66.80 % LDO reported storing and transportation of vaccine was done in refrigerator. However, ice pack and cool box were also used by 40.80 % and 38.00 % respondents respectively. Although majority of the officers (61.60 %) have not reported the occurrence of the disease after vaccination, 35.60 % respondents reported vaccine failure in the field condition in their opinions. Cause of vaccine failure was reported to be improper storage and transportation (17.20 %) which means poor maintenance of cooling chain from vaccine production to vaccine delivery to animals for immunization. Second cause of vaccine failure was untimely vaccination (10.80 %).

Table - 4 A: Vaccination of animals undertaken by the LDO:-

SL No	Particular	Frequency	% based on number of respondents
a	Foot & Mouth Disease (FMD)	243	97.20
b	Haemmorhegic Septicemia (HS)	233	93.20
c	Black Quarter (BQ)	230	92.00
d	Peti des Pestis Ruminitis (PPR)	229	91.60
e	Enterotoxemis (ET)	216	86.40
f	Ranikhet Disease (RD)	39	15.60
g	Fowl Pox (FP)	28	11.20
h	Brucellosis (BR)	14	5.60
i	Rabies (AR)	10	4.00
j	Gumbro disease (GD)	1	0.40
k	Sheep Pox (SP)	1	0.40

Table - 3 B: Vaccination scheduled of animals adopted by the LDOs:-

SL No	Particular	Vaccination Schedule	Frequency	% based on number of respondents
a	FMD	Once / year	7	2.80
		Twice / year	169	**67.60**
		As per supply	1	0.40
b	HS	Once/year	183	**73.20**
		Twice/year	15	6.00
		As per supply	2	0.80
c	BQ	Once/year	189	**75.60**
		Twice/year	13	5.20
		As per supply	2	0.80
d	PPR	Once/year	96	**38.40**
		Once/ 2 years	11	4.40
		Once/ 3 years	63	25.20
		As per supply	4	1.60

e	ET	Once / year	136	**54.40**
		Twice / year	33	13.20
		As per supply	3	1.20
f	RD	Once / year	2	0.80
		Twice/year	1	0.40
		As per supply	3	1.20
g	FP	As per supply	1	0.40

Table - 3 C: Vaccination storage, transport & failure:-

SL No	Particular	Frequency	% based on number of respondents
3	**How do you store & transport vaccine**		
a	Refrigerator	167	**66.80**
b	Cool Box	95	38.00
c	Ice Pack	102	40.80
d	Ice Box	37	14.80
e	Any Other	3	1.20
4	**Did you come across vaccine failure?**		
a	Yes	89	35.60
b	No	154	**61.60**
	Not reported	7	2.80
5	**If yes, what do you feel the cause of vaccine failure?**		
a	Poor quality vaccine	21	8.40
b	Improper storage and transportation	43	17.20
c	Untimely vaccination	27	10.80
d	Any Other	19	7.60
	Not reported	140	**56.00**

The results of the queries related to control of the parasitic diseases in animals are presented in Table 5. Among different methods of controlling external parasites, spraying was the most common (80.80 %) method used by field officers, which was followed by parenteral administration of medicine (51.20 %) and oral administration (32.00 %). The officials would arrange treatment by organization of animal health camp (58.80 %) followed by door to door visit of farmer (46.80 %). Frequency of applying acaricide was once / three months as reported by 47.20 % respondents followed by once / month (21.60 %). 47.60 % LDO reported the sufficient availability of acaricide in the dispensary while, 33.20 % reported insufficient availability. Regarding the control of internal parasites, majority of the officers (73.20 %) reported that they did deworming once in three months, whereas 16.80 % LDO performed deworming once / six months. 67.20 % respondents informed sufficient availability of anthelmentic in the dispensary. However, 27.20 % reported insufficient availability of anthelmentics (Table – 5).

Table - 5: Control of Parasitic diseases:-

SL NO	Particular	Frequency	% based on number of respondents
1	**Methods used for control of external parasite**		
a	Spraying	202	**80.80**
b	Diping	42	16.80
c	Oral administration	80	32.00
d	Parentral administration	128	51.20
e	Any Other	2	0.80
2	**How do you generally organize treatment**		
a	Organization of camp	147	**58.80**
b	Door to door visit	117	46.80
c	Ask the owner of animal to spray acaricide	75	30.00
d	Through livestock supervisor	14	5.60
e	Any Other	1	0.40
3	**How often do you advice to spray acaricide**		
a	Once every month	54	21.60
b	Once in three months	118	**47.20**
c	Once in six months	35	14.00
d	Once in a year	8	3.20
e	Rarely	9	3.60
	Not reported	26	10.40
4	**Do you have ready availability of acaricide ?**		
a	Sufficient	119	**47.60**
b	Insufficient	83	33.20
c	Not present	28	11.20
	Not reported	20	8.00
5	**How often do you advice for deworming ?**		
a	Once every month	20	8.00
b	Once in three months	183	**73.20**
c	Once in six months	42	16.80
d	Once in a year	4	1.60
e	Rarely	1	0.40
6	**Do you have ready availability of anthelmentics ?**		
a	Sufficient	168	**67.20**
b	Insufficient	68	27.20
c	Not present	9	3.60
	Not reported	5	2.00

Part 6 of the questionnaire was related to the queries on production/reproduction activities and minor surgeries performed by the officers. The analysis of the results revealed that 94.40 % LDO informed that farmers come regularly to them for advice

on feeding and breeding of their livestock (Table – 6). Artificial Insemination was preferred over natural service by farmers for breeding of livestock as reported by 83.60 % respondents. Regarding the availability of semen straw, 91.60 % LDO reported that they got sufficient quantity of semen straw for AI. Conception rate in AI was reported to be 45.27 %, whereas number of AI / conception was reported to be 2.85. Easy availability (46.00 %) and better conception rate (43.60 %) were the reasons of preference of AI by most of the farmers. Majority of LDOs (87.20 %) reported that they performed minor surgical procedures such as dehorning, castration, branding and hoof trimming. Patteler desmotomy was reported to be performed by 55.20 % LDO. 90.80 % officers reported to have handled dystocia cases and 56.40 % officials performed caesarian section with the success rate of 67.13 %.

Table – 6: Animal Production / Animal Reproduction and Minor Surgery undertaken by LDO :-

SL NO	Particular	Frequency	% based on number of respondents
1	**Do the animal owners ask for advice on feeding and breeding?**		
a	Yes	236	**94.40**
b	No	12	4.80
	Not Reported	2	0.80
2	**Which method is preferred by the farmers for reproduction?**		
a	Natural Service	36	14.40
b	AI	209	**83.60**
	Not Reported	5	2.00
3	**Do you get enough good quality semen straw for AI ?**		
a	Yes Sufficient	229	**91.60**
b	Insufficient	10	4.00
c	No	4	1.60
	Not Reported	7	2.80
4	**What is the conception rate (%) in AI**	45.27	
	What is the number of AI / conception?	2.85	
5	**Why do you feel AI is preferred / not preferred by majority of famers?**		
a	Better conception rate	109	43.60
b	Easy availability	115	**46.00**
c	Economical	94	37.60
d	Increased milk production	103	41.20
e	Any other	2	0.80
	Reason of non-preference	6	2.40
a	Less conception rate	4	1.60
b	Not easily available	1	0.40
c	Any other	1	0.40
6	**Do you undertake dehorning, castration, branding, hoof trimming?**		
a	Yes	218	**87.20**
b	No	23	9.20

	Not Reported	9	3.60
7	**Do you perform pattelerdesmotomy?**		
a	Yes	138	**55.20**
b	No	103	41.20
	Not Reported	9	3.60
8	**Do you handle dystocia case?**		
a	Yes	227	**90.80**
b	No	14	5.60
	Not Reported	9	3.60
9	**Do you perform caesarian section?**		
a	Yes	141	**56.40**
b	No	95	38.00
	Not Reported	14	5.60
10	**If yes, success rate (%)**		67.13

IV. DISCUSSION

Survey of 250 livestock development officers (LDO) revealed that most of the participants were from Nagpur district of Maharashtra. It was observed that most of the LDO were holding charge of one hospital, treating livestock of 6 – 10 villages with animal population of < 500. Most of the LDOs were involved in different extension works such as implementation of Gov. Schemes, survey work and cattle show etc. besides animal treatment. The most common disease condition was digestive followed by reproductive disorder and metabolic diseases. However, it was reported (2) that the digestive diseases were the major cause of mortality in cattle in Maharashtra. Lack of proper hygiene and sanitation in animal shed, lack of balance feeding, improper housing and feeding management were the contributing factors for higher digestive disorders. The cause of lower parasitic and infectious disease was due to regular deworming and vaccination programme conducted by LDOs of Maharashtra animal husbandry department. Most common method of diagnosis of different cases was by clinical examination. Most of the LDO informed about sufficient stock of vaccine, anthelmentis, but scarcity of vitamin and mineral mixture in their respective dispensary.

In respect of occurrence of diseases during past few years, LDO reported highest incidence of Foot and Mouth Disease (FMD) in cattle, followed by PPR (Pesti des Petits Ruminitis) in goat and Hemorrhagic Septicemias (HS) in cattle. In another study (3), it was revealed that Pesti des Petits Ruminants in goat was most important infectious disease in Maharashtra followed by Foot and Mouth Disease and Blood Protozoan Diseases in cattle & buffalo. In contradiction to present findings it was reported (4) that outbreak of livestock diseases in Maharashtra during 2005 – 16, was highest in Black Quarter (203) followed by Haemorrhagic Septicaemia (176), Pesti des Petits Ruminants (137), Swine Fever (36), Sheep and Goat Pox (33), Foot and Mouth Disease (6), Sheep and Goat Anthrax (18), Enterotoxaemia (17) and Bovine Anthrax (7). They also informed that most frequently collected material for outbreak investigation by the officers was faecal samples. Finally almost all LDO informed that they undertook follow up visit of outbreak area. It was also revealed from survey that in cattle and buffalo FMD vaccination was done maximum followed by HS and BQ vaccination. In goat PPR vaccination was done maximum followed by ET vaccination. Most of the officers reported that storing and transportation of vaccine was done in refrigerator. Quite a good number of respondents reported vaccine failure in the field condition in their opinions and cause of vaccine failure was reported to be improper storage and transportation.

Among different methods of controlling external parasites, spraying was the most common method used by field officers. Frequency of applying acaricide and deworming against internal parasite was reported mostly to be once / three months. Most of the officials informed sufficient availability of acaricide and anthelmentic in the dispensary. However. scarcity of medicine was also reported by few LDOs. Most of the respondents reported that artificial insemination was preferred over natural service by farmers for breeding of livestock due to easy availability of semen and better conception rate. Regarding the availability of semen straw, mostly reported that they got sufficient quantity of semen straw for AI. Majority of LDOs reported that they performed minor surgical

procedures such as dehorning, castration, branding and hoof trimming etc. and Patteler desmotomy was reported to be performed by mostly. It was also reported that most of the LDOs handle dystocia cases and perform caesarian section with the high success rate.

V. CONCLUSION

Veterinary and animal husbandry services of the state Governments play a vital role for optimum production in livestock sector as well as proper disease and health management of the livestock. The present survey on veterinary health care delivery system in Maharashtra state revealed a satisfying performance in terms of disease control and management measures adopted in the state. It also highlighted the keenness of the officers to reach out to the farmers and undertake different activities for the benefit of the livestock owners. However, there seems to be some areas for improvement such as inadequate number of LDOs in certain areas as reflected by officers having the charge of 3 to 5 dispensaries/hospitals and had to cover more area and large number of animals, which may affect the service delivery. Further, strengthening of the support system of laboratories for testing and rapid diagnosis would be of great help in disease and health care management. Moreover all the animal health centers / dispensaries should ensure availability of most of the important medicines, particularly mineral & vitamin mixture and vaccine for the livestock owners for maintaining health and production of livestock

ACKNOWLEDGEMENT

Authors are thankful to Mr D Bhashkara Rao, Technical Officer, TEC, ICAR - Indian Veterinary Research Institute for providing necessary help as and when required. Authors acknowledge all the Livestock Development officers of respective Veterinary Dispensary, Department of AH & Veterinary Services, Govt. of Maharashtra for providing necessary information. Authors also duly acknowledge Director, ICAR – Indian Veterinary Research Institute, Izatnagar, Bareilly, UP for necessary cooperation, guidance and funding.

REFERENCES

[1] Anonymous. (2019). 20 th Livestock Census. Dept. of Animal Husbandry and Dairying, Ministry of Fisheries, Animal Husbandry and Dairying, Govt. of India.

[2] Bangar Y., Khan T. A., Dohare A. K., Kolekar D. V., WakchaureN. And Singh B. (2013). Analysis of morbidity and mortality rates in cattle in Pune division of Maharashtra state, *Vet. World, 6 (8)*: 512 – 515.

[3] Das S. K., Aithal H. P. and Bhilegaonkar K. N. (2020). A Survey on the Occurrence of Livestock Diseases and Constrains in Controlling those Disease in Maharashtra. *International J. Livestock Res., 10 (2)*: 89 - 96.

[4] Krishnamoorthy P., Tatwarthy S.B., Suryawanshi S.N., Shome B.R., Suresh K.P. and Roy Parimal. (2018). Spatial and Temporal Epidemiological Analysis of Livestock Diseases in Maharashtra State. Research & Reviews: *Journal of Veterinary Science and Technology, 7(1)*: 16 - 23.

[5] Snedecor, G. W. and Cochran, W. G. (1994). Statistical Methods. 6 th Edition. Oxford and IBH Pub Co., New Delhi.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

The Effect of Addition of AMF (Arbuscular Mycorrhizal Fungi) and Yomari Liquid Organic Fertilizer Concentration on the Growth of Agarwood Production Plants (*Aquilaria malacensis* Lamk.) on Ex-Lime Mining Soil

Benni Satria, Rachmad Hersi Martinsyah, Armansyah, Dini Hervani, dan Warnita

Study Program Agrotechnology

Received: 13 Nov 2022; Received in revised form: 11 Jan 2023; Accepted: 19 Mar 2023; Available online: 26 Mar 2023

Abstract— *This plant has a very large opportunity to be developed on ex-mining land, considering that this plant is an adaptive non-timber forest product plant that grows and produces naturally without inoculation (injection) on ex-mining land: limestone, nickel, rocky sand, tin and coal. and added witharbuscular mycorrhizal fungi (AMF) and liquid organic fertilizer such as Yomari on Aquilaria malacensis Lamk. AMF is able to increase root growth, root range, so that it can facilitate roots to absorb water and nutrients throughexternal hyphae and later obtained quality seeds which have many and strong roots. Yomariliquid organic fertilizer has high organic and nutrient content, can increase soil organisms and improve soil pH and. This study aimed to obtain the best interaction between the doseof AMF and the concentration of Yomari liquid organic fertilizer on the growth of Aquilaria malacensis Lamk seedlings. in the ex-limestone mine soil, the best dose of AMFwas obtained on the growth of Aquilaria malacensis Lamk seedlings. in limestone ex- mining soil and the best concentration of Yomari organic fertilizer on the growth of Aquilaria malacensis Lamk. in the former limestone quarry. This research was conducted from June to November 2022 in the nursery of the Faculty of Agriculture, Andalas University. This study used a factorial experimental method in a Completely Randomized Design (CRD) with 2 factors, namely the first factorwas the administration of the AMF dose which consisted of 5 levels: 0.0 grams (C0); 15 grams (C2); 30 grams (C3) and 45 grams (C4) and the second factor concentration of Yomari organic fertilizer consisted of 5 levels: 0.00 ppm (Y0); 25.00 ppm (Y1); 50.00 (Y2); 75.00 ppm (Y3) and 100.00 ppm (Y4), each treatment level consisted of 4 replications. Observational data in the form of qualitative and quantitative data were analyzed using the F-test at a significance level of 5%. The different effects on the treatmentwere analyzed by further test of LSD at 5% level. Observations were made including: percentage of live seedlings, increase in seedling height, increase in number of leaves, widest leaf width, root weight, and percentage of roots infected by AMF on lime-mined soil media. There is an interaction between the dose of AMF and the concentration of liquidorganic fertilizer on the growth of agarwood-producing plant seeds (Aquilaria malacensisLamk.)) on the ex-limestone mining soil. Giving a dose of AMF 45 grams with a concentration of 100 ppm liquid organic fertilizer was the best in increasing the percentage of life, increasing the number leaves, increase in plant seed height, widest leaf width, percentage of agarwood-producing plant seeds infected with AMF.*

Keywords— ***Seedlings, agarwood, Yomari liquid organic fertilizer, AMF, limestonemining soil***

I. INTRODUCTION

Limestone is a solid rock that contains a lot of calcium carbonate (Lukmanet al., 2012 and Sucipto et al., 2007). Calcium carbonate is an inorganic mineral that is known to be commercially available cheaply. Physical properties of calcium carbonate such as morphology, phase, size, and size distribution must be modified according to the field of application (Kirboga and Oner, 2013; Lailiyah et al., 2012). Ex-lime mining land at PT. Holcim Indonesia Tbk West Java, precisely in the Cirebon area, obtained the results of chemical analysis of lime soil including the pH value of H2O 8.4, KCL 7.8 while organic matter C was 0.98%, N 0.7% and C/N 14% and for available P it was obtained at 25 ppm (Wildasari, 2016 and Wahdi, 2016).

Rehabilitation activities of ex-lime mining land generally require quality seeds, however, the seedlings die in large numbers after being planted in the field because the availability of nutrients and water is not met for growth and development, as a result of the plant roots being few, shallow, not strong and damaged (Sari, 2018 and Kimi, Sutoyo and Satria, 2021). This root problem can be overcome by using liquid organic fertilizers such as Yomari fertilizer and Arbuscula mycorrhizal fungi (AMF) at a certain dose.

Yomari liquid organic fertilizer is a fertilizer that functions to increase the development of soil organisms, increases soil pH and stimulates vegetative growth of plants, plays a role in the formation of leaf green matter and stimulates plant roots to become more abundant and stronger. Soaking the coffee cuttings in 1 ml/l of Yomari liquid organic fertilizer and spraying the cuttings 3 times at a dose of 1ml/l within 10 days will produce many cutting shoots, have many roots with strong roots (Satria *et al*, 2021). The presence of AMF can increase the availability of nutrients, especially Phosphate (P) which is very low in the soil of ex-lime mining, improve soil structure, increase water absorption and protect plants from root pathogens and toxic elements. Inoculation of 40 grams of AMF on ultisols and in planting media from limestone ex-mining soil can increase the growth of

plant seeds Aquilaria malacensis Lamk .) and Satria, Fadli, Herawati and Aprisal,2021).

This plant has a very large opportunity to be developed on ex-mining land, considering that this plant includes adaptive non-timber forest products that grow and produce naturally on ex-mining land: nickel, rocky sand, tin and coal (Sari, 201 and Kimi *et al. al*, 2021). In connection with the explanation above, the researchers have conducted a study entitled "**The Effect of Dosage of AMF (*Fungi*) and Yomary Liquid Organic Fertilizer Concentration on the Growth of Agarwood-Producing Plant Seeds (*Aquilaria malacensis Lamk.)*) on Ex-Limestone Mining Soil".**

This research was conducted to answer some of the problems formulated in the following questions: 1. Is there an interaction between the dose of AMF and the concentration of Yomari organic fertilizer on the growth of gaharu-producing plant seeds (*Aquilaria malacensis* Lamk.) in the former lime-mining soil? 2. What is the effect of the dose of AMF? on the growth of these seedlings in the former limestone quarry soil? And 3. How is the effect of Yomari organic fertilizer concentration on the growth of the seeds in the former lime-mining soil?

The specific objectives of this research are: 1. To obtain the best interaction between the dose of AMF and the concentration of Yomari organic fertilizer on the growth of gaharu-producing plant seeds (*Aquilaria malacensis* Lamk.) in the former limestone quarry; 2. Obtaining the best dose of AMF for the growth of these seedlings in the former lime-mining soil; 3. Obtaining the best concentration of

Yomari organic fertilizer on the growth of these seeds in the former lime-miningsoil.

This research can provide information about the seeds of gaharu-producing plants (*Aquilaria malacensis* Lamk.) which are able to associate well with the dose of AMF and Yomari organic fertilizer concentration and are compatible to be planted on ex-lime mining land.

The results of this study are expected to contribute to the development of plant science, especially plant breeding. These contributions include: Providing information on the standard method of AMF Dosage and concentration of Yomari Liquid Organic Fertilizer and Types of AMF) on the Growth of Agarwood- Producing Plant Seeds (*Aquilaria malacensis Lamk.)*in Ex-Limestone Mining Soils Provide a positive contribution to the development of plant cultivation science and technology gaharu (*Aquilaria malacensis*) and become a reference in adaptability and germplasm preservation.

II. METHODS

The research was conducted in the experimental garden of the Faculty of Agriculture, Andalas University. The research is planned for 8 months starting in June 2022 until November 2022.

The tools used in this research are hoe, bucket, polybag, scissors, hotplate, ruler, digital, meter, stationery, tweezers, scissors, cover glass, hose, tea filter, object glass, camera, and microscope. The materials used

were gaharu-producing plant seeds of Aquilaria malaccensis Lamk species, limestone ex-mining soil, ultisol, compost, Yomari liquid organic fertilizer, Arbuscula mycorrhizal fungi (Acaulospora sp., Gigaspora sp., and a mixture of Acaulospora sp. and Gigaspora sp.), NPK fertilizer, Aquadest, KOH 10%, HCL 2%, Trypan blue which is useful for root coloring, as well as clean water.

This study used a factorial experimental method in a Completely Randomized Design (CRD) with 2 factors, namely the first factor was the administration of the AMF dose which consisted of 5 levels: 0.0 grams (C0); 15 grams (C2); 30 grams (C3) and 45 grams (C4) and the second factor concentration of Yomari organic fertilizer consisted of 5 levels: 0.00 ppm (Y0); 25.00 ppm (Y1); 50.00 (Y2); 75.00 ppm (Y3) and 100.00 ppm (Y4), each treatment level consisted of 4 replications. Observational data in the form of qualitative and quantitative data were analyzed using the F-test at a significance level of 5%. The different effects on the treatment were analyzed by further test of BNT at 5% level.

The seedlings of agarwood plant species Aquilaria malaccensis Lamk came from the Gaharu Kanagarian farmer group Muaro Linggae, Sijunjung Regency. The seeds were prepared in each polybag measuring 8 cm X 9 cm and when the research was going to be carried out, the plants were transferred to polybags measuring 12 cm X 17 cm. Seedlings with seed criteria were not attacked by pests and diseases, had a height ranging from 5- 15 cm with 2-5 leaves. The soil used is the former limestone mining soil of PT Semen Padang mixed with Ultisol obtained from the experimental garden area of the Faculty of Agriculture, Andalas University. The soil is treated evenly and the planting media is put into a polybag measuring 12 cmx 17 cm.

The doses of AMF used included: 0 grams/polibaq, 15 grams/polibaq, 30 grams/polibaq and 45 grams/polibaq with multispora AMF types (a mixture of Acaulospora sp and Gigaspora sp) to plants by sprinkling them in the planting holes and then seedlings, then covered again with soil in the polybag . Furthermore, seedlings aged 4 and 8 weeks after planting were watered with Yomari liquid organic fertilizer concentration according to treatment. Observations included: percentage of viable seedlings, number of leaves, increase in seedling height, widest leaf width, weight of seedling roots and percentage of plant roots infected with AMF.

III. RESULTS AND DISCUSSIONS

A. Persentase Hidup Bibit Tanaman Pnghasil Gaharu

The results of the analysis of variance showed that there was an interaction between the AMF treatment and LOF treatment on the percentage of live seedlings (Appendix 4 and Table 1). The best response was found at a dose of 45 g of AMF with a concentration of 100 ppm LOF which showed a significant difference with other treatments at the age of 3 months after planting (DAT). This is because the higher the dose of AMF and the higher the concentration of LOF given to agarwood-producing plants, the higher the percentage of live agarwood seedlings.

Table 1. Percentage of Life of Agarwood-Producing Plant Seeds due to AMF and LOFtreatment at 3 months of age

age	Concentration LOF (ppm)				
	0	25	50	75	100
	%				
0	55.00 aD	60.00 bCD	65.00 c BC	67.50 cAB	72.50 dA
15	50.00 a D	62.50 b C	70.00 bc B	75.00 b B	82.50 c A
30	52.50 a E	65.00 ab D	72.50 b C	80.00 b B	92.50 b A
45	55.00 a D	70.00 a C	82.50 a B	87.50 a B	100.00 a A
CV = 6.24%					

Note: The numbers followed by the same uppercase letter in the same row and the numbers followed by the same lowercase letter in the same column are not significantly different according to theLSD

That can increase economic value. The existence of AMF that has been inoculated into the agarwoodseedling media, makes the agarwood seeds have high economic value and better productivity. This is, in accordance with the opinion of Kimi *et al*,. 2020 that AMF can help plant growth, increase crop productivity and quality through increasing theavailability and absorption of nutrients in the soil, especially plants grown on less fertile lands such as infertile lands such as ex-lime mining lands. Mosse *et al*. (1981)also added that the seedling phase is a phase that is highly dependent on mycorrhizae, plants associated with ACM can adapt better to critical lands that have limited nutrient conditions.

Yomari liquid organic fertilizer is a fertilizer that functions to increase soil organisms, increase soil pH and stimulate plant vegetative growth, helps formation of cell division albumin for leaves, fruit, flower seeds and plays a role in the formation of leaf green matter and improvement of plant nutrients to stimulate plantroots to grow. more and stronger. This fertilizer contains several nutrients needed by plants and has aftif ingredients. The composition of nutrients contained in this fertilizer includes: Methyl Purine is a substance that can make plants resistant to allweather, Potassium 2,4 Dinitrophenol is a substance that synthesizes amino acids and proteins that make plants grow optimally, Potassium 5 Nitroguailacol and Potassium Paranitrophenol. Besides, this fertilizer contains organic C, organic N, elements P, K, Fe, MN, Zn and (Satria *et al*, 2021)

B. Increase in the number of leaves of agarwood-producing plant seeds

The results of the analysis of variance showed that there was an interaction between AMF treatment and LOF treatment on the increase in the number of leaves of agarwood-producing plant seeds (Appendix 4 and Table 2). The best response was found at a dose of 45 g of AMF with a concentration of 100 ppm LOF which showed a significant difference with other treatments at the age of 3 months after planting (DAT). This was because the higher the dose of AMF and the higher the concentration of LOF given to agarwood-producing plants, the higher the number of leaves of agarwood-producing plant seeds increased.

Table 2. Increase in the number of leaves of agarwood-producing plant seedsdue to AMF and LOF treatment at the age of 3 months of seedlings

Dosage AMF (g)	Concentration LOF (ppm)				
	0	25	50	75	100
	helai				
0	7.75 aC	8.25 bC	9.25 bB	9.50 bAB	10.25 bA
15	7.75 aD	8.75 abC	9.50 bBC	9.75 bB	10.75 bA
30	7.25 aC	9.25 aB	9.75 abB	10.00 bB	11.00 bA
45	7.50 a	9.50 a	10.50 a	11.25a	12.50 a
	D	C	B	B	A
CV = 5.6%					

The percentage of live seeds is influenced by various biotic and abiotic factors. Biotic factors such as seed quality, plant seeds used from both species came from healthy seeds. The characteristics of healthy plants are that they have green leaves and stems, the seeds are not diseased, the stems are straight, which is in accordance with the Indonesian national standard (SNI) 01-5006.1-2006 regarding seed quality which states that healthy seeds are fresh seeds. that are not attacked bypests and diseases, and do not show symptoms of nutrient deficiency (stems are notstraight and pale yellow in color).

The high percentage value of live seedlings *Aquilaria malacensis* seedlings had the best growth response to the AMF dose treatment with the highest LOF concentration.

Thewhich has a good impact, and can produce productsNote: The numbers followed by the same uppercase letter in the same row and the numbers followed by the same lowercase letter in the same column are not significantly different according to theLSD

This is because the higher the dose of LOF given and the higher the dose of AMF given to agarwood-producing plants, the higher the number of leaves of agarwood-producing plant seeds. LOF contains optimum nutrients for plant D.growth heterophyllum (Satria and Raesi, 2021).

C. Agarwood-producing Plant Seed Height Increase

The results of the analysis of variance showed that there was an interaction between AMF treatment and LOF

treatment on the increase in agarwood-producing plant seed height (Appendix 4 and Table 3). The best response was shown in the 45 g AMF treatment with 100 ppm LOF treatment, which was significantly different from the other treatments at 3 months after planting (DAT).

Table 3. Plant Seed Height Increase due to AMF and LOF treatment atseedling age of 3 months

Dosage AMF (g)	Concentration LOF (ppm) 0	25	50	75	100
	cm				
0	7.1250 cD	7.8750 dC	8.0625 dBC	8.4375 dB	8.6875 dA
15	7.8125 bD	8.3750 cC	8.5000 cB	9.5000 cB	10.6250 cA
30	8.2500 aE	9.5000 bD	10.8125 bC	11.8750 bB	12.5000 bA
45	8.4375 aE	10.3125 aD	11.5625 aC	12.9375 aB	14.4375 aA

Note: The numbers followed by the same uppercase letter in the same row and the numbers followed by the same lowercase letter in the same column are not significantly differentaccording to the LSD test

This is because this is because the higher the dose of LOF given and the higher the dose of AMF given to agarwood-producing plants, the higher the growth of agarwood-producing plant seeds. In addition, this plant is able to utilize N2 in the air, and the organic matter produced by this plant is rich in N nutrients (Kimi et al., 2020).

The results of the analysis of variance showed that there was an interaction between AMF treatment and LOF treatment on the widest leaf width of agarwood-producing plant seeds (Appendix 4 and Table 3). The best response was shown in the 45 g AMF treatment with 100 ppm LOF treatment, which was significantly different from the other treatments at 3 months after planting (DAT).

D. Widest Leaf Width of Agarwood Seedlings

Table 4. Widest Leaf Width of Agarwood-Producing Plant Seeds due to AMFand LOF treatment at 3 months of seedling

Dosage AMF (g)	Concentration LOF (ppm) 0	25	50	75	100
	cm				
0	2.0250 bD	2.1350 cCD	2.2750 cBC	2.3925 cB	2.5975 cA
15	2.1100 bC	2.3550 bB	2.4250 bcB	2.4725 cB	2.6950 cA
30	2.3675 aC	2.4100 bC	2.5400 bC	2.8125 bB	3.4825 bA
45	2.4500 a E	2.6500 a D	2.8425 a C	3.5400 a B	4.3550 a A
KK = 5.11%					

Note: The numbers followed by the same uppercase letter in the same row and the numbers followed by the same lowercase letter in the same column are not significantly different according to theBNT test

This is because the higher the dose of POC given and the higher the dose of AMF given to the producing plant, the wider the width of the widest leaf of agarwood-producing plant seeds. In addition, this plant is able to utilize N2 in the air, and the organic matter produced by this plant is rich in N nutrients (Kimi et al.,2020).

E. Root Weight of Agarwood Seedlings

The results of the analysis of variance showed that there was an interaction between AMF treatment and POC treatment on root weight of agarwood-producing plant seeds (Appendix 4 and Table 3). The best response was shown in the 45 g AMF treatment with 100 ppm POC treatment, which was significantly different from the other treatments at 3 months after planting (DAT).

Table 5. Root Weight of Agarwood-Producing Plant Seeds due to AMF andPOC treatment at 3 months of seedling age

Dosage AMF (g)	Concentration LOF (ppm)				
	0	25	50	75	100
	g				
0	11.3000 cC	12.3175 bB	12.9925 cB	13.1600 cAB	13.8675 cA
15	12.2325 bC	13.0750 bBC	13.5550 cAB	13.7150 cAB	13.9900 cA
30	13.0275 bD	14.1000 aC	15.1225 bB	15.8875 bB	17.2300 bA
45	14.3925 a C	14.8600 a C	16.8500 a B	17.5800 a B	20.6975 a A
CV = 4.12%					

Note: The numbers followed by the same uppercase letter in the same row and the numbers followed by the same lowercase letter in the same column are not significantly different according to theLSD test at the 5% level.

This is because the higher the dose of AMF given and the higher the concentrationof LOF given to agarwood-producing plants, the higher the root weight of agarwood-producing plant seeds, nitrogen is needed for the formation and growth of vegetative plant parts such as leaves, stems and roots. Meanwhile, phosphorus can help increase plant growth, produce chlorophyll, increase protein levels and accelerate leaf growth (*Satria et al.*, 2021).

F. Percentage of Roots of Agarwood-Producing Plant Seedlings infected with AMF

The results of the analysis of variance showed that there was an interaction between AMF treatment and LOF treatment on the widest leaf width of agarwood-producing plant seeds (Appendix 4 and Table 3). The best response was shown in the 45 g AMF treatment with 100 ppm LOF treatment, which was significantly different from the other treatments at 3 months after planting (DAT).

This could be due to the fact that mycorrhizal fungi with a dose of AMF and LOF concentration were able to develop AMF on a planting medium which was dominated by sandy soil and had larger soil pores compared to clay soil and this condition was thought to be suitable for the development of AMF spores which tend to larger and capable of infecting plant roots (Asmarahman, 2018).

Table 6. Percentage of Roots of Agarwood-Producing Plant Seedlings infectedwith AMF due to AMF and LOF treatment at 3 months of age

Dosage AMF(g)	**Concentration LOF (ppm)**				
	0	25	50	75	100
	%				
0	0.0000 aA	0.0000 aA	0.0000 aA	0.0000 aA	0.0000 aA
15	32.7500 bE	34.5000 bD	36.2500 bC	38.2500 bB	44.2500 bA
30	36.0000 bE	43.5000 cD	46.5000 cC	51.5000 cB	58.0000 cA
45	57.5000 c E	62.5000 d D	65.7500 d C	85.7500 d B	94.5000 d A
CV = 1.85%					

Note: The numbers followed by the same uppercase letter in the same row and the numbers followed by the same lowercase letter in the same column are not significantly different according to the LSD test

According to Brundrett (1996) mycorrhizae is a form of mutualistic symbiotic relationship between fungi and plant roots, both symbionts benefit. AMF includes obligate symbionts, which means that AMF can work after infecting the host plant. AMF is able to infect the root system of the host plant which can be seenin Figure 4, then it will produce an intensive network of hyphae so that mycorrhizal plants are able to increase their capacity to

absorb nutrients from LOF and water.

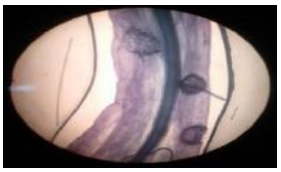


Fig.4. The shape of the roots infected by AMF as seen from themicroscope with 400X magnification

The additional colonization of AMF begins with the formation of an appresorium. Appresorium is an important structure that is in the AMF life cycle, is a key event for successful interaction with potential host plants, then the contactphase will be followed by a symbiotic phase. Since that phase, fungi complete the complex morphological process by producing intercellular and intracellular hyphae, vesicles, and arbuscules, the main structures of AMF are arbuscules, vesicles, external hyphae, and spores (Dewi, 2007). The opinion of Sufaati *et al.* (2011) arbuscula is a hyphal structure derived from branching hyphae in the corticalcells of the root of the host plant, the shape of the arbuscule resembles a small treethat functions as a place for the exchange of primary metabolites (especially glucoseand phosphorus) between fungi and plant roots. The distribution of external hyphaeis influenced by biotic and abiotic factors such as chemical properties, soil physics, organic matter, microflora and microfauna around the soil as a planting medium (Trisilawati *et al.*, 2012).

IV. CONCLUSIONS

Based on the results of research on the effect of giving doses of AMF and yomari liquid organic fertilizer on the growth of agarwood-producing plant seeds (Aquilaria malacensis Lamk.)) on limestone ex-mining soils, it can be concluded that: 1. There is an interaction between the dose of AMF and the concentration of liquid organic fertilizer on the growth of agarwood-producing plant seedlings (Aquilaria malacensis Lamk.)) on the ex-lime mining soil, and 2. Administration of 45 grams of AMF with a concentration of 100 ppm liquid organic fertilizer is the best in increasing the percentage of life. , increase in number of leaves, increase inplant seed height, widest leaf width, percentage of agarwood-producing plant seedsinfected with AMF.

ACKNOWLEDGEMENT

This research was fully funded by Agriculture Falculty and the Center for Research and Community Service through Research Grant for Professorship Acceleration. Our gratitude was also dedicated to the Head of Agronomy Laboratory for providing the required facilities during this research.

REFERENCES

[1] Asmarahman, C., SW Budi., I. Wahyudi., E. Santoso. 2018. Identification of Potential Microbes of Arbuscular Mycorrhizal Fungi (AMF) on Post- Mining Land PT. Holcim Indonesia Tbk. Cibinong, West Java. Journal of Natural Resources and Environmental Management Vol.8(3):279-285.

[2] B. Satria, M. Fadli, N. Herawati and Aprisal. 2021. Ultilization of Arbuscular Mycorrhizal Fungi (AMF) for Growth and ready to release of three genotypes of Gaharu (Aquilaria spp). ICBEAU 2021. IOP Cnf, Series: Earth and Environmental Science 741(2021)012049. 8 p.

[3] Brundrett, N., B. Bougher, T. Dell, Grove, N. Malajazuk. 1996. Working With Mycorrhizas In Forestry And Algiculture. Australian Center for International Agriculture Research (ACIAR). Canberra. pp. 162-171.

[4] De Lima, CLR, Ezequiel, CCM, Luis, CT, Eloy, AP, Alvaro, PS 2012. Soil Compressibility And Least Limiting Water Range Of A Constructed Soil Under Cover Crops After Coal Mining In Southern Brazil. Soil & Tillage Research. 124 : 190–195.

[5] Dewi, IR 2007. The Role and Function of Phytohormones for Plant Growth. [Thesis]. Bandung. Faculty of Agriculture. Padjadjaran University. 43 p.

[6] Kimi, AP, Sutyo and Satria B. Growth Response of Several Species of Agarwood (Aquilaria spp.) Due to Administration of AMF (Arbuscular mycorrhizal fungi) in Limestone Mining Land Media. Thesis. Andalas University Faculty of Agriculture. 32 pages

[7] Kirboga, S and Oner, M. 2013. Effect of The Experimental Parameters on Calcium Carbonate Precipitation. Chemical Engineering Transactions, Vol. 32, ISSN:1974-9791. Italy : AIDIC.

[8] Lailiyah, Q., Baqiya, M and Darminto.CO2 Gas Flow Rateand on the Synthesis of Calcium Carbonate Precipitation by Bubbling Method. 6 Pg.

[9] Lukman, M., Yudyanto., and Hartatiek.BiomaterialsComposite Based on Natural Materials (Limestone and Quartz Sand) with Variations in Heating Temperature and Its Effect on Porosity, Hardness, and Microstructure. Journal of Science Vol 2(1): 1-7.

[10] Makmur A., 2010. Early Growth of Agarwood Tree (Gyrinop sp.) From West Nusa Tenggara In Education Forest, Hasanudin University. Journal of Forests andSociety Vol. 6, No. 2. Hasanudin University. Macassar.

[11] Mansur, I., Ariani, D. 2013. Growth of Samama (Anthocephalus macrophyllus (Roxb.) Havil) seedlings planted with ground cover plants. Journal of Tropical Silviculture. Vol. 04 No. 03

[12] Mosse, S. 1981. Vesicular Arbuscular Mycoriza Research For Tropical Agriculture.

[13] Research Bulletin. Vol 88(2): 207-212.

[14] Sari, NI 2018. Responses of Two Types of Agarwood Seedlings Inoculated by Arbuscular Mycorrhizal Fungi in

Ex-Coal Mine Soil Media. Faculty of Agriculture. Andalas University. field. 67 pages
[15] Satria B and E. Raesi. 2021. Effect of POC Concentration on Robusta Coffee SeedGrowth. Independent Research. 28 p.
[16] Sucipto and Edi, 2007. The Relationship of Exposure to Dust Particles in Limestone Processing on Decreased Lung Function Capacity. [Thesis]. Semarang: Diponegoro University. 119 p.
[17] Sufaati S, Suharno, Bone I. 2011. Endomycorrhizae Associated with Non-Legume Agricultural Crops in Agricultural Land in the Transmigration Area, Jayapura City. Papuan Biology Journal. Vol. 3(1): 8 Pg.
[18] Trisilawati O, Towaha J, Daras U. 2012. The Effect of Mycorrhizae and NPK Fertilizer on Growth and Production of Young Cashew. RISTRI Bulletin. Vol. 3(1) : 263-273.
[19] Wahdi, E. 2016. Isolation and Characterization of Phosphate Solubilizing Bacteria from the Palimanan Coal Mining Area. [Thesis]. Bogor. Bogor Agricultural Institute. 42 p.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Towards Carbon Neutral Airport Operations Through the Use of Renewable Energy Sources: The Case of Chhatrapati Shivaji Maharaj and Indira Gandhi International Airports, India

Glenn Baxter

School of Tourism and Hospitality Management, Suan Dusit University, Huahin Prachaup Khiri Khan, Thailand, 77110.

Received: 05 Feb 2023; Received in revised form: 10 Mar 2023; Accepted: 18 Mar 2023; Available online: 27 Mar 2023

Abstract—*A very significant development in the global airport industry in recent times has been the introduction and use of green renewable energy systems, such as solar and wind powered hybrid systems. Airports are very energy intensive and have a significant carbon footprint. Thus, the use of renewable green energy is enabling airports to reduce their carbon footprint thereby mitigating their environmental impact. Using an in-depth instrumental case study research design, this study has examined the use of renewable green energy systems by Delhi's Indira Gandhi Airport and Mumbai's Chhatrapati Shivaji Maharaj International Airport. The case study revealed that Chhatrapati Shivaji Maharaj International Airport has entirely switched to green sources for its energy consumption needs, thereby making it one of India's 100 per cent sustainable airports. In April 2022, Mumbai Airport enhanced its usage of green energy when it deployed a 10Kwp Hybrid SolarMill consisting of 2Kwp TurboMill (three Savonious vertical axis type wind turbine (VAWT) and 8Kwp Solar PV modules. The new system has enabled Chhatrapati Shivaji Maharaj International Airport to reduce its carbon footprint as the new system will reduce its carbon dioxide (CO_2) emissions by 120,000 tonnes per year. In 2022, Delhi's Indira Gandhi Airport became the first airport in India to be powered entirely by hydro and solar energy sources. This energy-related measure is one of the airport's key actions to realize its 2030 objective of being a Net Zero Carbon Emission Airport. By moving to renewable sources for its energy requirements, the airport is expected to reduce its carbon footprint by around 200,000 tons of carbon dioxide (CO_2) emissions per annum. The use of green energy sources has helped the airports to mitigate the harmful environmental impact from the use of fossil-based fuels.*

Keywords— ***Airports, Airport photovoltaic (PV) systems, Airport hybrid renewable energy systems, Carbon footprint mitigation, Sustainable airport energy management.***

I. INTRODUCTION

Airports play a vital role in the global air transport industry. The increase in both passenger and air cargo traffic has led to an increase of energy requirements. In response to the growing energy consumption, airports have introduced a wide range of energy saving procedures (O'Meara et al., 2020), as part of their sustainability policies and strategies. Indeed, sustainability is gaining more importance in the air transportation industry (Koç & Durmaz, 2015). Airports have been considering their impact upon the environment and as a result many airports have sought to green their operations, with the goal of becoming a green airport (Korba et al., 2022). A "green airport" is an airport which has a minimal impact on the environment and is one that endeavors to become a carbon neutral facility in terms of carbon emissions, with the aim to ultimately produce zero greenhouse gas emissions (González-Ruiz et al., 2017). The concept underlying a

"green airport" is for the airport to create a centre of sustainable practices (Sumathi et al., 2018). Furthermore, many airports have increased their focus on energy efficiency as part of their efforts to reduce their impact on the environment (Preston, 2015). The increased focus by airports on their energy efficiency is because airports are extremely energy intensive (Bujok et al., 2023; de Rubeis et al., 2016; Ortega Alba & Manana, 2017). Airports are sites that have high and intense energy consumption (Akyuz et al., 2019). The improvement in energy efficiency and environmental performance of buildings is increasingly viewed as being one of the major priorities for airports all around the world (Fesanghary et al., 2012). In recent years, there has been a growing interest in targeting energy efficiency as a roadmap for carbon mitigation strategies and measures, limiting energy use, improving buildings' energy performance, and reducing energy consumption for achieving sustainable buildings (Hafez et al., 2023). One of the most significant trends in the global airport industry in recent times has been the introduction and use of green renewable technologies. Many airports around the world have now installed photovoltaic (PV) solar systems as a key environmental measure (Baxter, 2022b; Smagulov et al., 2021; Wybo, 2013).

The Indian air transport industry is among the top ten in the world in terms of its size (Choudhuri et al., 2015). In recent times, India has emerged as the ninth largest aviation market globally, with the country now having more than 120 operational airports. India now has 34 international airports in operation (Thummala & Hiremath, 2022). India's aviation industry has evolved since the first flight in 1911. Prior to 1953, there were nine airlines, including Air India, and Indian Airlines, serving the market. An important development occurred in 1953, when the airlines were nationalized and merged into Indian Airlines. In 1986, private companies were permitted to operate as air taxis (Choudhuri et al., 2015). In August 2003, Air Deccan commenced operations as India first low-cost carrier (LCC) (Shukla, 2013). In 2005, GoAir, Indigo, Kingfisher, Paramount, and SpiceJet launched their operations (Zhang & Zhang, 2017). The industry witnessed some consolidation in 2007 when Jet Airways acquired Sahara, Kingfisher acquired Air Deccan, and Air India acquired Indian Airlines (Choudhuri et al., 2015; Zhang & Zhang, 2017). In 2006, the Indian Government approved the restructuring of Mumbai and Delhi Airports through public-private partnerships (Zhang & Zhang, 2017).

An important development in India's airport industry in recent times has been the increasing use of renewable and green energy. Nowadays, airports' interest in solar photovoltaics (PVs) is growing and many Indian based airports now use photovoltaic (PV) solar systems as one of their key energy sources. These systems provide a way to lower the burden of energy costs and to show environmental stewardship by airports (Sreenath et al., 2020a). The solar photovoltaic cells have received special attention during recent times due to their rapid renewability consideration, particularly in international airports because of airport sustainability goals and the high cost of fossil fuel (Sher et al., 2021). Furthermore, solar energy is viewed as being one of the most suitable renewable energy options in India (Kalita et al., 2019).

The objective of this study is to examine the green renewable technologies implemented by Mumbai International Airport (Chhatrapati Shivaji Maharaj Airport) and Delhi International Airport (Indira Gandhi International Airport). A secondary objective is to examine the environmental-related benefits that the airports will achieve from the implementation of the green renewable technologies. A third objective is to examine the impact that these new renewable technologies will have on the airport's footprint and their goal to become carbon neutral airports. Airports consume energy, and hence, their carbon footprint should be considered (Bahadir, 2022). Chhatrapati Shivaji Maharaj Airport has entirely switched to green sources for its energy consumption needs, thereby making it one of India's 100 per cent sustainable airports (International Airport Review, 2022; Loreng, 2022). In 2022, Delhi's Indira Gandhi Airport became the first airport in India to be powered entirely by hydro and solar energy sources (Airports Council International, 2022a). Importantly, both airports are committed to reducing their carbon dioxide (CO_2) emissions and maintaining their Airport Carbon Accreditation (ACA) carbon neutral certification.

The remainder of the paper is organized as follows: the literature review is presented in Section 2 and this establishes the context for the in-depth case study. The research method used in the study is described in Section 3. The case study is presented in Section 4. The key findings of the study are presented in Section 5.

II. BACKGROUND

2.1. Energy Usage at Airports

Airports and their key stakeholders require power to operate their equipment, systems, heating, ventilation, and air conditioning (HVAC) systems, as well as for the lighting of their buildings. In addition, airports require power for their airfield infrastructure, for example, runway and taxiway lighting. Airport energy usage also includes the fuel necessary to power ground support equipment (GSE) (Nam, 2019). The primary areas of energy consumption at an airport are heating, cooling, lighting,

and the energy required for operating the airport's facilities and systems (Janić, 2011; Radomska et al., 2018). Electrical energy is also used at airports for powering the aids that are used to facilitate air transport operations, and for airport buildings, aircraft hangers and other airport facilities (Kazda et al., 2015). At many airports, crude oil is often used for producing the fuel used to power the ground service equipment (GSE) and vehicles that are used in an airport's airside and landside areas, especially in the aircraft ground handling process (Janić, 2011). Fuel is also used for airport's heating boiler systems and emergency generators (Ortega Alba & Manana, 2016). The airport terminal's heating, ventilation, and air conditioning (HVAC) systems use the largest amount of energy (Akyüz et al., 2017). Fuel is also used for airport's heating boiler systems and emergency generators (Ortega Alba & Manana, 2016). Airports consume large quantities of electricity (Sreejaya et al., 2020). Typically, airport terminal buildings consume more energy than other buildings that are located within the airport precinct due to the terminal building's functional and operational characteristics (Yildiz et al., 2022). The airport terminal's heating, ventilation, and air conditioning (HVAC) systems use the largest amount of energy. It has been estimated that around 70% of the energy consumed in airport terminal buildings is used for heating, cooling, and air conditioning purposes. This energy consumption rate is higher in those countries that have a cold climate (Akyüz et al., 2017). Indeed, airport terminals have a high level of energy consumption for space heating in cold climate zones (Liu et al., 2021). Airport terminal buildings also have a high energy demand due to their cooling demand. This is especially so in hot arid climates, where airports cool their terminal buildings to achieve passenger thermal comfort (Abdallah et al., 2021).

The operation of more efficient heating and cooling systems and the performance of the building envelope can result in significant reductions in energy consumption. This can be achieved without compromising comfort conditions in the airport terminal buildings (Akyüz et al., 2018). To ensure that energy demand can be met when the needs arise, airports are increasingly focusing on energy-conservation measures in the design (and operations) of terminal buildings and infrastructure (Thomas & Hooper, 2013).

2.2. The Factors that Influence an Airport's Energy Consumption

An airport's energy consumption is influenced by a range of factors, which include:

- The airport's size.
- The airport's architecture (compact, finger passenger terminals, satellite passenger terminals, and remote satellite passenger terminals).
- Location and climate.
- Airport operational hours.
- Insulation level of terminal(s) building(s),
- Heating, ventilation, air conditioning (HVAC) system.
- Airport energy actors' energy usage behavior.
- Energy management.
- Level of airport maintenance.
- Capacity of aircraft maintenance facilities.
- Daylight utilization.
- Solar heating.
- Traffic density.
- Number of passengers handled at the airport.
- Smooth operations of electrical and mechanical systems (Akyuz et al., 2019, p. 28).

2.3. Airports Growing Use of Solar Photovoltaic (PV) Systems

Consumption of fossil fuel generated electrical energy can be reduced substantially through the application of renewable energy systems in transportation-related facilities such as airports (Choudhary et al., 2021). The integration of solar energy systems is now viewed as being crucial to achieving the global goals for sustainability as well as the reduction of greenhouse gases and pollutants emissions, which have an adverse impact upon the environment (Lykas et al., 2022). Renewable energy has become an increasingly cost-effective commerce preference for airports due to technological advancement, market ripeness, together with the public-sector investment (Emeara et al., 2021). Photovoltaic power (PV) has now become the fastest-growing source of renewable electricity. Renewable electricity sources are anticipated to play a crucial role in the transition towards a net-zero emission energy system (Bosmans et al., 2022). A key environmental-related trend in the global airport industry in recent times has been the use of renewable energy sources, such as, photovoltaic (PV) solar systems, by airports (Figure 1). The use of renewable energy resources has provided airports with several favorable environmental related advantages. Green energy produces no greenhouse gas emissions from the combustion of fossil fuels. As a result, this reduces some forms of harmful air pollution (United States Environmental Protection Agency, 2022). Furthermore, renewable energy systems provide the airport

with an alternative clean source of power (Kramer, 2010). An airport normally occupies a large area, has no obstructions and so there is potential for development of solar energy within its precinct (Hermawan, 2017). Solar energy and wind energy can be combined to form Solar-Wind Hybrid Power System (SWHPS), which will enhance the qualities and environmental benefits of each other (Vasant & Pawar, 2017).

Fig.1: Photovoltaic PV Solar System at Denver International Airport

Photograph Provided Courtesy of Denver International Airport

3.1. A Brief Overview of Photovoltaic (PV) Solar Systems and the Key Issues for Airports

Nowadays, there has been an increased interest by airports in solar photovoltaics (PVs) systems (Sreenath et al., 2020a). An airport's carbon footprint can be reduced through the substitution of the conventional source of energy with solar PV based power generation (Sukumaran & Sudhakar, 2017a). This is because the atmospheric pollution from airport operations can be decreased through the consumption of renewable energy (RE)-based electricity generation (Sreenath et al., 2019). Passenger terminal buildings and car parking lots are ideal locations for photovoltaic (PV) installation. The future trend towards the electrification of the aviation and automobile industries will increase the electricity demand at airports and this could potentially involve the integration of photovoltaic (PV) systems with airport infrastructure (Jiang et al., 2021). Considering this concern as to the adverse impact of their carbon footprint on the environment, many airports around the world have installed photovoltaic solar (PV) systems (Baxter, 2021; Sreenath et al., 2020b, 2021a, 2021b; Sukumaran & Sudhakar, 2017b). The solar photovoltaic (PV) systems being installed at airports are normally customized so that they optimize the use of the selected site (Baxter et al., 2019).

Solar photovoltaic (PV) systems are customized depending upon the requirements of the site. There are different environmental factors at each site. These factors will influence the type of system required and its level of performance. PV systems include the following components:

- The solar resource – the sun is the power source for all PV systems.
- Photovoltaic cells – when treated with chemical impurities (this process is referred to as doping), these thin sections of semi-conductor material react to sunlight, creating voltage and current.
- Panel or module.
- Array – an array is comprised of multiple panels wired together in series and in parallel to provide specified voltages and current (The array is typically fastened to a mounting structure).
- Battery – a battery can be defined as a direct current (DC) electrical energy storage device.
- Inverter – the DC-AC inverter converts direct current (DC) power into alternating power (AC).
- Charge controller – a charge controller regulates, charges, and maintains battery voltage.
- Electrical load – this includes the appliances and other devices that use the energy generated by the PV system.
- Wiring – the PV system wiring includes the wires that are known as conductors that connect the system components to complete circuits; and
- Surge protector – this is a device that safeguards against electrical shock from short circuits and damaging power fluctuations (Balfour et al., 2013, pp. 4-5).

Solar systems can be installed either fixed or adjustable to increase the amount of solar energy (Emeara et al., 2021). Importantly, there are different environmental factors that will be applicable for each site. Consequently, these factors will influence the type of photovoltaic (PV) system that is required, and they will also impact its level of performance. Photovoltaic (PV) systems are comprised of the solar resource, photovoltaic cells, panel or module, array, battery, inverter, charge controller, electrical load – this includes the appliances and other devices that use the energy generated by the PV system, wiring and the surge protector – this is a device that safeguards against electrical shock from short circuits and damaging power fluctuations. The photovoltaic (PV) system wiring includes the wires that are known as conductors that connect the system components to complete circuits (Balfour et al.,

2013). Quite often photovoltaic solar systems are collective in nature, that is, they are centralized systems that provide electricity to a group of users. These users include commercial customers (Bhattacharyya, 2015).

However, there are several key issues that airport's need to be cognizant of when considering the installation and use of a photovoltaic (PV) solar system (Baxter et al., 2019). Solar photovoltaic (PV) systems are required to be installed at a sufficient distance from the airport's runway(s) and these systems should adhere to all relevant safety and fire measures applicable at the airport (Kandt & Romero, 2014). If inappropriately located at the airport, then there is a risk that the solar photovoltaic (PV) systems at airports can impact pilots, air-traffic controllers, aircraft, and air navigation systems due to the glare reflection (Mostafa et al., 2016). The solar system could cause either glint or glare, or possibly a combination both. This could potentially result in a brief loss vision, which would be an important safety concern for aircraft pilots (Anurag et al., 2017). Consequently, glare due to the reflection of sunlight from the metal parts of a solar PV panel could potentially provide a risk that may result in an adverse impact on aviation safety (Mostafa et al., 2016). There are several measures that an airport can use to mitigate the glare from their solar system. The first measure involves the application of anti-reflective coatings (Solanki & Singh, 2017). The second measure involves the surface texturing of the systems panels (Ahmed et al., 2017). Neither of these measures should have a noticeable impact on the solar PV system performance but will greatly assist in minimizing reflection from the PV system (Kandt & Romero, 2014).

The performance of a photovoltaic (PV) solar system is highly dependent on the amount of solar penetration to the solar cell, the type of climatic season, the temperature of the surroundings, and the environmental humidity present at its location (Mohamad Radzi et al., 2023). The amount of power that can be produced by these systems is dependent upon the type of photovoltaic (PV) solar system used at the airport, the PV system's orientation, and the available solar resource (Kandt & Romero, 2014). Many airports quite frequently have large tracts of open space that could be potentially used for the installation and operation of a solar photovoltaic (PV) system (Baek et al., 2016; Curran, 2016). Consequently, many airports who meet the spare land use requirement are now installing or plan to install large surfaces of PV panels (Wybo, 2013).

2.3.2. The Environmental Related Benefits of Photovoltaic (PV) Solar Systems for Airports

Solar power is a clean and abundant energy source, and it is an environmentally friendly energy solution (Moukhtar et al., 2021). Solar power photovoltaic (PV) systems lower the airport's ground emissions (Sukumaran & Sudhakar, 2017b). The airport's carbon footprint (carbon dioxide CO_2 emissions) can also be reduced by substituting solar PV based power generation for traditional, more heavily polluting, fossil-fuel based energy sources (Sukumaran & Sudhakar, 2017a; Wybo, 2013). In addition, the use of green or renewable energy sources provides the user with an important opportunity to optimize energy efficiency (Arman & Yuksel, 2013). Another advantage is that renewable energy sources normally have very little waste (Yerel Kandemir & Yayli, 2016). Other advantages of solar power are that they do not emit any greenhouse gases, such as carbon dioxide (CO_2) into the atmosphere, there are no releases of toxic gases, such as sulphur dioxide (SO_2), photo-voltaic (PV) solar systems can make use of barren land, the systems allow for individual installation and use, and they can decrease transmission line costs in existing electricity grids. The disadvantages of solar power are the electrical energy produced by the system may be intermittent and unstable (Aktaş & Kirçiçek, 2021; Alotto et al., 2014; Muhammed & Baladraf, 2021), the generation of electrical energy is reliant on natural events, large powerful photovoltaic solar systems require large tracts of land for their installation, and the surfaces of the solar panels must be cleaned periodically in order not to reduce system efficiency (Aktaş & Kirçiçek, 2021). Thus, solar is an uncertain energy sources, since it varies throughout the day, season, and geographic location (Correia & Ferreira, 2021).

2.4. An Overview of the Environmental Benefits of Hydropower

Hydropower has important environmental benefits. Hydropower is a clean, renewable, and environmentally friendly source of energy (Berga, 2016; Tong, 2019; Wagner & Mathur, 2011). As hydropower is a renewable source of energy, the energy produced through hydropower relies on the water cycle, which is driven by the sun, making it a renewable energy source. Hydropower is fueled by water, and this therefore makes it a clean source of energy. Hydropower provides low-cost electricity and durability over time when compared to other sources of energy. Importantly, hydropower complements other renewable energy sources (Office of Energy Efficiency and Renewable Energy, 2022). Hydropower does not pollute the air, thereby providing a reduction in carbon dioxide (CO_2) emissions (McKinney et al., 2007; Wagner & Mathur, 2011; Walsh et al., 2020) unlike power plants that burn fossil fuels, such as, coal or natural gas (Spellman, 2022; Tong, 2019). Furthermore, hydro power does not produce any toxic, hazardous, or radioactive waste (McKinney et al., 2007). Hydropower

does have some disadvantages: large land disturbance and the potential relocation of people, high methane (CH_4) emissions from rapid biomass decay in shallow tropical waters, and the disruptions to downstream eco-systems (Tyler Miller & Spoolman, 2012). Hydropower may also affect marine life (Majumdar, 2016), as fish populations can be impacted if they are unable to swim upstream to spawning grounds or to the ocean (Spellman, 2022).

2.5. Hybrid Renewable Energy Systems (HRES)

The renewable energy sources such as solar energy and wind energy are complementary in nature. The use of these natural resources to produce power reduces the power demand on the conventional power generation sector (Kumar et al., 2015). The sun and wind-based generation are increasingly being considered alternate source of green power generation which can be used to mitigate power demand issues (Saidi & Chellali, 2017). Accordingly, Hybrid Renewable Energy Systems (HRES) are becoming popular as stand-alone power systems for providing electricity (Kumar & Garg, 2013; Shirsath et al., 2016). Indeed, amongst the various renewable energy sources, photovoltaic (PV) and wind turbines (WT) have become very attractive due to the abundant local availability in nature, technological progress, and economic benefits provided from such a system (Malik et al., 2020). A hybrid energy system, or hybrid power, normally consists of two or more renewable energy sources which are used in tandem to provide increased system efficiency as well as a greater balance in energy supply (Shirsath et al., 2016). The hybrid combination of both distributed energy resources eliminates mutual intermittences due to their adverse nature; therefore, the reliability of the system will be improved. The basic key objective of these hybrid systems is to generate electrical energy by using renewable and clean energy with minimum pollution (Malik et al., 2020). A typical wind-PV hybrid system is comprised of a small wind turbine, a photovoltaic (PV) generator and an appropriate storage system together with the corresponding electronic equipment (Godson et al., 2013; Kosmas & Panagiotis, 2022).

A wind-solar hybrid system is a reliable alternative energy source because it utilizes solar energy combined with wind energy to create a stand-alone energy source that is both dependable and consistent. Solar power or wind power alone can fluctuate, however, when they are used together, they can provide a reliable source of energy. Thus, an ideal solution is to combine these two forms of energy sources to create a constant energy flow (Dalwadi et al., 2011).

III. RESEARCH METHODOLOGY

3.1 Research Method

This study used a qualitative instrumental case study research approach (Janis, 2022; Miller, 2022; van Vreden, 2022). An instrumental case study is the study of a case. An instrumental case study can study a firm(s). This research approach provides insights into a specific issue, enables researchers to redraw generalizations, or builds theory (Stake, 1995, 2005), whilst also facilitating the understanding of a specific phenomenon. An instrumental case study is designed around established theory (Grandy, 2010). The present study was designed around the established theory of airport energy management (Akyuz et al., 2019; Thomas & Hooper, 2013), green energy (Aswathanarayana, 2010; Bhowmik et al., 2017; Kalyani et al., 2015), the use of solar power by airports (Baxter et al., 2019; Sreenath et al., 2020b, 2021a, 2021b; Sukumaran & Sudhakar, 2017a), and wind power (Gipe, 2004; Maegaard et al., 2013; Manwell et al., 2009).

3.2 Data Collection

Data for the study was obtained from a variety of documents, airport industry-related journals, annual reports, press releases, company materials available on the internet and records as sources of case evidence. Documents included Delhi International Airport (Indira Gandhi Airport) and Mumbai International Airport (Chhatrapati Shivaji Maharaj International Airport) environmental policies, industry publications, and the airport's websites. Thus, this study used secondary data. The study followed data collection guidance of Yin (2018), that is, multiple sources of case evidence were used, a database on the subject was created, and there was of a chain of case evidence.

3.3 Data Analysis

Document analysis was used to analyze the documents gathered for the study. Document analysis focuses on the information and data from formal documents and company records that are gathered by the researcher(s) when conducting their case study (Andrew et al., 2011; Oates, 2006; Yin, 2018). The documents gathered for the study were assessed for their authenticity, credibility, representativeness and meaning (Scott, 2014; Scott & Marshall, 2009).

In this study, significant information was extracted from the secondary data collected using thematic analysis (Braun & Clarke, 2022; Guest et al., 2012; Terry et al., 2017). The thematic analysis was performed five discrete stages. First, the collected data was arranged according to its relevance to the study. In the second stage, the organized data was coded and recoded and was

subsequently classified into meaningful groups. In the third stage, the most relevant themes were searched and extracted from the classified data. In the fourth stage, the themes that had been produced were checked to ensure that they appropriately represented the meanings found in the data set as a whole. In the fifth and final stage, the themes were defined, named, and presented in the case study (Ojogiwa, 2021).

All the documents collected for the study were stored in a case study database (Yin, 2018). All the study's documents were in English. Each document was carefully read, and key themes were recorded in the case study (Baxter, 2022a).

IV. RESULTS

4.1. Chhatrapati Shivaji Maharaj International Airport

4.1.1. An Overview of Chhatrapati Shivaji Maharaj International Airport

Mumbai International Airport was privatized in 2006. At that time India's Ministry of Aviation contracted the management and operation of the airport to GVK, a private firm. As part of the agreement between the two parties, the land that belonged to the Airport Authority of India was leased out for thirty years (Ren, 2017). In November 2019, the Competition Commission of India granted its approval for Adani Properties Private Limited to acquire a shareholding in Mumbai International Airport Limited (Kumari & Aithal, 2020). Mumbai International Airport Limited (MIAL) is managed by Adani Airport Holdings Limited (AAHL), which is a subsidiary of Adani Enterprises. MIAL is a Public-Private Partnership (PPP) venture between AAHL, who holds a majority shareholding of 74%, and the Airports Authority of India, holding the remaining 26% of the company's shares (Chhatrapati Shivaji Maharaj International Airport, 2021). The initial Public Private Partnership agreement was for a term of 30 years, which took effect from May 3, 2006, and the agreement is extendable by a further 30 years subject to the terms of "Operations Management and Development of Agreements" (OMDA) signed between the Airports Authority of India (AAI) and Mumbai International Airport (MIAL). Mumbai's Chhatrapati Shivaji Maharaj International Airport is India's second busiest airport (Dan et al., 2017; Jaffe, 2015, Gaonkar 2013). The airport can handle around 50 to 52 million passengers per annum (Sharma, 2022).

The airport has three passenger terminals: Terminal 1 is used for domestic flights, Terminal 2 is used for both domestic and international flights, and the General Aviation terminal, which is used for private and non-scheduled flight operators. Mumbai airport is equipped with two crossing runways which are designated 09/27 and 14/32. Runway 14/32, (2,925m, 9,596ft) is the runway that runs between Terminals 1 and 2. The main runway 09/27 (3,445m, 11,302ft) intersects runway 14/32 just south of the terminal buildings (Airport Technology, 2020).

Chhatrapati Shivaji Maharaj International Airport is an ISO 50001:2018 (Energy Management System) and ISO 14001:2015 (Environmental Management System) certified company (Loreng, 2022). ISO 14001 is a worldwide meta-standard for implementing Environmental Management Systems (EMS) (Dentch, 2016; Grover & Grover, 2017; Heras-Saizarbitoria et al., 2011). Introduced in June 2011, the ISO 50001 International Standard was developed to provide a unified framework for energy management efficiency (Dzene et al., 2015; Gopalakrishnan et al., 2014; Yuriev & Boiral, 2018). The ISO 50001 Energy Management System standard also provides a basis for energy management improvement by a firm (Jovanović & Filipović, 2016).

The airport has been accredited at the Airports Council International Airport Carbon Accreditation (ACA) Level 4+, which signifies that it is a carbon neutral airport (Naik, 2022). Through the implementation of a certified ISO 50001 Energy Management System, the airport has developed a policy for the efficient use of energy, set goals and targets for the forthcoming years and adopted a robust mechanism to review its progress (Chhatrapati Shivaji Maharaj International Airport, 2020).

4.1.2. Chhatrapati Shivaji Maharaj International Airport Environmental Policy

Mumbai International Airport (Chhatrapati Shivaji Maharaj International Airport) defined and implemented a very comprehensive environmental policy in 2022. In accordance with the policy, Mumbai International Airport, while developing, maintaining, managing, and operating the airport, the airport is committed to achieving excellence and sustainability in the quality of its facilities and services, and the company manages the impact of its business on the environment (Chhatrapati Shivaji Maharaj International Airport, 2022).

Mumbai International Airport aims to continually improve is environmental performance by:

- Ensuring compliance with applicable legal and other requirements, including civil aviation safety legislation and standards.
- Provision and optimal use of resources whilst promoting re-use, recycling, and re-purposing.
- Protection of the environment by pollution prevention and waste minimization.

- Nurturing sustainability initiatives and development, including effective climate change and greenhouse gas (GHG) management (Chhatrapati Shivaji Maharaj International Airport, 2022).

Chhatrapati Shivaji Maharaj International Airport has historically placed a high focus on carbon neutrality, energy savings, emissions reduction, and climate action since its inception. The airport employs a holistic approach towards its sustainable operations and has carried out various initiatives under environment management. These include airport carbon management system, airport carbon neutrality, sustainability reporting, renewable energy installations, wastewater recycling, effective waste management system, and organic waste treatment, amongst others. Furthermore, the airport closely monitors its noise management, air quality monitoring, waste management and climate change, which helps minimize its environmental impact (Airports Council International, 2022c).

Chhatrapati Shivaji Maharaj International Airport's green policies focus on continuous energy reduction through the adoption of energy efficient products, operational efficiency, and the application of innovative technology to address the challenges associated with climate change (Airports Council International, 2022c).

A share of the airport's purchased electricity is used by concessionaires, government authorities and other stakeholders, which have operations at the airport. Hence, the electricity purchased by the airport also includes electricity is also consumed by other key stakeholders (Chhatrapati Shivaji Maharaj International Airport, 2020).

4.1.3. Chhatrapati Shivaji Maharaj International Airport Energy Sources

To sustain its operations and airport infrastructure, Chhatrapati Shivaji Maharaj International Airport uses a mix of energy sources. These energy sources are compressed natural gas, diesel, electricity, petrol, and solar energy (Chhatrapati Shivaji Maharaj International Airport, 2020)

4.1.4. Chhatrapati Shivaji Maharaj International Airport Hybrid Solar Mill System

As previously noted, Mumbai International Airport has shifted totally towards the use of green energy for its consumption needs. Out of the total 100 per cent, the airport procures around 95 per cent from green sources, such as, hydro and wind energy (International Airport Review, 2022; Loreng, 2022). Mumbai International Airport achieved 100% use of green energy sources in August 2022. The airport is committed to continuous reduction in energy consumption, and hence, a reduction in its carbon footprint. Mumbai Airport has installed a 1.06MW rooftop solar power plant, which can be increased to 4.66MW (International Airport Review, 2022).

Figure 1 presents Chhatrapati Shivaji Maharaj International Airport annual solar power generation and the year-on-year change for the period covering the 2016-2017 to 2019-2020 financial years. Figure 1 shows that there has been an upward trend in the airport's annual solar power generation during this period. Figure 1 shows that there was a very pronounced spike in this metric in the 2017-2018 financial year, at which time it increased by 110.91% on the 2016-2017 levels. This large increase was followed by two further significant annual increases in the airport's solar power generation, when it increased by 22.36% in the 2018-2019 financial year and by 27.80% in the 2019-2020 financial year (Figure 1) This upward trend is very favorable and highlights the importance of renewable energy usage by the airport operator.

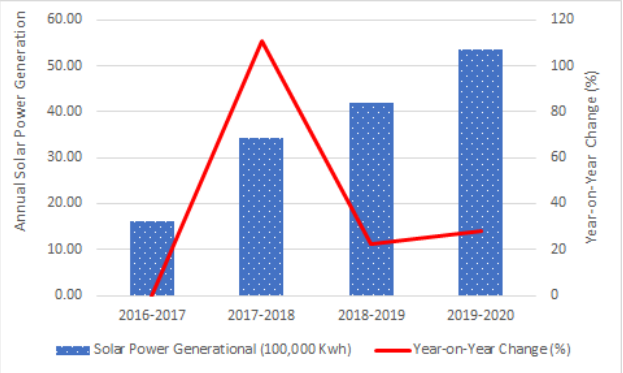


Fig.1: Chhatrapati Shivaji Maharaj International Airport Annual Solar Power Generation and Year-on-Year Change: 2016-2017 to 2019-2020 Financial Years

Source: Data derived from Chhatrapati Shivaji Maharaj International Airport (2020).

In April 2022, Mumbai Airport enhanced its usage of green energy when it deployed a 10Kwp Hybrid SolarMill consisting of 2Kwp TurboMill (three Savonious vertical axis type wind turbine (VAWT) and 8Kwp Solar PV modules, with an estimated minimum energy generation of 36 kWh/day. This first-of-its-kind, fully integrated, hybrid renewable energy product, harnesses both solar and wind energy that are combined to generate electricity at the airport (International Airport Review, 2022; Loreng, 2022). Importantly, wind energy (WE) is increasingly emerging as a green and clean energy source (Chawda et al., 2023). In addition, the development of modern photovoltaic thermal systems (PV/T) is regarded as being one of the most important steps in the application of using

solar energy to produce both electricity and heat (Chaichan et al., 2022).

4.1.5. The Environmental Benefits of Chhatrapati Shivaji Maharaj International Airport Hybrid Solar Mill System

The new green energy powered system will enable Chhatrapati Shivaji Maharaj International Airport to reduce its carbon footprint as the new system will reduce its annual carbon dioxide (CO_2) emissions by 120,000 tonnes (The Economic Times, 2022). The reduction in carbon dioxide emissions (CO_2) is contributing to the airport's goal of Net Zero emissions by 2029. As noted earlier, a very important benefit of the use of photovoltaic (PV) solar systems by airports is that these systems lower the airport's ground emissions, and hence, the airport's carbon footprint (Sukumaran & Sudhakar, 2017a; Wybo, 2013). Reducing the use of fossil fuels considerably reduces the amount of carbon dioxide (CO_2) produced, as well as reducing the levels of the pollutants released into the atmosphere (Demirbaş, 2006). This is especially important for airports because the global aviation industry generates a substantial carbon footprint which is predicted to increase in the future (Filimonau et al., 2018). The aviation industry has set a goal of net zero emissions by 2050 (Amankwah-Amoah et al., 2023; Bergero et al., 2023; Serafimova & Finger, 2022). Airports can play a key role in achieving this goal by deploying and using green energy.

A further environmental-related benefit of the renewable energy system is that reduces the negative effects of fossil fuel-based energy (Midilli et al., 2006). Indeed, the transition towards more renewable sources reduces a firm's dependence on fossil fuels (Mutezo & Mulopo, 2021; Omer, 2008). Fossil fuels produce harmful emissions that negatively impact the environment (Ağbulut & Sarıdemir, 2021).

In addition, the use of green or renewable energy sources provides the user with an important opportunity to optimize energy efficiency (Arman & Yuksel, 2013). Indeed, this is a very important advantage of Chhatrapati Shivaji Maharaj International Airport new renewable green technology system as the new system is very energy efficient.

4.2. An Overview of Indira Gandhi Airport

4.2.1. An Overview of Indira Gandhi Airport

Indira Gandhi Airport is located 16 kilometres from the centre of Delhi. The airport has three passenger terminals and three runways. Runway 11-29 has a length of 4,430 metres, whilst the airport's Runway 10-28 has a length of 3,810 metres. The airport's third runway, Runway 09-27, is 2,813 metres in length. Terminal 3 is an integrated terminal, and thus, it handles both domestic and international passenger traffic (Delhi Indira Gandhi Airport, 2022). Delhi's Indira Gandhi Airport handled 37,139, 957 passengers in 2021, making it the world's 13th busiest passenger airport in 2021(Airports Council International, 2022b). Indira Gandhi Airport is now amongst the twenty busiest airports in the world (Ganguly, 2019). The airport is India's busiest airport (Agarwal et al., 2018; Zhou et al., 2019).

On January 31, 2006, a consortium that was led by GMR Infrastructure, and including Germany headquartered Fraport AG, and others, won the contract to modernize Delhi Airport (Pratap & Chakrabarti, 2017). Following the privatization of the airport in 2006, Delhi International Airport Private Ltd. (DIAL) was formed with the key objectives of operating, maintaining, developing, designing, constructing, upgrading, modernizing, financing, and managing the Indira Gandhi International Airport (Chaudhuri & Chaudhuri, 2017).

Delhi's Indira Gandhi Airport has placed a very high focus on sustainability and, as a result, the airport has implemented various initiatives such as renewable energy development and usage, energy efficiency, green building, programs with airlines, operational efficiency measures, green transportation, tree plantation, and management of greenhouse gases (GHG) in accordance with the Airport Council International's (ACI) Airport Carbon Accreditation program (Delhi Airport, 2022; Gandhiok, 2022). In 2020, Delhi Airport became the first airport within the Asia-Pacific region to achieve "Level 4+" under ACI's Airport Carbon Accreditation program (Delhi Airport, 2022). This indicates that besides being a carbon-neutral airport, Delhi International Airport has adopted long-term absolute emission reduction goals in line with the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) 1.5-degree scenario (Airports Council International, 2022a).

4.2.2. Indira Gandhi Airport Environmental Policy

Delhi International Airport has defined and implemented a comprehensive environmental policy. Delhi International Airport is committed to conducting its business in an environmentally friendly manner and the airport aims to minimize the impact of its activities on both the environment and the community. As part of this policy, environmental management is an integral part of the airport's business strategy that is designed to ensure that the airport achieves credibility and business sustainability. Delhi International Airport Private Ltd (DIAL) is committed to the protection of the environment, and the mitigation of climate change. The airport also ensures the

sustainable usage of resources at Indira Gandhi Airport (Delhi International Airport Limited, 2020).

Delhi International Airport Private Ltd (DIAL) being a responsible organization strives to fulfill its environmental obligations and commitments by:

- Fulfilling all applicable environmental compliance obligations.
- Establishing and maintaining a management system to fulfil its commitments as well as safeguarding the interests of all interested parties.
- The airport comprehensively assesses and manages all environmental risks and opportunities associated with its development and operational activities.
- The airport sets, monitors, and reviews its environmental objectives and targets to ensure continual improvement of its Environmental Management System to enhance its environmental performance.
- The airport develops and reviews environmental objectives and targets so it can ensure continual improvement of its Environmental Management System, and thereby, enhance its environmental performance.
- The airport develops adequate competency in its employees and other relevant stakeholders to manage environmental risks and opportunities associated with their activities.
- The airport establishes an integrated approach toward its long-term absolute greenhouse gas (GHG) emission reduction targets and the sustainable management of natural resources.
- The airport promotes the "green" supply chain to the maximum degree and considers all stakeholder expectations.
- The airport promotes the use of the "green building" concepts in all of Indira Gandhi International Airport infrastructure (Delhi International Airport Limited, 2020).

Indira Gandhi International Airport has an ISO 14001: 2015 certified Environmental Management System and an ISO 50001: 2018 certified Energy Management System (GMR Infra, 2021).

4.2.3. Indira Gandhi Airport Energy Sources

Indira Gandhi Airport direct energy sources are diesel, and petrol. Grid electricity is Indira Gandhi Airport's primary indirect energy source. The airport has an onsite solar energy plant, and the airport also uses open access renewable energy. In India, the open access is a mechanism under which consumers can purchase electricity directly from power producers, rather than through electricity distribution companies (Gupta, 2022). In India, commercial and industrial consumers can procure Open Access power from three kinds of renewable energy plants – third-party owned, wholly owned (captive) or owned by a group of consumers (group captive) (Garg et al., 2022). More than 90% of the gross electricity consumed by Delhi Airport was sourced from renewable energy sources in the 2020-21 financial year (GMR Infra, 2021).

4.2.4. Indira Gandhi Airport Hydro and Solar Energy System

In 2022, Delhi's Indira Gandhi Airport became the first airport in India to be powered entirely by hydro and solar energy sources. This energy-related measure is one of the airport's key actions that it has taken to move closer to realising its 2030 objective of being a Net Zero Carbon Emission Airport (Airports Council International, 2022a; Delhi Airport, 2022).

At the time of the present study, the airport was sourcing around 6% of its electricity requirement from onsite solar power plants and the remaining 94% from hydropower plants (Delhi Airport, 2022; Joshi, 2022). For its hydropower, the airport has signed a long-term power purchase agreement (PPA) with Himachal Pradesh-based hydropower producing company to supply hydroelectricity for the airport until 2036 (Joshi, 2022).

Delhi's Indira Gandhi Airport has used solar power for quite some time and following the introduction of the new system it is now fulfilling its major electricity requirements from a hydropower plant (Gandhiok, 2022).

The airport has also installed a 7.84 MW solar power plant on the airside, and, as part of stakeholder collaboration, operators of the air cargo terminals at the airport have added a further 5.3 MW rooftop solar power plant (Airports Council International, 2022a; Joshi, 2022).

4.2.5. The Environmental Benefits of Indira Gandhi Airport Hydro and Solar Energy System

As previously noted, Indira Gandhi Airport has moved to green energy, and since June 1, 2022, now only uses only hydro and solar power for all its energy requirements. This initiative is a key part of the airport's goal of becoming a Net Zero Carbon Emission Airport by 2030 (Airports Council International, 2022a). The airport's operator, Delhi International Airport Limited (DIAL), has estimated that by moving to renewable sources for its energy requirements the airport is expected to indirectly reduce 200,000 tons of carbon dioxide (CO_2) emissions every year

(Delhi Airport, 2022; Gandhiok, 2022; Joshi, 2022). Consequently, the airport has been able to reduce its carbon footprint from the use of its new renewable green energy system. In addition, the airport has also been able to increase its energy efficiency, which is a very favorable outcome. A further important environmental-related benefit is that the airport has been able to reduce its use of energy that may have been produced from fossil-based fuels. This alleviates harmful emissions produced from the consumption of fossil fuels that may have been used in the generation of electricity previously used by the airport cause environmental damage (Hao & Van Brown, 2019; Nicoletti et al., 2015).

V. CONCLUSION

Using an in-depth instrumental case study research approach this study has examined the role played by renewable green energy technologies and systems at Mumbai's Chhatrapati Shivaji Maharaj International Airport, and Delhi's Indira Gandhi International Airport. The qualitative data used in the study was examined by document analysis. The case study was underpinned by the case study research framework as recommended by Yin (2018).

The case study revealed that Chhatrapati Shivaji Maharaj International Airport has entirely switched to green sources for its energy consumption needs, thereby making it one of India's 100 per cent sustainable airports. Mumbai International Airport achieved 100% use of green energy sources in August 2022. The airport is committed to continuous reduction in energy consumption, and hence, a reduction in its carbon footprint. In April 2022, Mumbai Airport enhanced its usage of green energy when it deployed a 10Kwp Hybrid SolarMill consisting of 2Kwp TurboMill (three Savonious vertical axis type wind turbine (VAWT) and 8Kwp Solar PV modules, with an estimated minimum energy generation of 36 kWh/day. This first-of-its-kind, fully integrated, hybrid renewable energy product, harnesses both solar and wind energy that are combined to generate electricity at the airport. The new green energy powered system will enable Chhatrapati Shivaji Maharaj International Airport to reduce its carbon footprint as the new system will reduce its annual carbon dioxide (CO_2) emissions by 120,000 tonnes (The Economic Times, 2022). The reduction in carbon dioxide emissions (CO2) is contributing to the airport's goal of Net Zero emissions by 2029. Another important environmental-related benefit of the new system is that it is assisting the airport to enhance its energy efficiency.

Like Mumbai's Chhatrapati Shivaji Maharaj International Airport, Delhi's Indira Gandhi Airport has also taken a range of steps to "green" its operations and to make the airport more sustainable. In 2022, Delhi's Indira Gandhi Airport became the first airport in India to be powered entirely by hydro and solar energy sources. This energy-related measure is one of the airport's key actions that it has taken to move closer to realizing its 2030 objective of being a Net Zero Carbon Emission Airport. The airport's operator, Delhi International Airport Limited (DIAL), has estimated that by moving to renewable sources for its energy requirements the airport is expected to indirectly reduce 200,000 tons of carbon dioxide (CO_2) emissions every year. Consequently, the airport has been able to reduce its carbon footprint from the use of its new renewable green energy system. In addition, the airport has also been able to increase its energy efficiency, which is a very favorable outcome for the airport. At the time of the present case study, the airport was sourcing around 6% of its electricity requirement from onsite solar power plants and the remaining 94% from hydropower plants.

By embracing the use of renewable and green energy sources, both airports have been able to reduce the use of fossil fuels and, as a result, they have been able to reduce their carbon dioxide (CO_2) emissions, and hence, their carbon footprint. This is very important for airports because the global aviation industry generates a substantial carbon footprint. In addition, by using renewable and green energy sources the two airports have been able reduce their dependency on fossil fuels, and consequently, they have reduced pollutants being released into the atmosphere. The use of clean green energy sources has helped the two airports to mitigate the environmental damage associated with fossil fuel usage.

REFERENCES

[1] Abdallah, A.S.H., Makram, A., & Abdel-Azim Nayel, M. (2021). Energy audit and evaluation of indoor environment condition inside Assiut International Airport terminal building, Egypt. *Ain Shams Engineering Journal*, 12(3), 3241-3253. https://doi.org/10.1016/j.asej.2021.03.003

[2] Agarwal, M., Aggarwal, A., Pathak, K.G., Sachet., & Ahirwar, J. (2018). Airport with a circular runway in India. *International Journal of Advance Research, Ideas, and Innovations in Technology*, 4(3), 919-922.

[3] Ağbulut, U., & Sarıdemir, S. (2021). A general view to converting fossil fuels to cleaner energy source by adding nanoparticles. *International Journal of Ambient Energy*, 42(13), 1569-1574. . https://doi.org/10.1080/01430750.2018.1563822

[4] Ahmed, S.S.U., Salehin, S., Rahman, M.M., & Sadral Islam, A.K.M. (2017). Harvesting solar energy: Fundamentals and applications. In P. Mondal & A.K. Dalai (Eds.), *Sustainable utilization of natural resources* (pp. 381-416). Boca Raton, FL: CRC Press.

[5] Airport Technology. (2020). Chhatrapati Shivaji International Airport, India. Retrieved from https://www.airport-technology.com/projects/chhatrapati/.

[6] Airports Council International. (2022a). Delhi Airport switches to renewable sources for its energy needs; Becomes India's first airport to run entirely on hydro and solar power. Retrieved from https://www.aci-asiapac.aero/media-centre/perspectives/delhi-airport-switches-to-renewable-sources-for-its-energy-needs-becomes-india-s-first-airport-to-run-entirely-on-hydro-and-solar-power.

[7] Airports Council International. (2022b). Final data released: Top 20 busiest airports confirmed. Retrieved from https://aci.aero/2022/07/25/final-data-released-top-20-busiest-airports-confirmed/.

[8] Airports Council International. (2022c). Mumbai Airport spreads the message of green living with travellers on World Environment Day. Retrieved from https://www.aci-asiapac.aero/media-centre/news/world-environment-day-csmia-spreads-the-message-of-green-living-with-the-travellers-with-the-theme-only-one-earth.

[9] Aktaş, A., & Kirçiçek, Y. (2021). *Solar hybrid systems: Design and application*. London, UK: Academic Press.

[10] Akyüz, M.K., Altuntaş, Ö., & Söğüt, M. Z. (2017). Economic and environmental optimization of an airport terminal building's wall and roof insulation. *Sustainability*, 9(10), 1849. https://doi.org/10.3390/su9101849

[11] Akyuz, M.K., Altuntas, O., Sogut, M.Z., & Karakoc, T.H. (2019). Energy management at the airports. In T. Karakoc, C. Colpan, O. Altuntas & Y. Sohret (Eds.), *Sustainable aviation* (pp. 9-36). Cham, Switzerland: Springer International Publishing.

[12] Akyüz, M.K., Altuntas O., Sogut M.Z, Karakoc T.H., & Kurama, S. (2018). Determination of optimum insulation thickness for building's walls with respect to different insulation materials: A case study of International Hasan Polatkan Airport terminal. *International Journal of Sustainable Aviation*, 4(2), 147-161. https://doi.org/10.1504/IJSA.2018.094228

[13] Alotto, P., Guarnieri, M., & Moro, F. (2014). Redox flow batteries for the storage of renewable energy: A review. *Renewable and Sustainable Energy Reviews*, 29, 325-335. https://doi.org/10.1016/j.rser.2013.08.001

[14] Amankwah-Amoah, J., Debrah, Y., & Anag, S. (2023). Greening aviation in era of COVID-19: Towards conceptualizing and operationalizing decarbonization. *Journal of Environmental Management*, 326(Part A), 116649. https://doi.org/10.1016/j.jenvman.2022.116649

[15] Andrew, D.P.S., Pedersen, P.M., & McEvoy, C.D. (2011). *Research methods and design in sport management*. Champaign, IL: Human Kinetics.

[16] Anurag, A., Zhang, J., Gwamuri, J., & Pearce, J.M. (2017). General design procedures for airport-based solar photovoltaic systems. *Energies*, 10(8), 1194. https://doi.org/10.3390/en10081194

[17] Arman, H., & Yuksel, I. (2013). Preface. In H. Arman & I Yuksel (Eds.), *New developments in renewable energy* (pp. xi-xii). Rijeka, Croatia: InTech.

[18] Aswathanarayana, U. (2010). Introduction. In U. Aswathanarayana., T. Harikrishan., & K.M Thayyib Sahini. (Eds.), *Green energy technology, economics, and policy* (pp. 1-4). Boca Raton, FL: CRC Press.

[19] Baek, S., Kim, H., & Joon Chang, H. (2016). Optimal hybrid renewable airport power system: Empirical study on Incheon International Airport, South Korea. *Sustainability*, 8(6), 562. https://doi.org/10.3390/su8060562

[20] Bahadir, S. (2022). The relationship between civil aviation, renewable energy consumption, economic growth, and CO_2 emissions: The case of Sub-Saharan African countries. In S. Batal (Ed.), *Academic studies in social, human and administrative science* (pp.135-160). Ankara, Turkey: Gece Publishing.

[21] Balfour, J.R., Shaw, M., & Nash, N. (2013). *Introduction to photovoltaic system design*. Burlington, MA: Jones & Bartlett Learning

[22] Baxter, G. (2021). Mitigating an airport's carbon footprint through the use of "green" technologies: The case of Brisbane and Melbourne Airports, Australia. *International Journal of Environment, Agriculture and Biotechnology*, 6(6), 29-39. https://dx.doi.org/10.22161/ijeab.66.4

[23] Baxter, G. (2022a). Assessing the carbon footprint and carbon mitigation measures of a major full-service network airline: A case study of Singapore Airlines. *International Journal of Environment, Agriculture and Biotechnology*, 7(5), 81-107. https://dx.doi.org/10.22161/ijeab.75.9

[24] Baxter, G. (2022b). Mitigating aircraft auxiliary power unit carbon dioxide (CO_2) emissions during the aircraft turnaround process from the use of solar power at the airport gate: The Case of Moi International Airport, Kenya. *International Journal of Environment Agriculture and Biotechnology*, 7(1), 14-22. https://dx.doi.org/10.22161/ijeab.71.2

[25] Baxter, G., Srisaeng, P., Wild, G. (2019). Environmentally sustainable airport energy management using solar power technology: The case of Adelaide Airport, Australia. *International Journal for Traffic and Transport Engineering*, 9(1), 81 – 100.

[26] Berga, L. (2016). The role of hydropower in climate change mitigation and adaptation: A review. *Engineering*, 2(3), 313-318. https://doi.org/10.1016/J.ENG.2016.03.004

[27] Bergero, C., Gosnell, G., Gielen, D., Kang, S., Bazilian, M., & Davis, S.J. (2023). Pathways to net-zero emissions from aviation. *Nature Sustainability*, 1. https://doi.org/10.1038/s41893-022-01046-9 et al., 2023

[28] Bhattacharyya, S. (2015). Introduction. In P. Mohanty, T. Muneer, & M. Kolhe (Eds.), *Solar photovoltaic system applications: A guide for off-grid electrification* (pp. 1-6). Cham, Switzerland: Springer Nature Switzerland.

[29] Bhowmik, C., Bhowmik, S., Ray, A., & Murari Pandey, K. (2017). Optimal green energy planning for sustainable development: A review. *Renewable and Sustainable Energy Reviews*, 71, 796-813. https://doi.org/10.1016/j.rser.2016.12.105

[30] Bosmans, J., Schipper, A., Mielke, K., Ćengić, M., Gernaat, D., van Vuuren, D., & Huijbregts, M. (2022). Determinants of the distribution of utility-scale

photovoltaic power facilities across the globe. *Environmental Research Letters*, 17(11), 114006.

[31] Braun, V., & Clarke, V. (2022). *Thematic analysis: A practical guide*. London, UK: Sage Publications.

[32] Bujok, P., Bjørn-Thygesen, F., & Xydis, G. (2023). Developing a sustainable energy strategy for Midtjyllands Airport, Denmark. *International Journal of Sustainable Transportation*, 17(3), 273-297. https://doi.org/10.1080/15568318.2022.2029632

[33] Chaichan, M.T., Mahdi, M.T., Kazem, H.A, Al-Waeli, A.H.A., Fayad, M.A., Al-Amiery, A.A., Roslam Wan Isahak, W.N., Kadhum, A.A.H., & Takriff, M.S. (2022). Modified Nano-Fe 2 O 3 -paraffin wax for efficient photovoltaic/thermal system in severe weather conditions. *Sustainability*, 14(19), 1-23. https://doi.org/10.3390/su141912015

[34] Chawda, G.S., Shaik, A.G., Mahela, O. P., & Padmanaban, S. (2023). Performance improvement of weak grid-connected wind energy system using FLSRF-Controlled DSTATCOM. *IEEE Transactions on Industrial Electronics*, 70(2), 1565-1575. https://doi.org/10.1109/TIE.2022.3158012

[35] Chhatrapati Shivaji Maharaj International Airport. (2020). Sustainability Report 2020: Mumbai International Airport. Retrieved from https://csmia.adaniairports.com/sustainabilityreport.pdf.

[36] Chhatrapati Shivaji Maharaj International Airport. (2021). Passenger traffic picks up pace ahead of festive season: Witnessed over 5 lakh at CSMIA. Retrieved from https://csmia.adaniairports.com/pressnotes/PressNote_Passenger_Traffic_Picks_Up_Pace_Ahead_Of_Festive_Season_Witnessed_Over_15_Lakh_Travellers_At_CSMIA.pdf.

[37] Chhatrapati Shivaji Maharaj International Airport. (2022). Quality, health, safety, and environment policy. Retrieved from https://csmia.adaniairports.com/operation/20220131_MIAL_QHSE_Policy.pdf.

[38] Chaudhuri, S., & Chaudhuri, R. (2017). A cost benefit analysis of Delhi Airport PPP project. *Journal of Air Transport Studies*, 8(1), 13-30.

[39] Choudhary, A., Saxena, B.K., & Mishra, S. (2021). Making Indian airports sustainable by using solar photovoltaic system: Analysis of three airports. *International Journal of Sustainable Energy*, 40(2), 149-174. https://doi.org/10.1080/14786451.2020.1797739

[40] Choudhuri, S., Dixit, R., & Tiwari, R. (2015). Issues and challenges of Indian aviation: A case study. *International Journal of Logistics & Supply Chain Management Perspectives*, 4(1), 1557-1562.

[41] Correia, D., & Ferreira, A. (2021). Energy harvesting on airport pavements: State-of-the-art. *Sustainability*, 13(11), 5893. https://doi.org/10.3390/su13115893

[42] Curran, S. (2016). Economic viability of using grid-connected photovoltaic energy in an airport in Jamaica. *The Journal of the Association of Professional Engineers of Trinidad and Tobago*, 44(1), 16-21.

[43] Dalwadi, P., Shrinet, V., Mehta, C.R., & Shah, P. (2011). Optimization of solar-wind hybrid system for distributed generation. *Proceedings of the Nirma University International Conference on Engineering, Ahmedabad, India, 2011* (pp. 1-4).

[44] Dan, A., Pasi, A., Jalaluddeen, M., & Kumar Singh, S. (2017). Responding to the Ebola virus disease at point of entry: Experience from Mumbai – India. *Indian Journal of Public Health Research & Development*, 8(2), 163-166.

[45] Delhi Airport. (2022). Delhi Airport becomes India's first to run solely on hydro & solar power. Retrieved from https://www.newdelhiairport.in/blog/delhi-airport-becomes-indias-first-to-run-solely-on-hydro-solar-power.

[46] Delhi Indira Gandhi Airport. (2022). Fact sheet. Retrieved from https://www.newdelhiairport.in/medias/factsheet.

[47] Delhi International Airport Limited. (2020). Environment policy. Retrieved from https://www.newdelhiairport.in/media/1514/revised-evironmental-policy-211020.pdf.

[48] Demirbaş, A. (2006). Global renewable energy resources. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 28(8), 779-792. https://doi.org/10.1080/00908310600718742

[49] Dentch, M.P. (2016). *The ISO 14001:2015 handbook: Using the process approach to building an environmental management system*. Milwaukee, WI: Quality Press

[50] de Rubeis, T., Nardi, I., Paoletti, D., Di Leonardo, A., Ambrosini, D., Poli, R., & Sfarra, S. (2016). Multi-year consumption analysis and innovative energy perspectives: The case study of Leonardo da Vinci International Airport of Rome. *Energy Conversion and Management*, 128, 261-272. https://doi.org/10.1016/j.enconman.2016.09.076

[51] Dzene, I., Polikarpova, I., Zogla, L., & Rosa, M. (2015). Application of ISO 50001 for implementation of sustainable energy action plans. *Energy Procedia*, 72, 111-118. https://doi.org/10.1016/j.egypro.2015.06.016

[52] Emeara, M.S., Abdelgawad, A.F., & El Abagy, A.H. (2020). A case study of Cairo International Airport "CIA" proposed installation of photovoltaic "PV" for high-energy production. *International Journal of Mechanical and Production Engineering Research and Development*, 10(5), 399–410.

[53] Emeara, M. S., Abdelgawad, A.F.., & El Abagy, A.H. (2021). A novel renewable energy approach for Cairo International Airport "CIA" based on Building Information Modeling "BIM" with cost analysis. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 85(2), 80-106. https://doi.org/10.37934/arfmts.85.2.80106

[54] Fesanghary, M., Asadi, S., & Geem, Z.W. (2012). Design of low-emission and energy-efficient residential buildings using a Multi-Objective Optimization Algorithm. *Building and Environment*, 49, 245-250. https://doi.org/10.1016/j.buildenv.2011.09.030

[55] Filimonau, V., Mika, M., & Pawlusiński, R. (2018). Public attitudes to biofuel use in aviation: Evidence from an emerging tourist market. *Journal of. Cleaner Production*, 172, 3102-3110. https://doi.org/10.1016/j.jclepro.2017.11.101

[56] Gandhiok, J. (2022). Delhi airport becomes India's first to run entirely on hydro and solar energy. Retrieved from

https://www.hindustantimes.com/business/delhi-airport-becomes-india-s-first-to-run-entirely-on-hydro-and-solar-energies-101655883952841.html.

[57] Ganguly, B. (2019). How solid is India's economy? In U. Tramballi & N. Missaglia (Eds.), *India's global challenge: Growth and leadership in the 21st century* (pp. 41-66). Milan, Italy: Ledizioni Ledi Publishing.

[58] Gaonkar, P.D. (2013). Analysis of airport ground accessibility in India by explicating the case of CSI Airport, Mumbai. *International Journal of Scientific and Research Publications*, 3(7), 1-7.

[59] Garg, V., Gulia, J., Thayillam, A., & Sharma, P. (2022). India's renewable energy open access market: Trends and outlook. Retrieved from https://ieefa.org/resources/indias-renewable-energy-open-access-market-trends-and-outlook.

[60] Gipe, P. (2004). *Wind power: Renewable energy for home, farm, and business*. White River Junction, VT: Chelsea Green Publishing Company.

[61] GMR Infra. (2021). GMR sustainability report 2021 – Airports. Retrieved from https://investor.gmrinfra.com/pdf/GMR%20Sustainability%20Report%202021%20-%20Airports.pdf.

[62] Godson, J., Karthick, M., Muthukrishnan, T., & Sivagamasundari, M.S. (2013). Solar PV-wind hybrid power generation system. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 2(11), 5350-5354.

[63] González-Ruiz, J.D., Duque, E., & Restrepo, J. (2017). Green airport infrastructure in Colombia: Opportunities for public-private partnerships schemes. *Pertanika Journal of Science & Technology*, 25, 37 – 46.

[64] Gopalakrishnan, B., Ramamoorthy, K., Crowe, E., Chaudhari, S., & Latif, H. (2014). A structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector. *Sustainable Energy Technologies and Assessments*, 7, 154-165. https://doi.org/10.1016/j.seta.2014.04.006

[65] Grandy, G. (2010). Instrumental case study. In A.J. Mills., G. Durepos., & E. Wiebe (Eds.), *Encyclopedia of case study research*, Volume 1 (pp. 473-475). Thousand Oaks, CA: SAGE Publications.

[66] Grover, R.C., & Grover, S. (2017). *Winning the environmental challenge with ISO 14001: 2015: Implementation of an Environmental Management System*. Chennai, India: Notion Press.

[67] Guest, G., MacQueen, K. M., & Namey, E. E. (2012). *Applied thematic analysis*. London, UK: SAGE Publications

[68] Gupta, U. (2022). India installed 1.9 GW of 'open-access' renewables in FY 2021-22. Retrieved from https://www.pv-magazine-australia.com/2022/08/23/india-installed-1-9-gw-of-open-access-renewables-in-fy-2021-22/#:~:text=From%20pv%20magazine%20India&text=Open%20access%20is%20a%20mechanism,all%20key%20renewables%2Drich%20states.

[69] Hafez, F.S., Sa'di, B., Safa-Gamal, M., Taufiq-Yap, Y.H, Alrifaey, M., Seyedmahmoudian, M., Stojcevski, A., Horan, B., & Mekhilef, S. (2023). Energy efficiency in sustainable buildings: A systematic review with taxonomy, challenges, motivations, methodological aspects, recommendations, and pathways for future research. *Energy Strategy Reviews*, 45, 101013. https://doi.org/10.1016/j.esr.2022.101013

[70] Hao, F., & Van Brown, B.L. (2019). An analysis of environmental and economic impacts of fossil fuel production in the U.S. from 2001 to 2015. *Society & Natural Resources*, 32(6), 693-708. https://doi.org/10.1080/08941920.2019.1574044

[71] Heras-Saizarbitoria, I., Landín, G.A., & Molina-Azorín, J.F. (2011). Do drivers matter for the benefits of ISO 14001? *International Journal of Operations and Production Management*, 31(2), 192-216. https://doi.org/10.1108/01443571111104764

[72] Hermawan, K. (2017). Design analysis of photovoltaic systems as renewable energy resource in airport. In *Proceedings of the 4th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), Semarang, Indonesia, 18-19 October 2017* (pp. 113-116).

[73] International Airport Review. (2022). Mumbai Airport becomes 100 per cent sustainable on green energy. Retrieved from https://www.internationalairportreview.com/news/180092/mumbai-airport-becomes-100-per-cent-sustainable-on-green-energy/#:~:text=Ushering%20into%20a%20sustainable%20future,of%20energy%20in%20August%202022.

[74] Jaffe, S.D. (2015). *Airspace closure and civil aviation: A strategic resource for airline managers*. Abingdon, UK: Routledge.

[75] Janić, M. (2011). *Greening airports: Advanced technology and operations*. London, UK: Springer Verlag London Limited.

[76] Janis, I. (2022). Strategies for establishing dependability between two qualitative intrinsic case studies: A reflexive thematic analysis. *Field Methods*, 34(3), 240-255. https://doi.org/10.1177/1525822X211069636

[77] Jiang, M., Qi, L., Yu, Z., Wu, D., Si, P., Wei, W., Yu, X., & Yan, J. (2021). National level assessment of using existing airport infrastructures for photovoltaic deployment. *Applied Energy*, 298, 117195. https://doi.org/10.1016/j.apenergy.2021.117195

[78] Joshi, G. (2022). Delhi Airport now runs entirely on hydro and solar power. Retrieved from https://simpleflying.com/delhi-airport-hydro-and-solar-power/.

[79] Jovanović, B., & Filipović, J. (2016). ISO 50001 standard-based energy management maturity model – proposal and validation in industry. *Journal of Cleaner Production*, 112(Part 4), 2744-2755. https://doi.org/10.1016/j.jclepro.2015.10.023

[80] Kalita, P., Das, S., Das, D., Borgohain, P., Dewan, A., & Kangsha Banik, R. (2019). Feasibility study of installation of MW level grid connected solar photovoltaic power plant for northeastern region of India. *Sādhanā,* 44, 207. https://doi.org/10.1007/s12046-019-1192-z

[81] Kalyani, V.L., Dudy, M.K., Pareek, S. (2015). Green energy: The need of the world. *Journal of Management Engineering and Information Technology*, 2(5), 18-26.

[82] Kandt, A., & Romero, R. (2014). Siting solar photovoltaics at airports. Retrieved from https://www.nrel.gov/docs/fy14osti/62304.pdf.

[83] Kazda, T., Caves, B., & Kamenický, M. (2015). Environmental control. In A. Kazda & R.E. Caves (Eds.), *Airport design and operation* (pp. 457-500) (3rd ed.). Bingley, UK: Emerald Group Publishing.

[84] Koç, S., & Durmaz, V. (2015). Airport corporate sustainability: An analysis of indicators reported in the sustainability practices. *Procedia - Social and Behavioral Sciences*, 181, 158-170. https://doi.org/10.1016/j.sbspro.2015.04.877

[85] Korba, P., Koščáková, M., Főző, L., & Sekelová, I. (2022). Current state and possible challenges in the development of green airports. In *Proceedings of the New Trends in Civil Aviation (NTCA), Prague, Czech Republic, 26-27 October* (pp. 191-197). https://doi.org/10.23919/NTCA55899.2022.9934733

[86] Kosmas, K., & Panagiotis, T. (2022). Wind-based stand-alone hybrid energy systems. In T.M. Letcher (Ed.), *Comprehensive renewable energy* (pp. 749-793) (2nd ed.). Amsterdam, The Netherlands: Elsevier.

[87] Kramer, L.S. (2010). *Airport revenue diversification: A synthesis of practice*. Airport Cooperative Research Program Synthesis Report 19. Washington, DC: Transportation Research Board.

[88] Kumar, A. V. P., Parimi, A.M., & Rao, K.U. (2015). Implementation of MPPT control using fuzzy logic in solar-wind hybrid power system. In *Proceedings of the* IEEE *International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES), Kozhikode, India, 19-21 February 2015* (pp. 1-5).

[89] Kumar, S., & Garg, V.K. (2013). A hybrid model of solar-wind power generation system. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 2(8), 4107-4116.

[90] Kumari, P., & Aithal, P.S. (2020). An overview of the aviation industry in India with special emphasis on privatization. *International Journal of Case Studies in Business, IT, and Education*, 4(2), 220-228.

[91] Liu, X., Zhang, T., Liu, X., Li, L., Lin, L., & Jiang, Y. (2021). Energy saving potential for space heating in Chinese airport terminals: The impact of air infiltration. *Energy*, 215(Part B), 119175. https://doi.org/10.1016/j.energy.2020.119175

[92] Loreng, A.C. (2022). Eco boost! Mumbai International Airport switches entirely to green sources for its energy needs. Retrieved from https://www.timesnownews.com/mirror-now/in-focus/eco-boost-mumbai-international-airport-switches-entirely-to-green-sources-for-its-energy-needs-article-94760410.

[93] Lykas, P., Georgousis, N., Bellos, E., Tzivanidis, C. (2023). A comprehensive review of solar-driven multigeneration systems with hydrogen production. *International Journal of Hydrogen Energy*, 48(2), 437-477. https://doi.org/10.1016/j.ijhydene.2022.09.226

[94] Maegaard, P., Krenz, A., & Palz, W. (2013). *The rise of modern wind energy: Wind power for the world*. Boca Raton, FL: CRC Press.

[95] Majumdar, B. (2016). *Fluid mechanics with laboratory manual*. New Delhi, India: PHI Learning Private Ltd.

[96] Malik, M.Z., Zehra, K., Ali, I., Ubedullah., Ismail, M., Hussain, A., Kumar, V., Abid, M., & Baloch, M.H. (2020). Solar-wind hybrid energy generation system. In *Proceedings of the IEEE 23rd International Multitopic Conference (INMIC), Bahawalpur, Pakistan, 5-7 November 2020* (pp. 1-6).

[97] Manwell, J.F., McGowan, J.G., & Rogers, A.L. (2009). *Wind energy explained: Theory, design and application* (2nd ed.). Chichester, UK: John Wiley & Sons.

[98] McKinney, M.L., Schoch, R.W., & Yonavjak, L. (2007). *Environmental science systems and solutions* (4th ed.). Sudbury, MA: Jones and Bartlett Publishers.

[99] Midilli, A., Dincer, I., & Ay, M. (2006). Green energy strategies for sustainable development. *Energy Policy*, 34(18), 3623-3633. https://doi.org/10.1016/j.enpol.2005.08.003

[100] Miller, D.R. (2022). Tacit cultural knowledge: An instrumental qualitative case study of mixed methods research in South Africa. In P. Ngulube (Ed.), *Handbook of research on mixed methods research in information science* (pp. 222-244). Hershey, PA: IGI Global.

[101] Mohamad Radzi, P., Akhter, N.A., Mekhilef, S., & Mohamed Shah, N. (2023). Review on the application of photovoltaic forecasting using machine learning for very short- to long-term forecasting. *Sustainability*, 15(4), 2942. https://doi.org/10.3390/su15042942

[102] Mostafa, M.F.A., Abdel Aleem, S.H.E., & Ibrahim, A.M. (2016). Using solar photovoltaic at Egyptian airports: Opportunities and challenges. In *Proceedings of the Power Systems Conference (MEPCON), 2016 Eighteenth International Middle East, Cairo, Egypt, 27-29 December* (pp. 73-80).

[103] Mostafa, M.F.A., Abdel Aleem, S.H.E., & Zobaa, A.F. (2016). Risk assessment and possible mitigation solutions for using solar photovoltaic at airports. In *Proceedings of the Power Systems Conference (MEPCON), 2016 Eighteenth International Middle East, Cairo, Egypt, 27-29 December* (pp. 81-88).

[104] Moukhtar, I., El Dein, A.Z., Elbaset, A.A., & Mitani, Y. (2021). *Solar energy: Technologies, design, modelling, and economics*. Cham, Switzerland: Springer Nature Switzerland.

[105] Muhammed, I., & Baladraf, T.T. (2021). Potential design of photovoltaics- pumped hydro storage system at ex-Pasar mine holes in East Kalimantan. In M. Muhammed, N. Nurhaliza & B.A.S. Turmono (Eds.), *ISTED 2021. Proceedings of the 1st International Seminar on Teacher Training and Education, Purwokerto, Indonesia, 17-81 July 2021* (pp. 61-68). Ghent, Belgium: European Alliance for Innovation.

[106] Mutezo, G., & Mulopo, J. (2021). A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. *Renewable and Sustainable Energy Reviews*, 137, 110609. https://doi.org/10.1016/j.rser.2020.110609

[107]

[108] Naik, Y. (2022). Mumbai International airport achieves highest rating in carbon sustainability. Retrieved from https://www.hindustantimes.com/cities/mumbai-news/mumbai-international-airport-achieves-highest-rating-in-carbon-sustainability-101671737261236.html.

[109] Nam, V.H. (2019). Green sustainable airports: The deployment of renewable energy at Vietnam Airports. Is that feasible? *Journal of Mechanical Engineering Research and Developments*, 42(5), 61-65.

[110] Nicoletti, G., Arcuri, N., Nicoletti, G., & Bruno, R. (2015). A technical and environmental comparison between hydrogen and some fossil fuels. *Energy Conversion and Management*, 89, 205-213. https://doi.org/10.1016/j.enconman.2014.09.057

[111] Oates, B.J. (2006). *Researching information systems and computing*. London, UK: SAGE Publications.

[112] Office of Energy Efficiency and Renewable Energy. (2022). Benefits of hydropower. Retrieved from https://www.energy.gov/eere/water/benefits-hydropower.

[113] Ojogiwa, O. T. (2021). The crux of strategic leadership for a transformed public sector management in Nigeria. *International Journal of Business and Management Studies*, 13(1), 83-96.

[114] Omer, A.M. (2008). Energy, environment, and sustainable development. *Renewable and Sustainable Energy Reviews*, 12(9), 2265-2300. https://doi.org/10.1016/j.rser.2007.05.001

[115] Ortega Alba, S., & Manana, M. (2016). Energy research in airports: A review. *Energies*, 9(5), 349. https://doi.org/10.3390/en9050349

[116] Ortego Alba, S.O., & Manana, M. (2017). Characterization and analysis of energy demand patterns in airports. *Energies*, 10(1), 119. https://doi.org/10.3390/en10010119

[117] Pratap, K.V., & Chakrabarti, R. (2017). *Public-private partnerships in infrastructure: Managing the challenges*. Singapore: Springer Nature Singapore Pte Ltd.

[118] Preston, K. (2015). Sustainability initiatives helping airports address climate change. *International Airport Review*, 19(5), 16-19.

[119] Radomska, M., Chernyak, L., & Samsoniuk, O. (2018). The improvement of energy-saving performance at Ukrainian airports. In T.H. Karakoç, C. Ozgur Colpan & Y. Şöhret (Eds.), *Advances in sustainable aviation* (pp. 189-203). Cham, Switzerland: Springer International Publishing.

[120] Ren, X. (2017). Fragile entrepreneurism: The Mumbai Airport slum redevelopment project. In K.C. Smitha (Ed.), *Entrepreneurial urbanism in India* (pp. 157-174). Singapore: Springer Science + Business Media Singapore.

[121] Saidi, A., & Chellali, B. (2017). Simulation and control of solar wind hybrid renewable power system. In *Proceedings of the 6th International Conference on Systems and Control (ICSC), Batna, Algeria, May 7-9* (pp. 51-56).

[122] Scott, J. (2014). *A dictionary of sociology* (4th ed.). Oxford, UK: Oxford University Press.

[123] Scott, J., & Marshall, G. (2009). *A dictionary of sociology* (3rd ed.). Oxford, UK: Oxford University Press.

[124] Serafimova, T., & Finger, M. (2022). Refuelling the transition to net zero emissions in the aviation sector. *Network Industries Quarterly*, 24(4), 23-29.

[125] Sharma, A. (2022) Air traffic outpacing infra at major domestic airports. Retrieved from https://www.livemint.com/economy/air-traffic-outpacing-infra-at-major-domestic-airports-11672333540331.html.

[126] Sher, F., Hazafa, A., Marintseva, K., Rasheed, T., Ali, U., Rashid, T., Babu, A., & Khzouz, M. (2021). Fully solar powered Doncaster Sheffield Airport: Energy evaluation, glare analysis and CO_2 mitigation. *Sustainable Energy Technologies and Assessments*, 45, 101122. https://doi.org/10.1016/j.seta.2021.101122

[127] Shirsath, P.P., Pise, A., & Shinde, A. (2016). Solar-wind hybrid energy generation system. *International Journal of Engineering Research and General Science*, 4(2), 546-550.

[128] Shukla, T. (2013). Low-cost carriers in India. In S. Gross & M. Lück (Eds.), *The low-cost carrier worldwide* (pp. 139-154). Abingdon, UK: Routledge.

[129] Smagulov, Z., Anapiya, A., Dikhanbayeva, D., & Rojas-Solórzano, L. (2021). Impact of module degradation on the viability of on-grid photovoltaic systems in Mediterranean climate: The case of Shymkent Airport. *International Journal of Renewable Energy Development*, 10(1), 139-147.

[130] Solanki, C.S., & Singh, H.K. (2017). *Anti-reflection and light trapping in c-Si solar cells*. Singapore: Springer Nature Singapore.

[131] Spellman, F.R. (2022). *Dictionary of environmental health*. Lanham, MD: Bernan Press.

[132] Sreejaya, K.V., Mubarak, K., & Al-Haddabi, A. (2020). Feasibility studies of solar energy as an alternative energy resource for Muscat International Airport. *INTI Journal*, 51, 1-6.

[133] Sreenath, S., Sudhakar, K., & Yusop, A.F. (2019). Carbon mitigation potential of the airport-based solar PV plants in the Indian context. *International Journal of Ambient Energy*, 43(1), 1311-1319. https://doi.org/10.1080/01430750.2019.1696888

[134] Sreenath, S., Sudhakar, K., & Yusop, A.F. (2020a). Airport-based photovoltaic applications. *Progress in Photovoltaics*, 28(8), 833-853. https://doi.org/10.1002/pip.3265

[135] Sreenath, S., Sudhakar, K., & Yusop, A.F. (2020b). Technical assessment of captive solar power plant: A case study of Senai Airport, Malaysia. *Renewable Energy*, 152, 849-866. https://doi.org/10.1016/j.renene.2020.01.111

[136] Sreenath, S., Sudhakar, K., & Yusop, A.F. (2021a). Effect of PV material, texturing, orientation and tracking on glare impact: A simulation study from an Indian Airport. *Cleaner Engineering and Technology*, 4, 100236. https://doi.org/10.1016/j.clet.2021.100236

[137] Sreenath, S., Sudhakar, K., & Yusop, A.F. (2021b). Energy-exergy-economic-environmental-energo-exergo-enviroecono (7E) analysis of solar photovoltaic power plant: A case study of 7 airport sites in India. *Sustainable Energy Technologies and Assessments*, 47, 101352. https://doi.org/10.1016/j.seta.2021.101352

[138] Stake, R.E. (1995). *The art of case study research*. Thousand Oaks, CA: SAGE Publications.

[139] Stake, R.E. (2005). Qualitative case studies. In N.K. Denzin & Y.S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (pp. 443-466). Thousand Oaks, CA: SAGE Publications.

[140] Sukumaran, S. & Sudhakar, K. (2017a). Fully solar powered airport: A case study of Cochin International airport. *Journal of Air Transport Management*, 62, 176-188. https://doi.org/10.1016/j.jairtraman.2017.04.004

[141] Sukumaran, S., & Sudhakar, K. (2017b). Fully solar powered Raja Bhoj International Airport: A feasibility study. *Resource Efficient Technologies*, 3(3), 309-316. https://doi.org/10.1016/j.reffit.2017.02.001

[142] Sumathi, N., Phanendra, M.G.V.S., & Teja, K.G. (2018). Green airports - Solution to stop pollution! *International Journal of Latest Technology in Engineering, Management & Applied Science*, VII(IV), 78-85.

[143] Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic analysis. In C. Willig & W. Stainton- Rogers (Eds.), *The SAGE handbook of qualitative research in psychology* (pp. 17-37). London, UK: SAGE Publications.

[144] The Economic Times. (2022). Mumbai Airport switches to green energy sources. Retrieved from https://economictimes.indiatimes.com/industry/renewables/mumbai-airport-switches-to-green-energy-sources/articleshow/94768590.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst.

[145] Thomas, C., & Hooper, P. (2013). Sustainable development and environmental capacity of airports. In N. J. Ashford., H.P. Martin Stanton., C.A. Moore., P. Coutu & J.R. Beasley. *Airport operations* (pp. 553-578) (3rd ed). New York, NY: McGraw-Hill.

[146] Thummala, V., & Hiremath, R.B. (2022). Green aviation in India: Airline's implementation for achieving sustainability. *Cleaner and Responsible Consumption*, 7, 100082. https://doi.org/10.1016/j.clrc.2022.100082

[147] Tong, C. (2019). Introduction to materials for advanced energy systems. Cham, Switzerland: Springer Nature Switzerland A.G.

[148] Tyler Miller, G., & Spoolman, S.E. (2012). *Living in the environment* (17th ed). Belmont, CA: Brooks/Cole.

[149] United States Environmental Protection Agency. (2022). Local renewable energy benefits and resources. Retrieved from https://www.epa.gov/statelocalenergy/local-renewable-energy-benefits-and-resources.

[150] van Vreden, M. (2022). Creating a musical for preschoolers in South Africa as pedagogical praxis for a tertiary music education module. *British Journal of Music Education*, 40(1), 109-123. https://doi.org/10.1017/S0265051722000079

[151] Vasant, L. G., & Pawar, V. R. (2017). Solar-wind hybrid energy system using MPPT. In *Proceedings of the International Conference on Intelligent Computing and Control Systems (ICICCS), Madurai, India, 15-16 June 2017* (pp. 595-597).

[152] Wagner, H.J., & Mathur, J. (2011). *Introduction to hydro energy systems: Basics, technology, and operation*. Berlin, Germany: Springer Verlag.

[153] Walsh, D., Kiryushin, S., Coleman-Pecha, J., & Rosenthall, B. (2020). The benefits of hydropower. Retrieved from https://environmentjournal.online/articles/the-benefits-of-hydropower/.

[154] Wybo, J.L. (2013). Large-scale photovoltaic systems in airport areas: Safety concerns. *Renewable and Sustainable Energy Reviews*, 21, 402-410. https://doi.org/10.1016/j.rser.2013.01.009

[155] Yerel Kandemir S., & Yayli, M. Ö. (2016). Investigation of renewable energy sources for airports. In T. Hikmet, M. Baris Ozerdem, C.O. Colpan, O. Altuntas, & E. Acikkalp (Eds.), *Sustainable aviation: Energy and environmental issues* (pp. 11-16). Cham, Switzerland: Springer International Publishing.

[156] Yildiz, O.F., Yilmaz, M. & Çelik, A. (2022). Reduction of energy consumption and CO_2 emissions of HVAC system in airport terminal buildings. *Building and Environment*, 208, 108632. https://doi.org/10.1016/j.buildenv.2021.108632

[157] Yin, R.K. (2018). *Case study research and applications* (6th ed.). Thousand Oaks: SAGE Publications.

[158] Yuriev A., & Boiral O. (2018). Implementing the ISO 50001 System: A critical review. In I. Heras-Saizarbitoria (Ed.), *ISO 9001, ISO 14001, and new management standards. Measuring operations performance* (pp. 145-175). Cham, Switzerland: Springer.

[159] Zhang, Y., & Zhang, A. (2017). Air transport development: A comparative analysis of China and India. In M. Finger & K. Button (Eds.), *Air transport liberalization: A critical assessment* (pp. 112-137). Cheltenham: Edward Elgar Publishing.

[160] Zhou, Y., Wang, J., & Huang, J.Q. (2019). Efficiency and robustness of weighted air transport networks. *Transportation Research Part E: Logistics and Transportation Review*, 122, 14-26. https://doi.org/10.1016/j.tre.2018.11.008

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Contribution of Tree Legumes in the Production Dynamics of Yellow Yam (*Dioscorea cayenensis Lam*) in the South Cameroon Plateau

Guy Aurélien Nganso Djakou*, Libert Brice Tonfack, Eddy Léonard Ngonkeu Magaptche, Emmanuel Youmbi

University of Yaounde I, Faculty of Science, Department of Plant Biology. POBox 812 Yaoundé, Cameroon.
*Corresponding author

Received: 11 Feb 2023; Received in revised form: 12 Mar 2023; Accepted: 22 Mar 2023; Available online: 01 Apr 2023

Abstract— *The overexploitation of agricultural soils as a result of the increased need for food by local populations is leading to serious dysfunctions in land restoration. These dysfunctions, aggravated by climate change, require the implementation of ecological engineering strategies to rehabilitate the soil. The soils of the South Cameroonian plateau suffer significant degradation in terms of loss of fertilizing elements due to extensive agricultural practices, which limits agricultural production. This work showed how tree legumes contribute to improving the yield of yellow yam (Dioscorea cayenensis) in the South Cameroonian plateau, to ultimately support the production of agroecosystems in this environment. Within the framework of this study, an experimental set-up was designed to measure the performance of tree legumes in the field. The experimental set-up is a randomized complete block trial with three treatments and three replications on 3000 m2. The control plot without shrubs, the plot with Calliandra, and the plot with Senna. This trial was carried out in the district of Mbankomo, Mefou, and Akono Department, Central Region. After monitoring the experiment, it was found that Senna spectabilis produced more nutrients than Calliandra calothyrsus. Thus, each Senna shrub produced 1.54 kg of litter in the first year and 2.04 kg in the second year for a quantity of nitrogen of 192.76 kg/ha and 260 kg/ha respectively in the first and second year. Each Calliandra shrub produced 1.46 kg and 1.87 kg of litter for a nutrient amount of 183 kg/ha and 236.81 kg/ha of nitrogen during the two years of the experiment. The combination of tree legumes and field crops increased yam yields by a factor of 2 or 3 compared to traditional agriculture. The growth rate of the yam is accelerated as well as its vegetative cycle, which is reduced from 7.5 months to 6 months as a result of the increase in soil organic matter through the shrub legume litter. Agroforestry practices could have a positive impact on soil characteristics and microbial communities, resulting in enhanced soil fertility and long-term sustainability of agricultural production. According to the results obtained, the insertion of tree legumes in agrosystems is a more efficient and less costly way to gradually and sustainably increase nitrogen availability and soil fertility.*

Keywords— ***South Cameroon Plateau, shrub legumes, litter, yellow yam, agrosystems.***

I. INTRODUCTION

The South Cameroon plateau is a vast platform that extends between the 2nd and 6th degrees of North latitude and between the 2nd and 6th degrees of East longitude. It comprises three administrative regions of Cameroon: the Centre, the South, and the East. The South Cameroonian plateau is bordered to the North by the Adamaoua plateau, to the East by the Central African Republic, to the West by the western highlands and the coastal plain, and to the South by Equatorial Guinea, Gabon, and Congo (Camerecole.org). It is also a vast erosion surface sloping towards the Congo basin in the

southeast, in the west it ends abruptly with an escarpment dominating the coastal surface. Its average altitude is about 650 m, but in Yaoundé, it is close to 750 m.

The South Cameroonian plateau has an equatorial climate of the Guinean type, characterized by constant temperatures (24 to 26°C), abundant rainfall, and the existence of four seasons: a long dry season from December to February, a short rainy season from March to May, a short dry season from June to August and a long rainy season from September to November. The entire southern Cameroonian plateau receives an average of 1,500 to 2,000 mm of rainfall per year, although some areas are relatively deficient due to the continental nature of the region and deforestation [1]. However, with the phenomenon of climatic disruption observed over the last few decades, the dry season has tended to lengthen to the detriment of the rainy season. This climatic disruption leads to a disruption of the rainfall calendar with the appearance of extreme phenomena and consequently a disorganization of agricultural activities. All this has effects on human health [2].

In this geographical area, there are extremely complex ferralitic soils that cover 2/3 of the country and have been in place for millions of years. These are nutrient-poor, acidic, and fragile soils. They are largely covered by forest, very permeable, and rich in humus [1]. These soils have suffered significant degradation in terms of loss of fertilizing elements due to extensive agricultural practices [3].

Agriculture remains the mainstay of the economy in this area and employs more than 50% of the working population in the Centre, nearly 75% in the East, and around 80% in the South (Camerecole.org). A wide variety of products are grown, both for export (cocoa, coffee) and for food (plantain, yams). Food crops are grown in fields where mixed cropping is common for production intended primarily for self-consumption. But increasingly, they are sold on domestic and sub-regional markets.

Cropping techniques and systems, as well as poor soils, contribute to reduced productivity and increased malnutrition, and poor living conditions for people. It can be seen that yam plays an important role in the food security of at least 60 million people [4], [5], [6]. However, there is rapid soil depletion accelerated by a significant erosion of cultivated plots leading to reduced productivity and yam production, coupled with the high cost and scarcity of imported chemical fertilizers [6].

To overcome these difficulties, the importance of shrub legumes with high nitrogen fixation capacities such as *Calliandra* and Senna becomes obvious, especially for regions where soils are generally fragile as in the southern plateau of Cameroon. Symbiotic nitrogen fixation by these legumes is also becoming an essential element of policies to limit the importation of nitrogen fertilizers, whether for economic, ecological, or agrosystem sustainability reasons [7], [8].

To improve yam yields and effectively combat soil infertility in the southern plateau of Cameroon, it was necessary to conduct a study on the contribution of tree legumes to yam production, using *Calliandra calothyrsus* and Senna spectabilis as species in the locality of Mbankomo in the Central Region.

II. MATERIALS AND METHODS

2.1. Materials

2-1.1. Location of the study site

The study was carried out in the Centre region, in the Mefou and Akono departments, and in the Mbankomo district, which is a locality in the secondary forest zone that has been degraded by urbanization and anthropization of the environment [9], [10]. The vegetation is characterized by tree species and swampy lowlands. The main forest species found in the area are Terminalia superba, Entandrophragma cylindricum, Baillonella toxisperma, Milletia exelsa, Disthemonianthus benthamianus, Triplochiton scleroxylon, Ceiba pentadra. The fallows are mainly colonized by Musanga cecropioides, Eupatorium sp., and Chromolaena odorata.

(Figure 1).

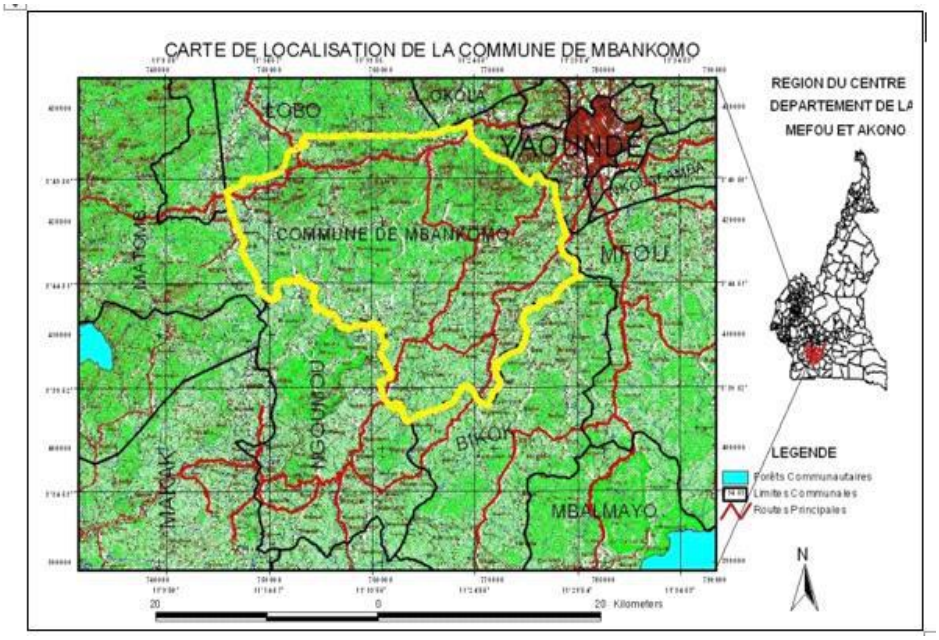


Fig.1: Localization map.

2.1.2. Materials used

The field equipment used in the framework of this work is made up of the A-frame for the measurement of the contour lines, the stakes to delimit the surface to be cultivated, the hoes for the making of mounds for the cultivation of the plant material and to fight against erosion. A strong, machetes, a triple decameter, stakes, an auger for various soil samples in the study site, a dendrometer to measure the height of the trees, gloves, boots, and a helmet to protect the hands, feet, and head, and tarpaulins to collect the leaves after pruning the shrubs.

The plant material consists of *Senna spectabilis* and *Calliandra calothyrsus* seeds for the shrub hedges, and yam seeds as a specimen to be cultivated in the experimental plots. The seeds of these shrubs are obtained from pre-existing trees and the traditional variety of yam seeds are obtained in the Mokolo market in Yaoundé and the mass of these seeds varies between 350 and 500g.

The laboratory equipment consists of sieves with different mesh sizes (2 mm, 0.5 mm) composed of metal support that encircles the screen or sieve and a soil conservation device. The sieve allows the removal of elements such as roots and other elements that are not part of our study. The conservation device maintains the soil with all the living organisms in it.

Each plant material (yam seed, leaf biomass of each legume, crop) is weighed using a commercial price-weight scale brand 56PPI. In addition, microbalances are used for weighing to the hundredth of a milligram, and an analyzer for chemical analysis of the crushed and dried leaf samples, an oven.

2.1.3. Experimental design

The experimental set-up is a randomized complete block trial with three treatments and three replications on 3000 m2. There is the control plot, the *Calliandra* plot, and the *Senna* plot. Each block covers an area of 1000 m2, containing the three treatments and representing one replication. Block 1 is located at Eloumden I (3° 29' N and 11° 16'E), Block 2 at Eloumden II (3° 50'N and 11°26'N), and Block 3 at Ekoko (3°49'N and 12° 7'E) [11].These trials were continued [12], and were conducted for two years on the same plots with the same treatments but with different doses of litter.

The different sites were chosen based on criteria such as the rapid increase in population in the locality of Mbankomo, galloping urbanization, a decrease in cultivable land, overexploitation of the soil, and a drastic decline in soil fertility [13]. The experiment takes place at the beginning of each rainy season. The preparation of the different plots is done manually with a hoe. But before this, the plots are already marked out and planted with shrubs. The control plot without shrubs covers an area of 190 m2 (Fig. 2), where yams are planted on mounds 40 cm high and spaced 1 m apart in all directions [14], [15].

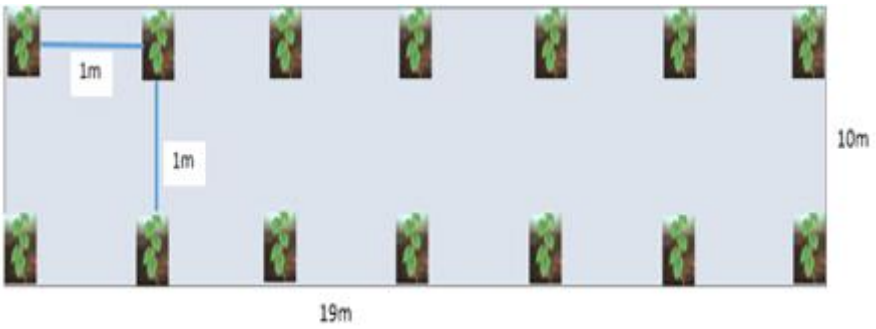


Fig.2: Experimental set-up of the control plot (PT)

The *Calliandra* and *Senna* plots (Fig. 3) are separated from each other by 3 m and cover a usable area of 190 m2 each, i.e. the area planted with yams without taking into account the space occupied by shrubs. The yams are planted at a density of 1m between plants and 1m between rows. The bushes are 50 cm apart in the rows and 6 m between rows.

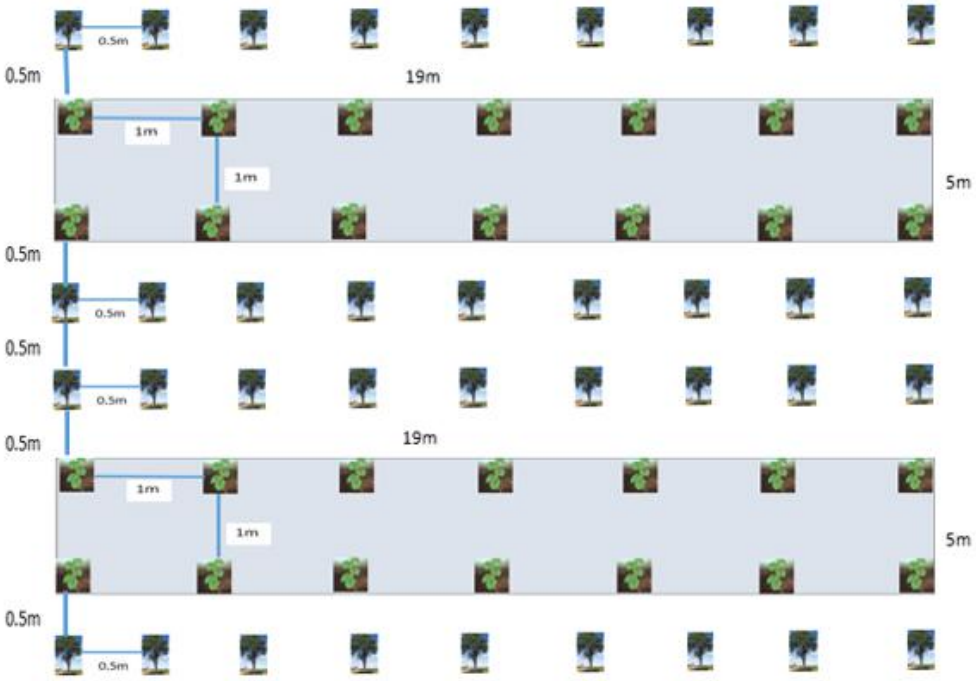


Fig.3: Legume Experimental plot dispositive [16]

2.2. Method

2.2.1. Burial of litter

In the plots planted with shrubs, each plot receives a dose of litter that will be buried at a depth of 15 cm. The dose is defined in advance and is 8 t/ha in the first year and 10 t/ha in the second year [17]. These different doses correspond to 152 kg and 190 kg in the first and second year respectively for each plot, namely the *Calliandra* (Pc) and *Senna* (Ps) plots. Two weeks after plowing in the organic matter [18], soil samples are taken before yam planting at 0-15 cm depth [19], using an auger following a Z pattern [20].

The yams are planted at a density of 1 m between plants and 1 m between rows on 40 cm high mounds.*Calliandra* and *Senna* are chosen based on their characteristics. These shrubs are fast growing, have a deep root system, abundant foliage, and provide stakes for yams. They fix atmospheric nitrogen (*Calliandra*) and tolerate acidic soils. This system was set up in August 2016 with the planting of shrubs from the nursery set up in June 2016.

The planting of shrubs that have reached 10 cm in height is done on contour lines, using the A-frame, at a distance of 6 m, following the spacing of 50 cm [21]. The height (H, m) of these shrubs is measured using both a triple decameter and a vertex electronic dendrometer, every two months on ten plants [19]. The first pruning took place in February 2017 and the second in February 2018 when the shrubs had reached heights of 3.5 m and 6.1 m for *Calliandra* and 4.25 m and 8.7 m for *Senna*.

2.2.2. Obtaining leaf biomass (litter)

Ten trees were selected based on their diameter for the estimation of leaf biomass. At the time of pruning, the diameter of *Calliandra* trees was between 15 and 18 cm and that of Senna trees between 22 and 24 cm. The biomass of the aerial compartments (leaves) was estimated from sampling based on the method described by [22]. Destructive sampling of shrubs was carried out. These shrubs were pruned to 50 cm from the ground [21] and the collected samples were used to estimate the leaf biomass. The leaves of these legumes were collected by dropping them on a large tarpaulin and weighing them. The branches are discarded to avoid cluttering the plot and are not included in the fertilizer.

2.2.3. Determination of nutrients in Calliandra and Senna leaves

To determine the nutrient content of *Calliandra* and *Senna* leaves, six months after planting and one year after the first pruning, the leaves were collected and the plant samples were dried at 65°C in ovens at the IITA laboratory in Nkolbisson, the evaluation of the nutrients was done by grinding the dried leaves. An aliquot of each ground sample is sent to the laboratory where it is further ground. A 3.5 mg test sample is weighed to the hundredth of an mg on the MX5 Mettler Toledo and MC5 Sartorius microbalances. The chemical analyses of the plant samples were carried out with the NCS 2500 Thermo Quest analyzer.

2.2.4. Chemical analysis of soils

Chemical analyses were carried out at the IITA laboratory in Nkolbisson using the following methods: soil samples were dried and crushed and then sieved using a 2 mm mesh sieve. For C and N, the soil samples were further crushed and sieved using a 0.5 mm mesh sieve. The pH-water is determined at 1:2.5 (w/v) of the suspended water. Organic carbon is determined by the chromic acid digestion method and by spectrophotometric analysis using the UV-VIS spectrophotometer [23].

Total nitrogen is determined by wet acid digestion [24] and analysis is done by colorimetry [25]. Exchangeable cations (Ca, Mg, K, and Na) are extracted using the Mehlich-3 procedure or method and determined by flame atomic spectrophotometric absorption (FAS). CECs are extracted using ammonium acetate at pH 7 and analyzed by colorimetry. Exchangeable acidity is extracted using 1M KCl and quantified by titration.

2.2.5. Shrub legume litter and yam production

2.2.5.1. Monitoring of yam growth

To monitor the growth of the aerial system of yam in each treatment on ten individuals, the criterion used is the evolution of the sum of the lengths of the aerial axes as a function of time [26]. Every 10 days after emergence, the length of each aerial axis is measured on a given individual, using a string applied along the winding of the axes. This staggered measurement could not be maintained throughout the growth period in some series where a large number of plants were highly developed and branched at the same time. The absolute error is of the order of one cm (main axis), and several cm (lateral axes). Growth is said to be linear when the increase in dimension Δ 1 is proportional to time. We have constant dl/dt. The successive values of the measured dimension are arranged on a straight line as a function of time. The linear growth phase is preceded by an accelerated growth phase and followed by a slow growth phase.

2.2.5.2. Evaluation of yam production

To assess yam production, ten plants per plot were harvested in the Z pattern and weighed using a commercial price-weight scale, brand 56PPI. The total mass of yam per plant is subtracted from the mass of seed used at planting to assess the gain or performance of the cropping system. The masses per plant and per plot are added together and divided by 10 to give the average mass of a plant. This mass is multiplied by the total number of plants per plot in kg/m2, then reduced to the hectare by multiplying by 10,000 to obtain the yield in tones/ha (paden@paden-senegal.org / www.paden-senegal.org).

2.2.6. Statistical analysis

Statistical analyses were carried out in three replications and the results are expressed as means plus or minus standard deviation. The data were analyzed using the ANOVA test and the Posthoc LSD test for multiple comparisons. The paired Student's t-test was used for pairwise comparisons. IBM/SPSS 20 for Windows was used at the 5% significance level. Microsoft Office Excel 2013 was used for graphical representations. Significant differences between treatments were observed in the number of nutrients returned to the soil via the application of litter from the shrub cut. The differences between the treatments in soil fertility and productivity were noted.

III. RESULTS AND DISCUSSION

3.1 Results

3.1.1. Growth of Calliandra calothyrsus Meisn.

Calliandra calothyrsus is a fast-growing shrub legume, its regeneration and management are simple. On impoverished and degraded soils, their germination does not require special fertilization. When *Calliandra* is associated with crops, it must be constantly pruned to prevent its shading from competing with the associated crops. The growth of tree legumes such as *Calliandra* differs from one area to another depending on soil, rainfall, and light. After transplanting *Calliandra*, a growth of 61.08 cm was obtained after 60 days i.e., from August to October 2016.

Shading considerably affects the growth of this legume if it is important for the plot to be cultivated. After the fourth month of our experiment, this growth was accelerated from 61.08 cm to 204.52 cm, an additional increase of 143.44 cm. In February 2017, the total growth of *Calliandra* was 299.37 cm with a standard deviation of 1.21 (Table 1). It appears that *Calliandra* which has a deep root system allows other crops to grow easily as a well-maintained leguminous hedge takes in the deep soil horizons and maintains a state of relative moisture in the organic horizon.

Table 1: Height of Calliandra (cm)

Date	Aug. 6, 2016	Oct.5, 2016	Dec. 5, 2016	Feb. 5, 2017
Height	10.12 ± 0.03^{a}	61.08 ± 0.34^{b}	204.52 ± 1.04^{c}	309.37 ± 1.21^{d}

Values are expressed as mean ± standard deviation (n = 3). Values with the same letter on the same line are not significantly different ($p > 0.05$).

When growing *Calliandra*, it was observed that after the second month of planting, the height of the shrub increased fourfold to 310 cm six months after planting (Figure. 4). The rapid growth of the shrub allows for a rapid and abundant supply of litter to enrich and nourish the soil life.

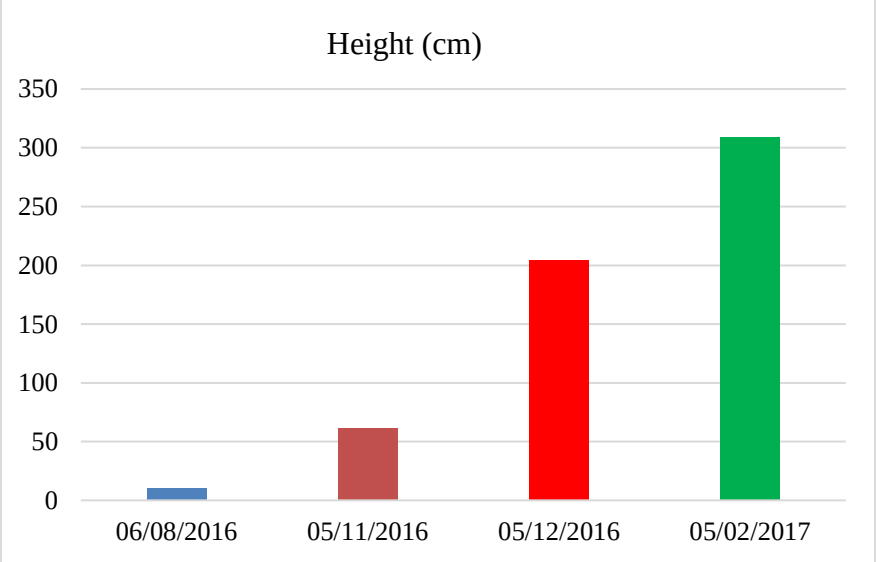


Fig.4: Height of Calliandra

3.1.2. Obtaining the leaf biomass of Calliandra

After planting the *Calliandra* shrubs in hedges 6 m apart with a spacing of 50 cm between the shrubs, we waited until these shrubs could reach a height of 3.10 m, the first pruning was done six months after planting. This pruning was done at 50 cm from the ground. Average annual leaf biomass of 8.46 tons/ha was obtained. Each shrub provided 1.46 kg/shrub as green matter. The harvesting of this plant material allowed us to fertilize the plot. In the second year of the experiment, the cutting took place twelve months after the first in February 2018.

This operation allowed us to obtain an average annual leaf biomass of 11.02 kg/ha, with each shrub producing 1.87 kg/shrub (Table 2). The amounts of leaf biomass/shrub, and total leaf biomass increased significantly from the year 2016 - 2017 to the year 2017 - 2018 with ($t = -33.84$; $p = 0.001$), ($t = -50.07$ $p = 0.000$) respectively. This increase in leaf biomass is because after

pruning, several shoots are formed on the shrub and the leaf mass increases similarly.

Table 2: Litter production of Calliandra hedges during the two years of experiment (tons/ha)

Quantity/shrub (kg)		Leaf biomass (t/ha)
2016 – 2017	1.46 ± 0.01	8.46 ± 0.21
2017 – 2018	1.87 ± 0.03	11.02 ± 0.17
t (student) probability	t = -33.84 (p = 0.001)	t = - 50.07 (p = 0.000)

3.1.3. Growth of Senna spectabilis H.S

Senna spectabilis is another example of green manure that is intended to improve soil fertility in agrosystems. It is planted in rows six meters apart, with a distance of 50 cm between plants in the rows. Pruning was carried out six months after planting and one year after the first pruning at a height of 50 cm from the ground. *Senna spectabilis* is also a very fast-growing plant. A very deep root system prevents competition with associated crops. After 60 days, the growth of the shrub is 68.67 cm.

After the fourth month, this growth increased from 68.67 cm to 217.93 cm to reach a height of almost 4.50 m before the first pruning took place six months after planting, with a standard deviation of 3.76. One year after the first pruning, the height reached 870 cm. With a very deep root system, *Senna spectabilis* draws mineral elements from deep in the soil and brings them to the upper soil surface. Table 3 shows a significant increase in the height of *Senna* from one date to the next.

Table 3: Measurement of the height of Senna spectabilis

Date	Aug. 6, 2016	Oct.5, 2016	Dec. 5, 2016	Feb. 5, 2017
Height	10.72 ± 0.10^{a}	68.67 ± 0.90^{b}	217.93 ± 2.17^{c}	434.90 ± 3.76^{d}

Values are expressed as mean ± standard deviation (n = 3). Values with the same letter on the same line are not significantly different (p > 0.05).

Four months after planting, the height of *Senna spectabilis*, which is 217 cm, doubled after two months (Figure5)

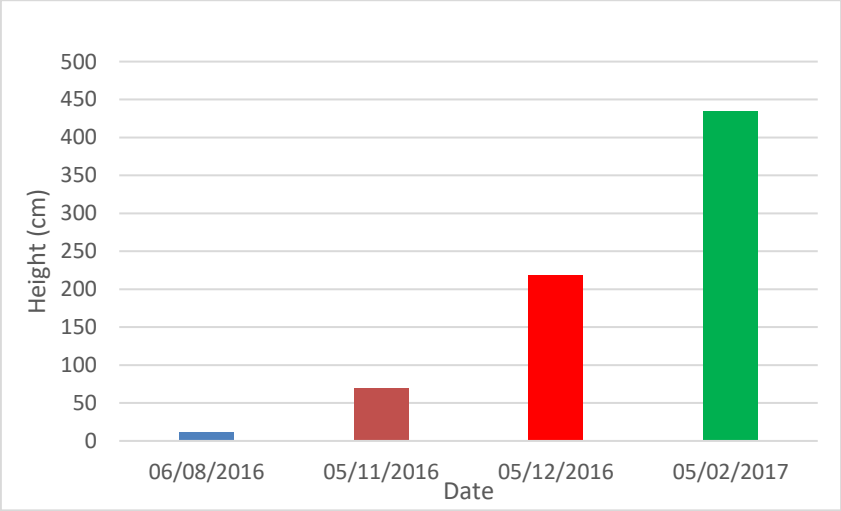


Fig.5: Height of Senna

3.1.4. Obtaining the leaf biomass of Senna

Senna plants spaced 50 cm apart and planted in 6 m rows reached a height of 4.5 m six months after planting. It produced an average annual leaf biomass of 9.25 tons per hectare after the first pruning six months after planting (Table 4). Each shrub produced a biomass of 1.57 kg. In the second year, 2017-2018, the leaf biomass per shrub increased by 0.5 kg, similarly increasing the average annual leaf biomass to 12.06 tons per hectare. After the first pruning of Senna spectabilis, several offshoots were formed, the number of which varied from 5 to 7 offshoots on the shrubs considered in our sample. The amounts of leaf biomass/shrub, and annual leaf biomass also increased significantly from the year 2016 - 2017 to

the year 2017 - 2018 with (t = - 16.09; p = 0.004), (t = - 16.15; p = 0.004) respectively. The leaf biomass of Senna spectabilis is all the higher as its root system is very deep, reaching more than 120 cm in depth. This allows it to draw mineral elements from deeper in the soil and bring them back to the soil surface.

Table 4: Litter production of Senna hedges during the two years of experiment (tons/ha)

Quantity/shrub (kg)		Leaf biomass (t/ha)
2016 – 2017	1.57 ± 0.04	9.25 ± 0.24
2017 – 2018	2.04 ± 0.05	12.06 ± 0.27
t (student) probability	t = -16.09 (p = 0.004)	t = - 16.15 (p = 0.004)

3.1.5. Amount of nutrients supplied by each type of litter

3.1.5.1. Amount of nutrients supplied by Calliandra calothyrsus

On the soils of our experimental plots, no fertilizer was applied to the shrub hedges during planting. The yield of the shrubs in fertilizer and the chemical composition of the foliage determines the number of nutrients supplied to the soil. After the various prunings of the shrubs, large amounts of litter were obtained. This litter released high amounts of nitrogen and other nutrients.

After using the *Calliandra* litter between 2016 and 2017, the amount of fertilizer added to the plot provided the following proportions: 183 kg/ha of nitrogen, 6.44 of phosphorus, 71.79 of potassium, 114.68 of calcium, and 25.57 of magnesium. In the following year, there was an increase of 53.81 kg/ha of nitrogen, 1.83 kg/ha of phosphorus, 21.07 kg/ha of potassium, 33.77 kg/ha of calcium, and 7.39 kg/ha of magnesium (Table 5). The number of nutrients supplied by *Calliandra* varied from 6.44 to 183 kg/ha for phosphorus and nitrogen respectively between 2016 and 2017

Table 5: Average annual amounts of nutrients supplied through Calliandra litter at Mbankomo, 2016- 2018

	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
2016 - 2017	183.00 ± 2.12	6,44 ± 0.06	71.79 ± 0.04	114.68 ± 0.07	25.57 ± 0.55
2017 – 2018	236.81 ± 2.64	8.27 ± 0.03	92.86 ± 0.71	148.45 ± 0.69	32.96 ± 0.51
t- student	t = -177.37	t = - 61.00	t = -51.78	t = 79.71	t = - 24.22
(probability)	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.002)

The amount of all nutrients (nitrogen, phosphorus, potassium, calcium, and magnesium) supplied by *Calliandra* increased significantly from the first year of the experiment (2016-2017) to the second year (2017-2018) (Fig. 6). the dry air consists mainly of noble gases, oxygen (21%) and nitrogen (78%). Thus, *Calliandra* contracts a symbiosis with a bacterium of the genus *Rhyzobium* to form the nodules, thus allowing privileged access to nitrogen from the air.

These bacteria have an enzyme, nitrogenase, which enables them to fix atmospheric nitrogen and transform it into NH4+ that can be directly used by the plant. This enzyme is irreversibly inhibited by oxygen, which is why the bacteria work anaerobically. Once the bacterium is installed in the nodules, the legume will trap the oxygen near the bacterium's nitrogenase to avoid an accumulation or an increase in O2 pressure.

3.1.5.2. Quantities of nutrients supplied by Senna spectabilis

Leguminous trees and shrubs contribute to maintaining soil fertility through nitrogen fixation. The high nitrogen production of *Senna spectabilis*, which does not nodulate, with a value of 259.30 kg/ha is very interesting. When *Senna* litter is used to enrich the soil in our agrosystem, the number of nutrients supplied increases considerably from year to year. For example, in 2016-2017, with a litter of 9.25 tons/ha, the amount of nitrogen is 192.76 kg, phosphorus is 6.76 kg and potassium is 76.82 kg.

In the second year of the experiment, 2017-2018, the increase in nitrogen was 66.54 kg, the increase in phosphorus was 2.38 kg, the increase in potassium was 26.05 kg, the increase in calcium was 41.39 kg and the increase in magnesium was 8.99 kg (Table 6). The number of nutrients supplied by *senna* varied from 6.76 to 192.76 kg/ha for phosphorus and nitrogen, respectively, between 2016 and 2018.

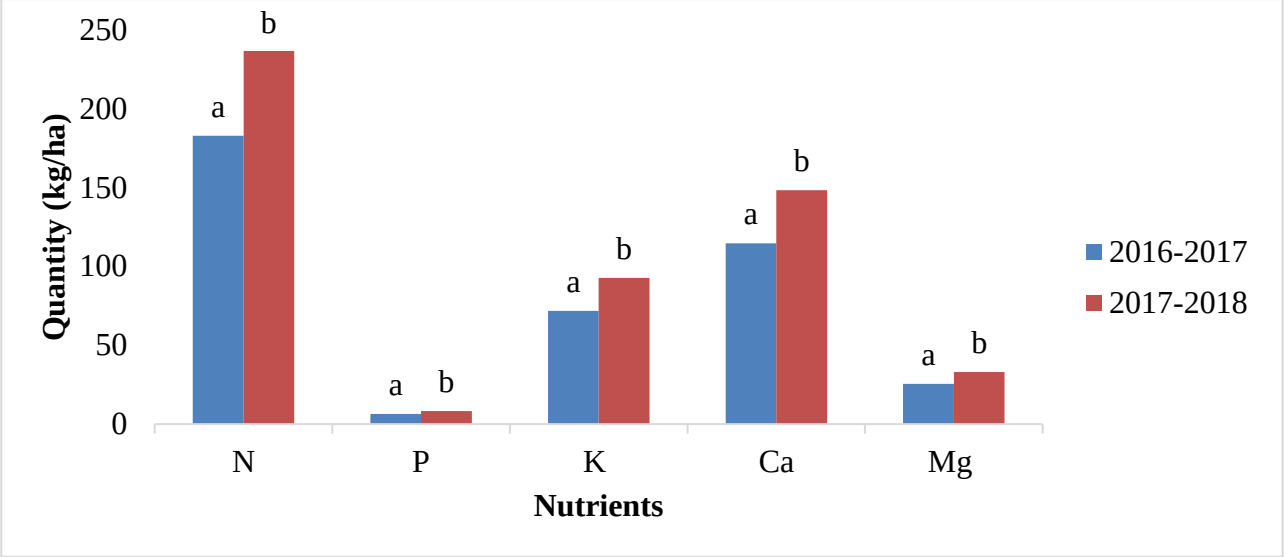


Fig.6: Amount of nutrients provided by Calliandra

Table 6: Average annual amounts of nutrients supplied through Senna litter at Mbankomo, 2016- 2018

	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
2016 - 2017	192.76 ± 0.49	6,76 ± 0.06	76.82 ± 0.48	122.44 ± 0.58	27.01 ± 0.86
2017 – 2018	259.30 ± 1.06	9.14 ± 0.06	102.87 ± 0.64	163.83 ± 0.03	36.00 ± 0.61
t- student	t = -149.15	t = - 37.32	t = -144.50	t = -118.78	t = - 42.76
(probability)	(p = 0.000)	(p = 0.001)	(p = 0.000)	(p = 0.000)	(p = 0.001)

The amount of all nutrients provided by *senna spectabilis* increased significantly between the years 2016 - 2018 (Figure7)

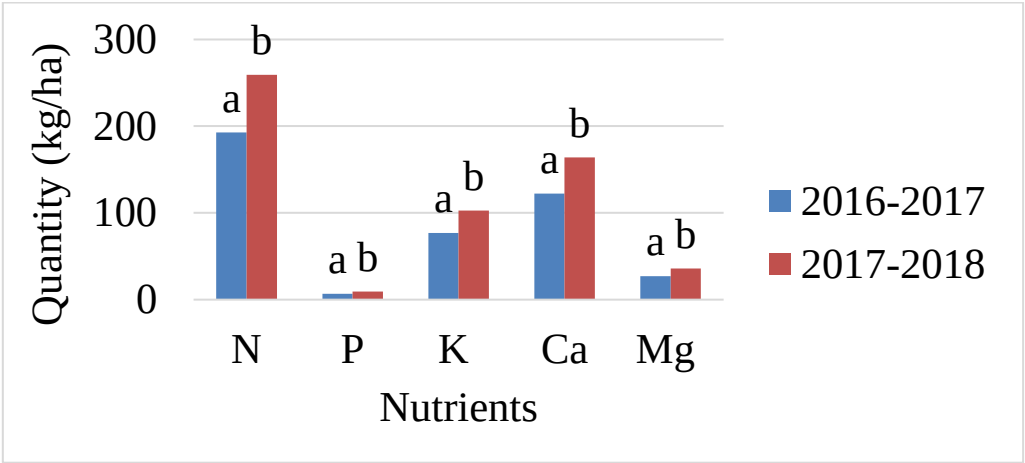


Fig.7: Amount of nutrients provided by Senna

3.1.5.3. Effects of tree legumes on soil fertility

3.1.5.3.1. Effects of tree legumes on soil fertility in the first year

Improving soil fertility is a fundamental value for agriculture. But too little attention has been paid to the conservation of fertile soils. Organic farming depends heavily on good natural soil fertility. Damaged and weakened soils can no longer provide the services expected of them. Soil fertility must be carefully maintained and sustained over a very long period. Soil fertility is both an ecological and biological process. Soil is inhabited by a huge diversity of microorganisms, animals, and plant roots. Fertile soil can provide healthy and

abundant crops for generations with little or no need for chemical fertilizers, plant protection products, and energy.

In healthy soil, the living organisms that inhabit it efficiently transform organic matter, build humus, protect plants against diseases and make the soil lumpy, a very suitable structure for agricultural soils because soil with a lumpy structure is easy to work, absorbs rainwater well and is effectively resistant to slaking and erosion. Our experimental field consists of three separate plots. The first is the control plot in which yams were planted without nutrients and had no association with legumes.

The mineral elements were observed before planting. In the first year in the control plot, at a depth of 0-15 cm, a pH of 4.31 is noted. The quantity of ions is 0.97 C mol (+) kg-1 for calcium, 0.45 C mol (+) kg-1 for magnesium, 0.22 C mol (+) kg-1 for potassium, and 0.013 C mol (+) kg-1 for sodium. The cation exchange capacity is 5.32 C mol (+) kg-1. Organic carbon is 1.42%, and total nitrogen is 0.130%. The C/N ratio is 10.92 (Table 7).

The permanent presence of leguminous shrub species that form microenvironments is considered as indicator of fertility islands. Thus, in the *Calliandra* plot, which is our second experimental plot, still, at a depth of 0-15 cm, a pH of 4.87 was evaluated. The value of the ions is 2.83 C mol (+) kg-1 for calcium, 1.52 C mol (+) kg-1 for magnesium, 0.27 C mol (+) kg-1 for potassium, 0.015 C mol (+) kg-1 for sodium. The cation exchange capacity is 7.22 C mol (+) kg-1.

An improvement in mineral elements can be noted thanks to the legumes introduced into the plot. In addition, the shrub *Senna spectabilis* has an equally high and significant fertilizer potential. Thus, at a depth of 0-15 cm, in the Senna plot representing the third plot, before the planting of yams in the first year, the mineral elements increased, as did the pH, the cation exchange capacity, and the C/N ratio, whose values are respectively 4.97, 8.39 and 10.29. This shows an improvement in soil fertility.

Thus, in the first year of the experiment, all the mineral elements of the soils collected in the *Calliandra* and *Senna* plots are significantly ($p > 0.05$) different compared to the soils of the control plot. However, the C/N ratio of the control plot is very high (10.92) compared to that of the *Calliandra* plot (10.60) and the *Senna* plot (10.29)

Table 7: Impact of legumes on soil fertility

Year	Plot	Depth (cm)	PH eau	Ca	Mg	K	Na	CEC	C org	N total	C/N
Cmol (+) /kg											
Year 1	control	0–15	4.31 ± 0.01^{a}	0.97 ± 0.01^{a}	0.46 ± 0.01^{a}	0.23 ± 0.02^{a}	0.01 ± 0.00^{a}	5.36 ± 0.04^{a}	1.42 ± 0.01^{a}	0.13 ± 0.00^{a}	10.92 ± 0.01^{c}
	Calliandra	0-15	4.90 ± 0.04^{b}	2.86 ± 0.04^{b}	1.55 ± 0.04^{b}	0.28 ± 0.02^{ab}	0.02 ± 0.00^{b}	7.27 ± 0.07^{b}	1.87 ± 0.02^{b}	0.16 ± 0.03^{ab}	10.60 ± 0.08^{b}
	Senna	0-15	4.97 ± 0.02^{b}	3.02 ± 0.04^{c}	1.69 ± 0.05^{c}	0.37 ± 0.07^{b}	0.02 ± 0.00^{b}	8.39 ± 0.05^{c}	1.85 ± 0.04^{b}	0.18 ± 0.00^{b}	10.29 ± 0.16^{a}

Values are expressed as mean ± standard deviation (n = 3). Values with the same letter in the same column in the same year are not significantly different ($p > 0.05$)

3.1.5.3.2. Effect of tree legumes on soil fertility in the second year

The introduction of tree legumes in the experimental plot showed a significant increase in soil mineral elements in the second season. When observing the evolution of mineral matter in the control plot after harvest, it is important to note that the pH decreased by 1. In this context, acidification of the control plot is noted. The other minerals also underwent a reduction in their proportions: 0.2 C mol (+) kg-1 for calcium, 0.1 C mol (+) kg-1 for magnesium, 0.1 C mol (+) kg-1 for potassium, 0.03 C mol (+) kg-1 for sodium, 2 C mol (+) kg-1 for the cation exchange capacity. Only the C/N ratio increased by 0.28.

In the *Calliandra* plot, a significant increase in the mineral matter was observed. This increase varies between 0.015 C mol (+) kg-1 and 9.22 C mol (+) kg-1 (Table 8). The regular addition of shrub pruning products on the reclaimed plots improves the soil pH. The pH of the soil increased from 3.31 in the control plot to 5.87 and 6.02 in the plots enriched with tree legumes. Furthermore, the cation exchange capacity increased by 6.53 C mol (+) /kg and the C/N ratio was around 10 in the *Calliandra* and *Senna* plots.

Thus, tree legumes affect soil properties. The soil during our experiment

Our experiment showed a clear improvement in the mineral content (Ca, Mg, K, Na) in the plots enriched with woody legumes compared to the control plot. The pH also increased from one year to the next in the leguminous plots and decreased in the control plot.

It can therefore be said that in the second year of the experiment, all the mineral elements measured were significantly ($p > 0.05$) higher in the soils collected from the *Calliandra* and *Senna* plots compared to the soils collected from the control plot. However, there is a significant difference in the soils from the *Calliandra* plot and the *Senna* plot except for the total N and C/N ratio where there is no significant difference between these two legume-enriched plots. The litter brought to the soil after pruning the shrubs is mineralized by soil microorganisms (bacteria, fungi, actinomycetes), thus providing the crops with the mineral elements they need for the hydromineral nutrition of the crops grown.

Table 8:Improvement of mineral elements by tree legumes (Cmol (+)/kg

Year	Plot	Depth (cm)	PH eau	Ca	Mg	K	Na	CEC	C org	N total	C/N
Cmol (+) /kg											
Year 2	control	0–15	3.31 ±	0.77 ±	0.35 ±	0.12 ±	0.01 ±	3.32 ±	1.20 ±	0.37±	11.69 ±
			0.01^{a}	0.01^{a}	0.01^{a}	0.01^{a}	0.00^{a}	0.01^{a}	0.02^{a}	0.46^{a}	0.42^{b}
	Calliandra	0-15	5.88 ±	2.24 ±	1.33 ±	0.21 ±	0.01 ±	9.93 ±	1.98 ±	0.19 ±	10.20 ±
			0.01^{b}	0.01^{b}	0.02^{b}	0.01^{b}	0.00^{a}	0.01^{b}	0.01^{b}	0.00^{a}	0.11^{a}
	Senna	0-15	6.04 ±	2.54 ±	1.47 ±	0.31 ±	0.02 ±	9.87 ±	2.03 ±	0.20 ±	10.15 ±
			0.03^{c}	0.03^{c}	0.03^{c}	0.03^{c}	0.00^{b}	0.03^{c}	0.03^{c}	0.00^{a}	0.10^{a}

Values are expressed as mean ± standard deviation (n = 3). Values with the same letter in the same column in the same year are not significantly different ($p > 0.05$)

3.1.5.3.3. Effects of tree legumes on yam growth.

3.1.5.3.3.1. Growth of the aerial system of yam in the different plots

During our experiment in the first year, on the 10 yam plants studied in the 190 planted on the control plot, three phases were obtained: the accelerated phase, the linear phase, and the slowing down phase for 63 days and the following results were obtained: in the accelerated phase, 4.9 m in length was obtained for 21 days. In the linear phase, the length achieved was 20.1 m in 33 days while in the slow phase, the growth was zero. The following year (2017-2018), differential growth of -1.1 m at the accelerated phase and -1.7 m at the linear phase was achieved in 70 days with a lift occurring after 37 days. This situation reflects degradation of soil fertility in Mbankomo (Table 9)

Table 9: Growth of all the aerial axes of Dioscorea cayenensis on the control plot

year	Number of plants	Survey (days)	Accelerated phase		Linear phase		Slow phase	Total duration (days)
2016-2017	10	35 ± 2 37 ± 2,11	D (j)	LR(m)	D (j)	LR (m)	D (j)	
			21 ±3	4,9 ± 1,2	33 ± 7	20,1 ±3,9	9 ± 6	63 ± 7
2017-2018	10		23 ± 3,2	3,8 ± 0,92	35 ± 7,42	18,4 ± 3,5	12 ± 8	70 ± 8

The *Calliandra* plot on our farm during the study period shows that of the 10 yam plants studied out of 190 planted, emergence occurred after 33 days in the first year, with the growth of 5.2 m in the accelerated phase and 25.1 m in the

linear phase in 58 days. In contrast, from 2017 to 2018, the following lengths were measured: 6.1 m in the accelerated phase and 26.5 m in the linear phase, i.e. an overall growth of 32.6 m during 53 days (Table 10). In the *Calliandra* plot, the vegetative cycle varies from 195 to 180 days, characterized by an emergence lasting one month

Table 10: Growth of all the aerial axes of Dioscorea cayenensis on the plot with Calliandra

year	Number of plants	Survey (days)	Accelerated phase		Linear phase		Slow phase	Total duration (days)
2016-2017	10	33 ± 1,8 30 ± 1,79	D (j)	LR(m)	D (j)	LR (m)	D (j)	
			20 ± 2,85	5,2 ± 1,27	30 ± 6,36	25,1 ± 4,87	8 ± 5,33	58 ± 5
2017-2018	10		18 ± 2,57	6,1 ± 1,49	28 ± 5,93	26,5 ± 5,14	7 ± 4,26	53 ± 3

In the *Senna* plot, of the ten yam plants studied, emergence occurred one month after planting in the first year of the experiment. The accelerated phase lasted 20 days, the linear phase 28 days, and the slow phase 7 days. The lengths reached during these different phases were 5.6 m for the accelerated phase, 25.8 m for the linear phase. In 2017-2018, the lift occurred after 28 days with the accelerated phase lasting two weeks, and the linear phase 25 days. The total duration of days was 55 days in the first year of the experiment and 45 days in the second year (Table 11)

Table 11: Growth of all the aerial axes of Dioscorea cayenensis on the plot with Senna

year	Number of plants	Survey (days)	Accelerated phase		Linear phase		Slow phase	Total duration (days)
2016-2017	10	32 ± 1,74 28 ± 1,67	D (j)	LR(m)	D (j)	LR (m)	D (j)	
			20 ± 2,85	5,6 ± 1,36	28 ± 5,93	25,8 ± 5,09	7± 4,66	55 ± 4
2017-2018	10		15 ± 2,14	7,05 ± 1,74	25 ± 5,29	29,4 ± 5,70	5 ± 3,32	45 ± 2

The observation of emergence frequencies shows a general tendency for emergence to be faster on a plot with legumes than on a plot without fertilizing shrubs.

3.1.5.3.3.2. Parameters for the end of yam growth on the different plots

From the general observation of yam growth, it can be noted that the aerial axis in the control plot between 2016 and 2017 reached a length of 27.8 m while the main axis had 5.6 m and produced 636 leaves during its vegetative period. From planting to drying out, it took about 214 days. In the second year, the observation period lasted 234 days, i.e. from planting to drying out, and the following lengths were measured: length of the aerial axes 24.7 m, length of the main axis 4.01 m with a total number of leaves of 512 (Table 12).

In the *Calliandra* plot, it is observed that the aerial axis increased by 35.8 m during the 2016-2017 crop year. The main axis reached an average length of 7.6 m and provided 797 leaves during its vegetative period. During the same period, the growth stoppage to desiccation was found to be 104 days. From senescence to desiccation was 30 days. The time from planting to desiccation is 195 days.

During the second year of the experiment, a differential evolution of some of the end-of-growth parameters of *Dioscorea cayenensis* was noted. The length of the main axis increased by 1.2 m, the length of the aerial axes by 2.7 m, and the number of leaves increased by 109 compared to the first season. Growth arrest to desiccation lasts about 97 days while senescence before desiccation is 28 days. Finally, the vegetative cycle of *Dioscorea cayenensis* of 180 days (Table 13)

Table 12: End of growth parameters of Dioscorea cayenensis on the control plot

Year	End of growth parameter				No growth		Vegetative cycle
	Length of the air axis (m)	Length of the main axis (m)	Total number of sheets	Number of leaves of the main axis	D (d) of stopped of growth at drying out	Senescence before drying out (J)	Duration planting to drying out (J)
2016-2017	27,8 ± 4,3	5,6 ± 0,5	636 ± 131	96 ± 11	115 ± 11	38 ± 15	214 ± 9
2017-2018	24,7 ± 3,82	4,01 ± 0,35	512 ± 105	81 ± 9	127 ± 12	41 ± 16	234 ± 10

Table 13: End of growth parameters of Dioscorea cayenensis on the Calliandra plot

Year	End of growth parameter				No growth		Vegetative cycle
	Length of the air axis (m)	Length of the main axis (m)	Total number of sheets		Length of the air axis (m)	Length of the main axis (m)	Total number of sheets
2016-2017	35,8 ± 5,83	7,6 ± 0,67	797 ± 164	105 ± 12	104 ± 10	30 ± 12	195 ± 8
2017-2018	38,5 ± 5,95	8,8 ± 0,78	906 ± 186	148 ± 17	97 ± 9	28 ± 11	180 ± 7

During the 2016-2017 season, it was observed at the end of the growth of *Dioscorea cayenensis* that the average length of the aerial axes was 36.05 m while the main axis was 7.9 m long. The average total number of leaves was 806 per plant on the *Senna* enriched plot. The duration from growth arrest to desiccation was noted to be 98 days. During this time, senescence before desiccation is observed, which is 28 days. It can therefore be concluded that the vegetative cycle of this crop is approximately 181 days (Table 14).

In the second season of 2017-2018, a differential increase in growth was observed in the length of the aerial axes, which is 4.05 m. This growth is also reflected in the main axis, which is 1.6 m. The average number of leaves increases from 806 to 980 leaves, with a reduction in the cessation of growth at drying out, which is one day. In terms of senescence before drying out, the duration has also decreased by one day. There was also a regression of the vegetative cycle by eleven days. The use of *Senna* in the experimental plot has shown its effectiveness in enriching the plot and in the evolution of our crop, which has increased the growth and reduced the vegetative cycle of *Dioscorea cayenensis*.

Table 14: End of growth parameters of Dioscorea cayenensis on the Senna plot

Year	End of growth parameter				No growth		Vegetative cycle
	Length of the air axis (m)	Length of the main axis (m)	Total number of sheets		Length of the air axis (m)	Length of the main axis (m)	Total number of sheets
2016-2017	36,05 ± 5,87	7,9 ± 0,69	806 ± 165,85	110 ± 12,57	98 ± 9,42	28 ± 11,2	181 ± 7,47
2017-2018	40,1 ± 6,19	9,5 ± 0,84	980 ± 201,19	158 ± 18,19	97 ± 9	27 ± 10,60	170 ± 6,61

Using the two legumes *Calliandra calothyrsus* and *Senna spectabilis* as soil fertilizers in our experimental plot for the cultivation of our specimen *Dioscorea cayenensis*, a difference in the growth of this yam variety was noted. The plot enriched with *Senna* appears to have the highest productivity with differences of 0.25 m in the aerial axes, 0.3 m in the main axis, 9 in the total number of leaves, and 5 in the number of leaves on the main axis.

A reduction of 6 days from growth arrest to desiccation is observed when using the *Senna* species. 2 days of reduction of senescence before desiccation and finally a reduction of the vegetative cycle of 14 days when using the latter species mentioned above in the first crop year. In the second crop year 2017-2018, there is no significant difference in the evolution of the late growth parameters. On the other hand, it is observed that the parameters of the cessation of growth at drying up are similar and remain limited to 97 days. (Table 15).

The litter provided by the tree legumes contributes to feeding the soil microorganisms. Living soil rich in microbial diversity allows crops to withstand various abiotic and biotic stresses. Thus, the production of molecules such as salicylic acid or exopolysaccharides by soil microorganisms allows plants to fight against water deficit and pathogens. This agricultural practice aims to provide shelter and food for microorganisms and more generally for soil life. This creates a favorable environment for maintaining a good soil structure with good organic matter levels and therefore better plant growth.

Another stress adaptation aid provided by rhizosphere microorganisms is the production of the enzyme AAC-deaminase. This enzyme limits the production of ethylene in plants and limits the effect of various stresses. AAC-deaminase is an enzyme that degrades the AAC molecule, which is a precursor of ethylene in the plant. Ethylene is a plant hormone that is naturally produced in plants, but when it is produced in too large quantities, often in response to various stresses, it can be an accelerator of early senescence and death of the plant

Table 15: Comparison of the parameters of end of growth of Dioscorea cayenensis enriched with Calliandra and Senna

Year		End of growth parameter				No growth		Vegetative cycle
		Length of the air axis (m)	Length of the main axis (m)	Total number of sheets		Length of the air axis (m)	Length of the main axis (m)	Total number of sheets
2016-2017	*Calliandra*	35,8 ± 5,83	7,6 ± 0,67	797 ± 164	105 ± 12	104 ± 10	30 ± 12	195 ± 8
	Senna	36,05 ± 5,87	7,9 ± 0,69	806 ± 165,85	110 ± 12,57	98 ± 9,42	28 ± 11,2	181 ± 7,47
2017-2018	*Calliandra*	38,5 ± 5,95	8,8 ± 0,78	906 ± 186	148 ± 17	97 ± 9	28 ± 11	180 ± 7
	Senna	40,1 ± 6,19	9,5 ± 0,84	980 ± 201,19	158 ± 18,19	97 ± 9	27 ± 10,60	170 ± 6,61

3.1.5.3.3.3. Crop production as a function of legume litter quality

Legumes

The increase in livestock and crop production in developing countries is a crucial issue not only for the people of these countries but also for their governments. The government of Cameroon intended to double its agricultural production and export volume by 2015. However, how food crops are grown influences their yield. This model is still extensive. When agricultural production is done without fertilizers, as in the case of the control plot where there are no legumes, production is 24 tons/ha in the first year. On the other hand, using Senna as a fertilizer shrub, production is 60.9 tons/ha. With *Calliandra*, production is 52.6 tons/ha in the first year of the experiment (Figure 8). By using tree legumes in our experiment, the crop production doubles compared to the control. The multiplication factor is 2.5 for *Senna spectabilis* and 2.2 for *Calliandra calothyrsus* in year 1.

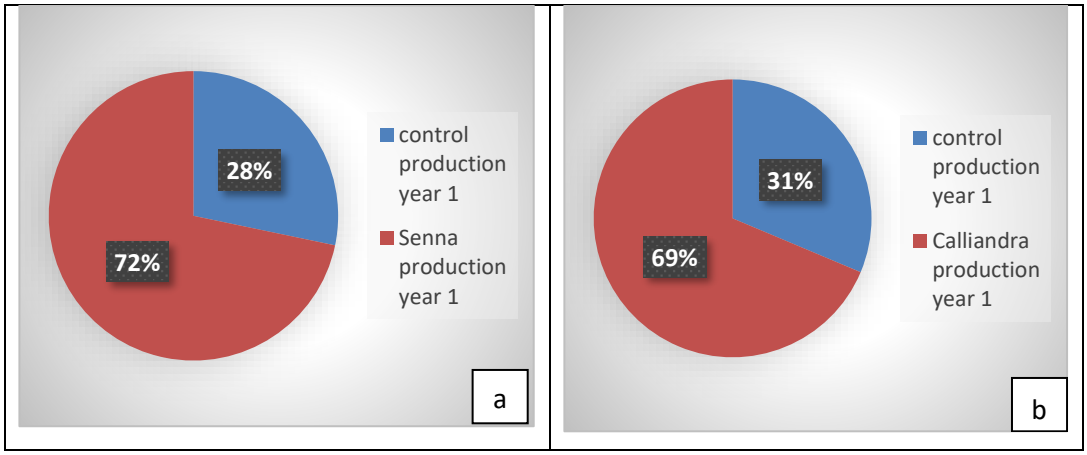


Fig.8: Agricultural production in the first year of study.

(a) Agricultural production according to *Senna* (b) Agricultural production according to *Calliandra*

Agricultural production has an economic, social, and even political impact. The stability of food production is precarious because of the progressive decline in soil fertility in tropical areas, hence the itinerancy observed in most Cameroonian peasantry in general and in Mbankomo in particular. This is in search of new cultivable land. From one year to the next, in our experiment, agricultural production decreased by 5.9 tons/ha in the control plot in the second year of our experiment. However, at the same time, i.e. in year 2, crop production increased steadily in the plots enriched with tree legumes. *Senna spectabilis*, gave a 4-fold increase in crop production compared to the control plot and *Calliandra calothyrsus* gave a 3.5-fold increase (Figure9).

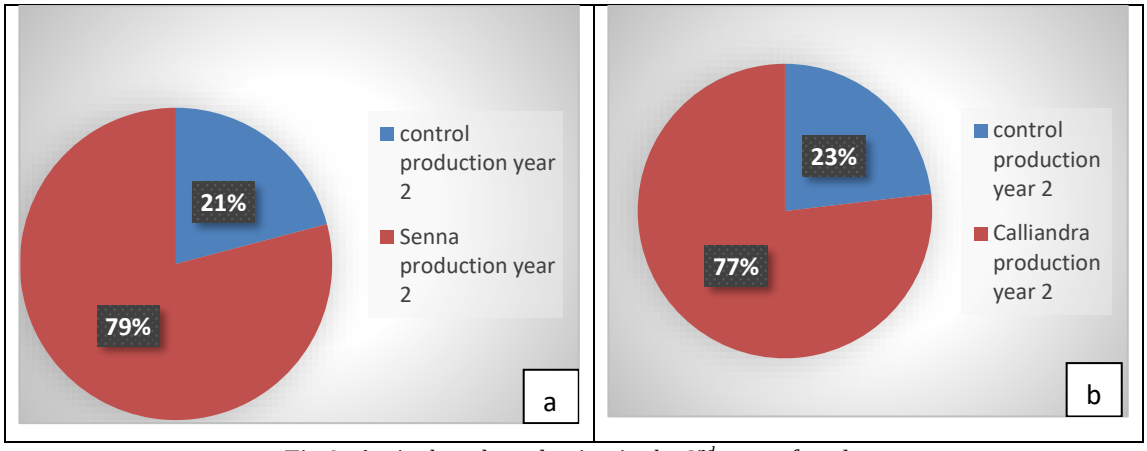


Fig.9: Agricultural production in the 2nd year of study.

(a) Agricultural production according to *Senna* (b) Agricultural production according to *Calliandra*

Evaluation of tree legume species for tree rows indicates that *Calliandra calothyrsus Meisn* and *Senna spectabilis HS* are well suited for our study area. The use of tree legumes, notably *Calliandra calothyrsus* and *Senna spectabilis*, is effective in restoring soils depleted by over-exploitation or erosion. Thanks to the cultivation of tree legumes, this cultivation technique has succeeded in increasing and stabilizing the productivity of degraded land to a significant extent. In the context of improving soil fertility, these species have also led to a significant reduction in runoff and soil erosion. An increase in yam tuber yields was then observed in both plots enriched with legumes. However, *Senna* is much more productive than *Calliandra* in terms of crop production (Figure10).

Nitrogen is a constituent element of chlorophyll, whose gross formula is C55H72O5N4Mg. Chlorophyll is a pigment that is involved in photosynthesis. The more intense the photosynthesis, the greater the production. Plots enriched with tree legumes have seen an increase in the amount of nitrogen incorporated into the soil. This contributed to a consequent increase in yam yield in plots enriched with leguminous shrubs.

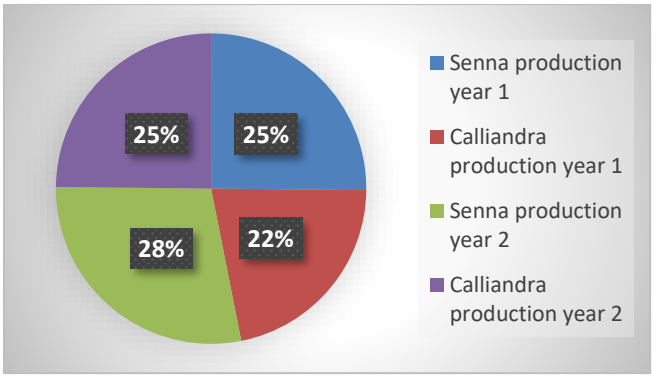


Fig.10: Comparison of total agricultural production by type of tree legumes

3.2. Discussion

The use of tree legumes in yellow yam production was intended to optimize the yield of this crop while improving soil fertility. However, this study had some constraints and limitations. The constraints are related to the time allocated to the study due to academic requirements. This made it possible to conduct the research within a short time frame and to obtain appreciable results. In addition, the scarcity of seeds did not allow for the establishment of a large-scale experimental farm that would allow for a better appreciation of the fluctuations in yam growth dynamics. Nevertheless, this constraint has made it possible to methodically monitor the vegetative cycle of this crop while collecting the data necessary for the development of this work. On the other hand, agroforestry techniques were the subject of some research in the 1980s and 1990s. This period does not offer recent results to enrich and compare our results with theirs covering the same period. However, this work has made it possible to update the knowledge related to this cropping technique and to add value in terms of improving yam yields and conserving soil biodiversity and fertility.

Soil fertility management is essential for improving and maintaining agronomic and biomass productivity. Nutrients removed from crops (i.e., cereals, roots and tubers, canes, fruits, and wood) must be replaced to ensure that the soil's innate nutrient capital is not eroded. Intensively managed agroecosystems are only sustainable in the long term if the production of all components is balanced by appropriate inputs, the number of nutrients needed to achieve the desired yield can be achieved through the use of legumes. The growth of tree legumes is not homogeneous in the experimental farms of Mbankomo locality because the growth of these legumes was a function of the soil, the volume of rainfall, and also the state of sunshine. This result shows a difference from the work done by [27] who observed a homogeneous growth using biological fertilizers. Furthermore, for the germination and growth of *Calliandra* and Senna, no fertilizer was applied to facilitate or accelerate their growth. This work is different from that of [28] who used rhizobial and mycorrhizal biofertilizers to facilitate the germination and growth of *Pericopsis elata*. The use of tree legumes no longer requires additional expenditure for the purchase of any fertilizer to boost their growth, this contributes to making economic gains.

An increase in dry matter yields and the chemical composition of the foliage was observed, which determine the number of nutrients incorporated into the soil. Nitrogen addition increased after each year. *Calliandra* and Senna can be considered better nutrient providers. This result is not similar to the one obtained by [29] where *Calliandra* provided low amounts of dry matter, i.e., 3.37 tons/ha and Senna 4.04 tons/ha. This different result is explained by the fact that the environment where their experiments were carried out was in a semi-arid zone with poor soil (Organic carbon = 8 g.kg-1, Total nitrogen = 0.75 g.kg-1, Bray 11 phosphorus = 8 mg.kg-1 PH water = 5.52, Exchangeable calcium = 13.0 m mol .kg-1, magnesium = 8.0 mmol.kg-1 and potassium = 4.9 m mol .kg-1). Despite these different results, legumes can be adapted in almost all ecosystems and give satisfactory results because the regular addition of legume litter even on nutrient-poor soil improves its fertilizing potential.

The dry matter yield of the shrubs and the chemical composition of the foliage determine the number of nutrients added to the soil. The addition of nitrogen varied from 183 Kg/ha to 260 Kg/ha. The best nitrogen provider was Senna spectabilis. These results are different from those of [29]. This difference can be explained by the fact that the soils were infertile, acidic, and nutrient-poor, as there is a relationship between the soils and the adaptation of the trees and shrubs on these soils. On the other hand, our results are similar to those of [30], [31], [32] as they were obtained under the same environmental conditions in sub-humid regions.

Shrub legumes recycle soil nutrients by supplying the soil with organic matter through litter, which varies from 8.46 tons/ha to 12.6 tons/ha. These results are different from those of [33]. They showed that a forest fallow was more effective than a leguminous or herbaceous cover in recycling nutrients and enriching the soil with organic matter. Traditional farmers in Africa in general and in Cameroon in particular kept some tree species on their land that would help the soil regenerate during the fallow. These include *Alchornea cordifolia*, *Acioa barterii*, *Anthonata macrophylla*, *Harungana*

madagascariensis, *Dialtum guineense*, *Crestis ferruginea*, and *Nuclea latifolia* on acidic soils [34], [35] and *Gliricidia sepium* on alkaline soils [36], [37]. However, efforts should be made to increase the efficiency of the fallow with tree species such as tree legumes that can accelerate the nutrient accumulation process and enrich and preserve soil organic matter. *Calliandra* and Senna accumulate more calcium and magnesium compared to the control plot.

Tree legumes release high amounts of nitrogen at six-meter row spacings and 50-cm plant spacings. *Calliandra* and Senna released 236.81 Kg/ha and 260 Kg/ha of nitrogen respectively. These results differ from those obtained by [31], [32] in that leguminous species and associated farming techniques showed that legumes such as *L. leucocephala* and *G. sepium*, planted in hedgerows for alley cropping purposes, only released high amounts of nitrogen if the shrub rows were very narrow. Separated by rows 4 m wide and after five annual prunings, *Leucaena* and *Gliricidia* have grown on degraded alfisol producing about 210 and 110 kg of nitrogen per hectare per year, respectively. [38] showed that nitrogen production could be further increased by pruning the trees to higher levels and by less frequent pruning of the parts that produced a large amount of biomass. The higher the amount of litter, the higher the number of nutrients added to the soil. However, *Senna spectabilis*, which does not nodulate, produced more nutrients than *Calliandra*. The high nitrogen production of 192.76 Kg/ha in 2016-2017 and 260 Kg/ha is very interesting. It seems that the root system of tree legumes recycles nutrients released from weathering rocks in the B/C or C horizons [39]. Under the growing conditions in our study area, the average annual amounts of nutrients added to the soil through the leaves of the legumes increased. This plant material restored the soil with large amounts of nitrogen, phosphorus, and potassium. Thanks to tree legumes, the use of synthetic chemical fertilizers will be reduced and farmers will no longer be dependent on synthetic fertilizers which are more expensive, destroy the soil and deteriorate the quality of the crops.

If nutrient additions were made to the plots, it should be noted that yam production was positive on our farm because yam cultivation exports quantities of nitrogen and potassium according to [40]: This shows that the harvest of one ton of fresh yam tubers exports 3.5 kg of nitrogen, 0.39 kg of phosphorus and 4.2 kg of potassium. The increase in the litter is explained by the fact that after pruning, several shoots are formed and therefore the leaf biomass is increased. This result is different from the work of [41]. According to the results of their trials in Machakos district, dry matter yields for Leucaena were about 1.5 kg/tree per season with an average row spacing of 0.62 m and a row spacing of 3.5 m. The production per hectare of leaves per season was thus approximately 6,900 kg, distributed over a cultivated area of 6,600 m2 (one-third of the total area being occupied by hedges), this quantity allowed an application rate of approximately 1 kg/m2. Thus, tree legumes help to compensate for nutrient losses due to crop exports and conserve soil organic matter.

Planting tree legumes in agrosystems help to maintain soil fertility through nitrogen fixation and nutrient recycling, preserves a reasonable amount of organic matter in the soil, allow the provision of mulch to protect the soil and control water infiltration, runoff and erosion, provision fuelwood, provision of stakes and woody materials for commercial use, provision of browse or fodder, with fallow limited to narrow corridors, thus saving land and allowing either continuous cropping or cropping interspersed with very short fallow periods. This result is different from that of [18]. In their work, they used the litter of species such as *Annona senegalensis*, *Parkia Biglobosa*, and *Terminalia macroptera* whose leaves were collected from under these trees and cut into fine particles before burial in the soil. The use of off-farm fertilizers includes transport and spreading costs, which affect production costs. On the other hand, the use of tree legumes contributes to the long-term practice of agriculture. One can farm the same plot for a very long time and have good results. These results are different from those of [42] who farmed for 20 years. This experiment contributes to permanent cultivation without fallow and during the same time the forest massif, which was already more than 60% degraded, is progressively reconstituted.

Yam yields increase strongly with the level of nitrogen and organic matter in the soil. The plot that enriches the soil with organic matter and nitrogen produces the highest yam yield. Indeed, the essential characteristic of legumes is their ability to symbiotically fix nitrogen through Rhizobium bacteria, enriching the soil with nitrogen. This result is similar to those obtained by [39], [43], [44] who confirmed the importance of the organic matter and nitrogen produced by leguminous trees and shrubs in improving soil fertility and agricultural yields.

However, it differs from those of [45] who showed that the fertility test of yam plots showed the superiority in yield of *A. mangium* (8.83 t/ha) and *A. auriculiformis* (5.22 t/ha) fallows over the natural *Chromolaena odorata* fallow which gave the lowest yields (2.67 t/ha). Shrub legumes increased the yields of the traditional *Dioscorea cayennensis* variety. Yield differences varied between treatments. Total yam production in our experimental plots

during the study period ranged from 18.1 tons per hectare to 70 tons per hectare. These results are different from those obtained by [46], [47]. Their average annual production of the yam *Dioscorea cayennensis rotundata* was 13062.5kg/cultivator or an overall average yield of 5160.5kg/ha. The difference in yam production in our study area and some West African countries is justified by the fact that our yam production technique was associated with the use of tree legumes which are plants with high soil enrichment potential. [49] obtained a yield of 8 to 15.5 tons of yam with mineral fertilization of 280 kg/ha of NPK (15 15 15) and 580 kg/ha of NPK (15 15 15). The observed difference in yield between the fertilization levels is very small to conclude from an optimal fertilizer dose. Our yields are well above the estimated world yields of 9.1 tons per hectare in 2003 (www.gret.org.). Yam production has exploded on the African continent since the 1980s (http://spore.cta.int).

Thus, our cultivation practice can be considered as a means of effectively combating the poor productivity of the soils in the South Cameroonian plateau because by using tree legumes, production is multiplied by 3 or 4. This result is similar to that of [36] who used *Gliricidia sepium* litter for yam fertilization. Furthermore, the seedling variety used in our experiment was the traditional variety and not the improved variety. The production would have had a significant margin of improvement not only with this cultivation practice but also by using the improved varieties. For example, [48] estimated that the use of improved varieties under rational farming conditions could result in annual production of about 140 t/ha of yams. Increasing crop yields is a challenge for agriculture in the 21st century as the area available for cultivation is shrinking and becoming scarce while the population is expanding. Tree legumes are an alternative to synthetic fertilizers that further impoverish farmers and degrade the quality of their environment.

IV. CONCLUSION

The need to establish agricultural practices and land management methods capable of enhancing and maintaining soil fertility in the long term in the southern Cameroonian plateau is a major challenge. The objective of this study was to show the contribution of tree legumes to the production dynamics of yellow yam in the southern plateau of Cameroon. Soil fertilization using the litter of shrub legumes increased the yields of the local variety of *Dioscorea cayenensis* without changing its taste. This technique can be seen as a means of combating poor soil productivity in equatorial regions.

The difference in yields observed between the treatment levels is sufficiently large to conclude that the introduction of tree legumes into agrosystems is important for boosting agricultural production and improving the living standards of rural populations. Moreover, these results do not only concern the increase in yields, the litter of tree legumes also feeds the soil microorganisms for good mineralization and an improvement of soil fertility for sustainable and environmentally friendly agriculture.

Moreover, these results only cover two years and three different sites, namely Eloumden I, Eloumden II, and Ekoko. For better precision of the effects of each of the tree legumes, the research could be carried out in various agroecological zones of Cameroon with different combinations of tree legumes.

REFERENCES

[1] N. Njopkou. Positionnement géographique des activités économiques du Cameroun. Atlas National de développement physique du Cameroun, 71 p. 2014.

[2] N. Eoné. Evaluation des paramètres agrohydroclimatiques pour l'amélioration des rendements agricoles au Cameroun.Thèse de Doctorat. Université de Yaoundé I.116 P. 2019.

[3] H. Robain. Présentation des sols du Sud-Cameroun, organisation et mise en place à l'échelle de l'unité du paysage. In: Delneuf Michèle (ed), Essomba, J.M.(ed.), Froment, A. (ed.). Paléo-anthropologie en Afrique centrale : un bilan de l'archéologie au Cameroun. Paris. LeHarmattan, P. 133-142. (Etudes africaines). Un bilan de l'archéologie au Cameroun, Yaoundé (CMR), 1994/11.ISSN2-7384-7405-5. 1998.

[4] A. A. Adeniji,M. Lawa. Effects of replacing groundnut cake with Moringa oleifera leaf meal in the diets of grower rabbits. *Int. J. Mol. Vet Res*.,2(3): 8-13. https://doi.org/105376/ijmvr. 2012.02.0003.2012.

[5] D. Cornet. Influence des premiers stades de croissance sur la variabilité du rendement parcellaire de deux espèces d'igname (*Dioscorea* spp.) cultivées en Afrique de l'Ouest. Thèse de Doctorat unique ès Sciences agronomiques et écologiques, Institut des Sciences et Industries du Vivant et de l'Environnement (AgroParisTech), 174 p. [Google Scholar]. 2015.

[6] N. Sanginga. and A. Mbabu. Racines et tubercules (manioc, igname, pomme de terre et patate douce). Documents de référence. Banque africaine de développement, 35 p. 2015.

[7] N. Alkama, N.E.Noureddine, A. Haddadj, H. Sadji, S. Issad, S. Amrani. La pratique de l'inoculation en agriculture et en foresterie : une biotechnologie à notre portée. Communication orale présentée au 2e congrès de Biotechnologie. Tunisie. 2002.

[8] H. Jeder, M. Akrimi, M. Zouaghi, P. Delayudie, M. Gillis, M.S. Zaofouri.Diversité des Rhizobia associés aux légumineuses pastorales des régions arides de la Tunisie. In : Drevon, J.J. et Sifi, B. (eds). Fixation symbiotique de

l'azote et développement durable dans le bassin méditerranéen. INRA Paris. Les colloques N° 100: 163-172. 2003.

[9] J. Wéthé. Use of macrophyteses for domestic wastewaters treatment in developing countries. 2e journée scientifique en Sciences et Techniques de l'Environnement. Université Paris 12. ENPC, CEREVC, Paris. Mai, 2001.

[10] J. Wéthé. Urbanisation et protection de la ressource en eau : une approche par les Systèmes d'Informations Géographiques (SIG) appliqués à Yaoundé-Cameroun. Mémoire de fin d'études du 3e cycle, en vue de l'obtention du Diplôme d'Etudes Professionnelles Approfondies (DEPA), option : Gestion de l'Environnement. Université Senghor d'Alexandrie (Egypte). Avril 1999.

[11] M.C. Palada, B.T. Kang, S.L. Claassen. Effect of alley cropping with *Leucaena leucocephala* and fertilizer application on yield of vegetable crops. Agroforestry Systems 19: 139-147. https://doi.org/10.1007/BF00138504.1992.

[12] P. Letourmy. Experimentation Agronomique Planifiée (support de cours). 50p. 1999.

[13] D.S. Ngambeki,G.F. Wilson. Economic and on -farm evaluation of alley cropping with *Leucaena leucocephala* 1980-1983: Progrss report. Institut International d'Agriculture Tropicale, Ibadan, Nigéria, 45p.1984.

[14] F. Adifon, I. Yabi, I. Balogoun, J. Dossou, A. Saïdou. Caractérisation socio-économique des systèmes de culture à base d'igname dans trois zones agro-écologiques pour une gestion durable des terres au Bénin. *European Scientific Journal* 15(12) : 211–232. DOI : 10.1944/esj. 2019.v15n12p211. [Google Scholar] 2019.

[15] A.W. WAITT. Review of yam research in Nigeria 1920-1961. Place: Published, 1-18.1961

[16] A. S.Lithourgidis, C.A. Dordas, C.A. Damalas, and D.N. Vlachostergios.Annual intercrops: an alternative pathway for sustainable agriculture. 16 p.2011.

[17] M. R. Tshibingu, B.T. Mutamba, D.M. Kabongo, L.B. Longanza, T.M. Munyuli.Improvement of Biodegradation of lignin in a compost environment: A review. *Bioresource Technology*, 72: 169–183. http://doi.org/10.1016/S0960-8524(99)00104-2. 2000.

[18] A. Ngakou, and A. Ibrahima. Responses of Maize and Tomato Crops to Fertilization with Three Agroforestry Litter Species (*Annona senegalensis*, *Terminalia macroptera* and *Parkia biglobosa*) DOI: 10.9734/IJPSS/2020/v32i330262. http://www.sdiarticle4.com/reviewhistory/55898. 2020.

[19] A. Ngakou, L. Ngo Nkot, D.Gomoung,. and S.Adamou. Mycorrhiza-RhizobiumVigna Subterranea Dual Symbiosis: Impact of Microbial Symbionts for Growth and Sustainable Yield Improvement. *International Journal of Agriculture and Biology*, 14, 915- 921.2012.

[20] D. Fotio, A. Monkièdje , S. Miépi Ngouopiho , J. Nguefack, et P.H. Amvam Zollo. Évaluation des résidus des pesticides et de leurs effets sur la qualité des récoltes, du sol et de l'eau en zone périurbaine de Yaoundé à cultures maraîchères. *Actes de l'atelier de Présentation des opérations de recherche participative, 21-23 février 2006, Yaoundé, Cameroun du Pôle de Compétence en Partenariat (PCP) Grand Sud Cameroun*, 33-39.2006.

[21] B.T. Kang, B. Duguma. Nitrogen management in alley cropping systems. *ln* Kang B.T., van der Heide J., éd. Nitrogen management in farming systems in humid and subhumid tropics. Institute of Soil Fertility, Haren, Pays-Bas, 269-284. 17.1985.

[22] J. P. Laclau. Dynamique du fonctionnement minéral d'une plantation d' eucalyptus. Effets du reboisement sur un sol de savane du Littoral congolais. Conséquences pour la gestion des plantations industrielles. Institut National Agronomique Paris, Grignon.@fre. 2001.

[23] D..L. Heanes. Determination of organic C in soils by an improved chromic acid digestion and spectrophotometer procedure. *Commun. Soil Sci. Plant Anal*., 15: 1191-1213.1984.

[24] A. Boundonno, A.A. Rashad, and E. Coppola. Comparising test for soil fertility.11. The hydrogen peroxyde/sulfuric acid treatment as an alternative to the copper/selenium catalyzed digestion process for routine determination of soil nitrogen-Kjeldahl. Comminication in soil science and plant analysis 26 : 1607-1619.1995.

[25] J. M. Anderson ,&J.S.I.Ingram. (Eds).Tropical soil biology and fertility. *A handbook of methods* (2 nd ed). Wallingford: CAB International.1993.

[26] M. F. Trouslot. Analyse de la croissance de l'igname *Dioscorea* complexe *cayenensis rotundata*. Thèse de Docteur es Science. Serie E N° 326, Université de Clermont Ferrand II, Clermont Ferrand.1983.

[27] P. Duchaufour. Pédologie, sol, végétation, environnement 4e édition, Masson, Paris. 324p. 1995

[28] D. M. Essono, D. Nwaga, L.D. Kono. Phénologie fruitière de *Pericopsis elata* dans la forêt équatoriale camerounaise. Soil Biology and Agriculture in the Tropics 234-245. 2012

[29] V. Balasubramanian. Alley cropping: urn it be an alternative to chemical f e r t i l i z e r s in Ghana? Paper given at the Third National Maize Workshop held *at* I Cuadeso, I Cumssi, Ghana. Feb. 1-3, 1983. Mimeo. 22 p.1983.

[30] A.S.R. Juo, R. Lal.The effects of fallow and continuous cultivation on the chemical and physical properties of an alfisol. Plant and soil, 47: 567-568. 1977.

[31] B.T. Kang, G.F. Wilson, L. Sipkens. Alley cropping maize *(Zea mays* L.) and *Leucaena (Leucaena leucocephala* Lam.) in southern Nigeria. *Plant and Soil*, 63: 165-179.1981.

[32] B.T. Kang, et B. Duguma. Nitrogen management in alley cropping systems. International Institute of Tropical Agriculture, Nigeria. 269-284. 1985.

[33] E.O. Jaiyebo,A.W. Moore. Soil fertility and nutrient storage in different soil vegetation systems in tropical rainforest environment. *Tropical Agriculture*, 41, 129-130.1964.

[34] J.K. Obi,P. Tuley. The bush fallow and alley farming in the oil palm belt of South eastern Nigeria. Land Resources Division, Overseas Development Administtration, Londres, R.U. Miscellaneous Report 161p.1973.

[35] B.N. Okigbo, D.J. Greenland. Intercropping systems in tropical Africa. In Papendick, F.L. et al., ed., Multiple Cropping African Studies Association, Madison, WI. E.U. Special publication27: 63-101.1976.

[36] A. Budelman. Woody species in auxiliary roles ; live stakes in yam cultivation ; effect of the application of the leaf mulch of *Gliricidia sepium* on the early development ; leaf nutrient contents and tuber yield of the water yam (*Dioscorea alata*). W. Rosemary, 151 p.1991.

[37] A. Getahum, G.F. Wilson, B.T. Kang.The role of trees in farming systems in the humid tropics. *In* Mc Donald, L.H., ed., Agroforestry in the African humid tropics. United Nations University, Tokyo, Japan, 28-35.1982.

[38] B. Duguma. Studies of factors affecting establishment of selected trees species of potential importance in agroforestry. University of Ibadan, Ibadan, Nigeria. Thèse de doctorat 413p.1985.

[39] A. Young. Ten hypotheses for soil agroforestry research. NAIROBI, ICRAF, *Agroforestry* today, tome 1.13-16.1989.

[40] B. LEBUANEC. Absorption et exportation des éléments minéraux majeurs par l'igname. Third international sympodium on tropical root crops. IITA, Ibadan, Nigeria. *In* L'igname : plante à racine tropicale. Maisonneuve et Larose ; ACCT, série techniques agricoles et productions tropicales, Paris.1972.

[41] F.K. Arap-sang, D.A. Hoekstra, R. Okumu. Preliminary results of on station green manure trials with leaves from *Leucaena leucocephala*, *Cassia siamea* and *Terminalia brownii*, Dryland Agroforestry Project, Kenya Agriculture Research Institute, Kikuyu, Kenya Research Report 1.1985.

[42] J. Reganold. Sustainability of organic, Conventional, and Integrated Apple Orchards. Crop Management. Doi:10.1094/CM-2006-0921-16-PS. http://www.plantmanagementnetwork.org/pub/cm/symposium/organics/Reganold/2006.

[43] J. Tassin. Agroforesterie et conservation des sols dans les régions chaudes - Edition : Nature et Progrès - Montpellier, 140 p.1992.

[44] M.A. Razafindrakoto. Evaluation de l'efficience de diverses techniques biologiques de gestion conservatoire de la fertilité des sols. Doctorat d'Etat Es-Sciences Physiques, Université d'Antananarivo, 192 p. 2004.

[45] Y.F. Kouassi. Effets des jachères à *Acacia mangium* et *Acacia auriculiformis* sur les propriétés chimiques du sol et les rendements de l'igname (*Dioscorea* spp). DEA en sciences et gestion de l'environnement. Université d'Abobo-Adjamé, Côte d'Ivoire, 50 p. 2005.

[46] A. Bakayoko Gone, F. Kouamé Kra, M. Boraud N'takpé Kama. Culture de l'igname au Centre-Est de la Côte d'ivoire : contraintes, caractéristiques sociodémographiques et agronomiques. *J. Appl. Biosci*. 10701-10713.2017

[47] Dognimeton Soro, D. Dao, J. Robert, Carsky, R. Asiedu, A. Ayemou. Amélioration de la production de l'igname à travers la fertilisation minérale en zone de savane de Côte d'ivoire. J. Y. Jamin, L. Seiny Boukar, C. Floret. Cirad-Prasac, 7p. 2003.

[48] Dokou, La sécurité alimentaire des pays en développement : racines, tubercules, plantains et bananes. www.fao.org . 1984

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Effect of Extract *Euphorbia hirta* Linn. Against Leaf and Fruit Pests on Plants Cucumber (*Cucumis sativus* Linn.)

Aulia Rahmah, Muhammad Indar Pramudi*, Noor Aidawati, Lyswiana Aphrodyanti

Plant Protection Study Program, HPT Department, Faculty of Agriculture, Lambung Mangkurat University
*Corresponding Author

Received: 15 Feb 2023; Received in revised form: 18 Mar 2023; Accepted: 26 Mar 2023; Available online: 04 Apr 2023

Abstract— *Euphorbia hirta which is commonly known as "patikan kebo" is small herb which gives milky latex. This study aims to determine the effect of E. hirta extract in reducing the intensity of leaf and fruit pest attacks on cucumber plants Cucumis sativus Linn. The results of this study showed that all treatments with this extract were able to suppress the intensity of pest attacks on cucumber plants and had a significant effect on reducing the intensity of pest attacks on cucumber plants. The best concentration that can reduce the intensity of these pest attacks is the treatment of 10% can reduce the intensity of leaf pest attacks on cucumber plants up to 4.64%. The intensity of pest attacks on cucumbers only occurred in the control and 2% extract treatment with percentages of damage intensity to cucumbers of 9.38% and 3.13%.*

Keywords— ***extract, intensity, organic pesticide, pest attack, percentages***

I. INTRODUCTION

Cucumber is one type of fruit vegetable that has many benefits and uses, including as a food ingredient, medicinal ingredient, and cosmetic ingredient. Based on data obtained from the Badan Pusat Statistik (2020) cucumber production in Indonesia from 2015 to 2020 has experienced fluctuations in productivity, 447,696, 430,218, 424,917, 433,931, 435,975, and 441,286-ton ha^{-1}, meanwhile, cucumber production in South Borneo from 2019 to 2020 has decreased in productivity, 4,680 and 4,290-ton ha^{-1}. The decrease in cucumber production can be caused by several factors and one of them is attack by pests and plant diseases.

Pest attacks on cucumber plantings can result in decreased productivity of cucumber plants both in terms of quality and quantity, if these pest attacks are not controlled, they can make farmers suffer losses and even crop failure. Pests that are often found on cucumber plants are caterpillar pests (*Diaphania indica), Aulacophora* sp., *Bemisia tabaci*, *Epilachna* sp., leafminer flies (*Liriomyza* spp.), and fruit flies (*Bactrocera*). The control used by farmers for pests that attack cucumber plants uses chemical pesticides. The use of chemical pesticides has many negative impacts on the environment and humans.

An alternative way to control pests on cucumber plants without harming environmental and human health is to utilize weeds that have the potential as insecticides. One of the weeds that can be used is *Euphorbia hirta*. Research results from Febrianti *et al.* (2021) showed that pesticides from *E. hirta* can control mustard leaf pests, *Plutella xylostella* L. (Lepidoptera: Plutellidae). According to Situngkir (2018), the secondary metabolites found in E. hirta are tannins, saponins, flavonoids, alkaloids, and steroids, extract can control armyworms (*Spodoptera litura* L.) because these secondary metabolites can be poison to the stomach or contact poison to the larvae. To determine the effect of giving extract *E. hirta* in reducing the intensity of leaf and fruit pest attacks on cucumber plants (*C. sativus*).

II. MATERIAL AND METHODS

The research was carried out from February 2022 to May 2022, in Sungai Kupang Village, Kandangan District, Hulu Sungai Selatan Regency, South Borneo, and at the Basic Laboratory of FMIPA, Lambung Mangkurat University, Banjarbaru. This study used a completely randomized design with 1 factor, namely the concentration of organic

pesticide, which consisted of 7 treatments, with 4 replications so that there were 28 experimental units. So all the plants used are 56 plants in the form of:

KA = Water control (without treatment)

KM = Chemical control of the active ingredient abamectin concentration = 0.1 ml + 49.9 ml of water

A = Extract E. hirta 2% (1 ml + 49 ml water)

B = Extract E. hirta 4% (2 ml + 48 ml water)

C = Extract E. hirta 6% (3 ml + 47 ml water)

D = Extract E. hirta 8% (4 ml + 46 ml water)

E = Extract E. hirta 10% (5 ml + 45 ml water)

2.1. Research Implementation

2.1.1. Preparation of Planting Media

The planting medium for cucumber plants is soil mixed with chicken manure. The soil and chicken manure are stirred and mixed evenly with a 1:1 ratio using a hoe, then put into the experimental polybag, then given a name using a marker according to the name of the treatment. The experimental poly bags used were 56 pieces with a polybag diameter of 20 cm. The ready poly bags were then placed in the experimental field at a distance of 30 x 40 cm.

2.1.2. Direct Investment

Plant the cucumber seeds directly into the planting holes that have been perforated in the previous polybag, which is approximately 3 cm deep with 2 seeds per planting hole then cover the planting holes that have been filled with cucumber seeds using a pinch of rice husk and cover it with banana stems for a few days until the cucumber plants have 2-3 leaves.

2.1.3. Maintenance

Plant maintenance during the implementation of the research included watering the cucumber plants every day in the morning and evening if there was no rain, weeding done on weeds or other disturbing plants that grew around the cucumber plants, applying *E. hirta* extract, and observations made every 4 days. Once as well as collection of observational data.

2.1.4. Making Patikan Kebo Extract (*Euphorbia hirta*)

Making extract using the Febrianti *et al*., method (2021) modified. The leaves and stems of *E. hirta* taken from the field are cleaned of dirt with water and then drained and air dried. The leaves and stems of the dried are chopped and mashed using a mortar and blender. The leaves and stems of *e. hirta* have been finely macerated by soaking the powder in 96% ethanol solvent. The powder solution is soaked for 24 hours at room temperature while occasionally stirring with a stirring rod. The solution was filtered using a filter cloth and filtered again using filter paper. The filtered filtrate is then evaporated with a rotary *evaporator* at a temperature of 55°C until the extract is obtained. The extract is ready to apply.

2.1.5. Fertilization

Fertilize cucumber plants using NPK fertilizer by sprinkling the fertilizer around the roots of cucumber plants at a dose of 40 g/cucumber plant, NPK fertilizer application starts from plants aged 10 DAPs, and fertilization is done once a week.

2.1.6. Installation of Bamboo Stake and Gawar Rope

Install a bamboo stake with a length of approximately 150 cm and a width of 3 cm next to the cucumber plants when the cucumber plants are 14 DAP, then attach a gawar rope so that the bamboo stakes support the plants more firmly.

2.1.7. Application of Patikan Kebo Extract (*Euphorbia hirta*)

The application of the *Euphorbia hirta* was carried out by spraying it on cucumber plantings using a hand *sprayer* with a dose of concentration of extract, 15 ml in one repetition for the total treatment. At the time of spraying, a barrier was given in the form of a modified plastic and bamboo barrier so that the spraying would not affect other plants. For the treatment of *E. hirta* extract, 0.025 ml of adhesive was added The application of the extract in the field was carried out from cucumber plants aged 7 DAP at intervals of 4 days until the plants were 51 DAP so that the application was carried out 12 times.

2.1.8. Observation

Observations in this study included the intensity of pest attacks on cucumber leaves and fruit as well as observations of pest attack populations on cucumber plants. Observation of the intensity of pest attacks on cucumber leaves was carried out 13 times. Observation of pest populations was carried out by observing the entire cucumber plant. Observation of the intensity of pest attacks on cucumbers was carried out from the beginning of harvest until the plants were 55 DAP (Day After Planting). The number of pest populations and types of pests that attack cucumber plants are counted every time the observation. Observations were made simultaneously with the application of *E. hirta* organic pesticide, so observations and applications were carried out on the same day. Cucumber harvesting is done at the time of observation. The observed samples were 28 plants, a total of 56 test plants.

Leaf attack intensity is calculated by the formula (Minarno & Ika, 2011):

$$IS = \sum_{N=4}^{n} \frac{(n\ x\ v)}{(z\ x\ N)}\ x\ 100\%$$

Description:

IS = Attack intensity (%)

n = Number of leaves indicating scale

v = Score of damage

N = Number of leaves observed

Z = Highest score (4)

Table 1. Leaf damage score

Damage Score	Information
0	**0% leaf area affected/damaged**
1	**≤ 25% of affected**
2	**> 25% – < 50% affected**
3	**> 50% – < 75% affected**
4	**≥ 75% – 100% affected**

Observation of the intensity of attack on cucumber fruit is calculated by the formula:

$$\textbf{IS} = \frac{a}{b} x\ 100\%$$

Description:

IS = Attack intensity (%)

a = The number of infected fruit

b = The total number of fruits observed

2.1.9. Data analysis

The data obtained will be analyzed using Bartlett's homogeneity test. If the data is homogeneous then continue with *Analysis Of Variance* (ANOVA). If the results of the analysis of variance have a significant effect, then proceed with the average difference test with a BNT of 5% (Smallest Significant Difference) to see the differences between treatments.

III. RESULT AND DISCUSSION

3.1. Observation of cucumber plant pests

The results of the observations showed that the pests that attacked the cucumber plants and the symptoms they caused were seen in the third observation (15 DAP). Pest attacks on cucumber plants cause cucumber leaves to become damaged such as rolling, wrinkled and with holes. Several types of pests found attacking cucumber plants in this study were caterpillar pests (*Diaphania indica*), *Aulacophora* sp., *Bemisia tabaci*, *Epilachna* sp., leafminer flies (*Liriomyza* spp.) and fruit flies (*Bactrocera*). The main pests that attacked cucumber plants at the time of the study were caterpillar pests (*D. indicates*) with symptoms of damage that can be seen in (Figure 1).

D. indica attack occurred since the cucumber plants were 15 DAP until the end of the observation (55 DAP) and the pest population increased as the age of the cucumber plants increased but the population was still low. This is thought to occur because all phases of cucumber plant growth are favored by this pest and support for its breeding so that its population continues to increase as the age of the cucumber plants increases.

Fig 1. Leaf caterpillar pests (D. indicates) and the symptoms of the attack

Aulacophora beetle or commonly known as ”pumpkin beetle”, attacks result in leaves becoming perforated, these pests eat cucumber leaves by making circles on the leaves and then eating them until they have holes. The eating activity is very fast so the damage caused by their eating activity is quite large. In the observations, there were 2 types of *Aulacophora* pests (Figure 2). The results of the identification showed A, *similis* (figure 2 a) and *A. femoral* (Figure 2b) (Herlinda *et al*., 2020).

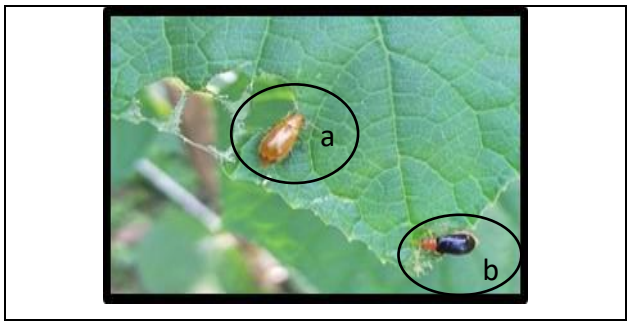


Fig 2. a. A. similis, b. A. femoral

Aulacophora beetle pest attacks occurred since the cucumber plants were 15 DAP until the end of the observation (55 DAP). According to Hasnawati (2019) the greater the beetle population *A. similis*, the higher the intensity level of the attack. An increase in the imago population causes an increase in damage to cucumber leaves.

Symptoms of leafminer fly (*Liriomyza* spp.), there are white lines that are irregular or turning in the form of burrows on the surface of cucumber leaves (Figure 3). This corresponds to Bororing*et al*. (2015) who stated that leafminer fly larvae (*Liriomyza* spp.) slit the leaves and make tunnels that turn irregularly like a spiral and in the end the leaves become dry and die.

Fig 3. Symptoms of leafminer fly pests (Liriomyza spp.)

Symptoms of leafminer fly attack (*Liriomyza* spp.) began to occur when the cucumber plants were 19 DAP, the attacks of leafminer flies continued to increase as the plants got older until entering the generative period the attacks began to decrease or no additional incisions were found on the cucumber leaves. This is presumably because the population of pests on cucumber plants during the vegetative period is high but when entering the generative phase the population decreases.

B. tabaci infestation occurred when the cucumber plants were 23 DAP. At the time of observation, this pest was often found under the surface of the leaf on the leaf buds or on young leaves. Symptoms of damage caused by whitefly infestation are not visible or even non-existent because the population on cucumber plantations is also very small.

Fruits that are attacked by fruit fly pests change color to yellow-brown and the fruit flesh decomposes and there are many larvae on the cucumber fruit. Initial symptoms are marked by the appearance of small black spots from the ovipositor puncture to lay eggs. Furthermore, due to the activity of pests in the fruit, these stains develop and become widespread. The fly larvae eat the flesh of the fruit so that the fruit is rotten before it ripens until the fruit falls. The most damaging fruit fly stage is the larval stage (Suputa *et al*., 2006).

Javelin beetle (*Epilachna* sp.) attacks the leaves of cucumber plants by biting the lower leaf surface so that the symptoms of this beetle attack are visible on the leaves, namely the presence of small holes (Figure 4).

Fig 4. Javelin beetle pests (Epilachna sp.)

3.2. The intensity of the cucumber leaf pest attack

Pest attacks on cucumber plants were not found during the first observation (7 DAP) before the plants were applied extract and attacks were still not found during the second observation (11 DAP), pest attacks on cucumber plants began to appear during the third observation (15 DAP). The percentage of attack intensity of cucumber leaf pests treated with *e. hirta* extract was lower than that of the control plants and the effect of giving extract was almost the same as that of chemical pesticides. Flavonoids, alkaloids and polyphenols which can prevent pests from approaching cucumber plants. According to Samsudin (2008), the content of bioactive compounds including saponins, flavonoids, polyphenols, and essential oils prevent pests from approaching plants (repellents) and inhibit the growth of larvae into pupae. From the results of the last observation, it can be seen that the higher the concentration of the extract given, the stronger the attack intensity of cucumber leaf pests will be (Figure 5).

The results of the analysis of variance showed that the treatment of concentrations of organic pesticide with extract had a very significant effect on the observed intensity of leaf damage due to attacks by cucumber plant pests. The results of observing the percentage of intensity of attack on cucumber leaf pests in the last observation showed that the highest damage percentage was in the KA treatment, which was 8.08%, while the lowest damage percentage was in the E treatment, which was 4.64% (Figure 5).

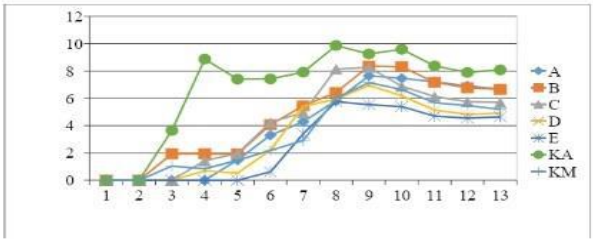


Fig 5. The intensity of cucumber leaf pest attack on all observations

After the LSD test was carried out in the vegetative phase (observation 7), the KM treatment was significantly different from the E, A, C, D, B, and KA treatments, while the D treatment was not significantly different from the B treatment but significantly different from the KM, E, A, C, and KA can be seen in Table 2.

Table 2. LSD test in the vegetative phase

Treatment	Middle value
KM	2,91a
KA	3,40b
A	4,29c
C	4,95d
D	5.41
B	5,45e
E	7,91f

In the generative phase observation test results (last observation) treatment E was significantly different from treatments D, KM, C, B, A, and KA but treatment B was not significantly different from treatment A but significantly different from treatments E, D, KM, C and KA can be seen in (Table 3).

Table 3. LSD test in the generative phase

Treatment	Middle value
KA	4,64a
D	4,91b
KM	5,19c
C	5,70d
B	6,66 e
A	6,68e
E	8,08f

Giving extract to treatment E with a concentration of 5 ml was the best concentration in suppressing the intensity of pest attacks on cucumber leaves, which was 4.64% compared to other concentrations with higher attack intensity because at a concentration of 5 ml *E. hirta* extract was the most effective concentration. height used. This can occur allegedly because the higher the concentration of extract applied, the more suppression of pest attacks on cucumber plants. This is following the results of research from Kholidi (2016) which states that the higher the concentration of organic pesticide is given to a plant, the less likely the plant will be attacked by pests, higher concentrations of organic pesticide can suppress and inhibit pest attacks in plants so that the rate of decline in production in plants can be controlled. Toana (2007) stated that the higher the concentration of the extract applied to the plant, the more active ingredient content of the extract which can be translocated to all plant leaves so that the plant is not consumed by pests. This situation causes the intensity of pest attacks on plants to decrease.

The highest percentage of damage to cucumber plants due to pest attacks was in the control treatment, this occurred allegedly because in this treatment no pesticides were sprayed either chemical or vegetable and only watered with water so that pests could easily attack cucumber plants because there was no protection or any toxic compounds to prevent pest attack on control. According to Febrianti *et al.* (2021), the high rate of damage to control plants is caused by the absence of toxic compounds that can inhibit leaf-damaging pests and the development of various pest populations, as well as weather factors that support pest development. *E. hirta* leaf extract caused rats to produce more urine and more electrolytes (Abuarra *et al.*, 2010).. *E. hirta* exhibits galactogenic, anti-anaphylactic, antimicrobial, antioxidant, anticancer, antifeedant, anti-platelet aggregation and anti-inflammatory, aflatoxin inhibition, antifertility, anthelmintic, antiplasmodial, antiamoebic, antimalarial, larvicidal, and repellent and antifeedant activities against *Plutella xylostella* (Kiran *et al*., 2015). Diwan and Saxena (2010) [2] reported that 3% of *E. hirta* leaf extracts shown 100 per cent mortality of *Callsobruchus chinensis*

3.3. The intensity of attack by cucumber fruit pests

Treatments B, C, D, E, and KM were not attacked by pests and there was no damage to yields in treatments A and KA there was damage to the fruit where the intensity of damage was in treatments A and KA by 3.13% and 9.38%.

Fig 6. a. Leaf caterpillar pests (D. indica), b. Rotten fruit due to fruit fly attack (Bactrocera sp.)

Damage to cucumber fruit caused by fruit fly pests (*Bactrocera* sp.)) where the fruit changes color to brownish yellow and the fruit rots and in the fruit flesh many fruit fly larvae are found while the fruit is attacked by caterpillar pests (*D. indicates*) become holes or there are dry cracks on the skin of the fruit and the fruit becomes abnormal.

IV. CONCLUSION

Euphorbia hirta is a tropical weed with an erect herb and soft stem which usually grows in paddy field yards and roadsides. Leaf extracts were prepared using extraction methods of pressing, boiling, steeping, and macerating extracts with ethanol solvents. *E.hirta* extract can be used

as an organic pesticide because it has the effect of suppressing the intensity of leaf and fruit pest attacks on cucumber plants. The best concentration that can reduce the intensity of pest attacks is 10% extract treatment.

REFERENCES

[1] Abuarra, B.R, Z. Zakaria, S.S. Sasidharan, L. Y. Latha, and S. Amutha. (2010). Assessment of Euphorbia hirta L. Leaf, Flower, Stem and Root Extracts for Their Antibacterial and Antifungal Activity and Brine Shrimp Lethality. *Molecules* 15(9), 6008-6018.

[2] Arsi, Hendra, S. SHK, Y. Pujiastuti., S. Herlinda, H. Hamidson, B. Gunawan, C. Irsan, S. Suwandi, R. A. Efendi, S. I. Nugraha, L. Lailaturrahmi, and R. P. Munandar. (2020). Identifikasi Serangga Hama pada Tanaman Mentimun di Desa Bumi Agung, Kecamatan Lempuing, Kabupaten Ogan Komering Ilir, Sumatera Selatan. Universitas Sriwijaya. *Prosiding Seminar Nasional Lahan Suboptimal ke-8 Tahun 2020*, 978–979.

[3] Bororing, A. R., J. M. E. Mamahit, D. S. Kandowangko, and N. N. Wanta. (2015). Jenis dan Populasi Serangga Hama yang Berasosiasi pada Tanaman Kentang (Solanum tuberosum L) di Kecamatan Modoinding. *Cocos* 6(6), 1-15.

[4] BPS (Badan Pusat Statistik). (2020). Statistik Indonesia 2020. Badan Pusat Statistik. Jakarta. https://www.bps.go.id.

[5] Diwan R. K and R. C. Saxena. Insecticidal activity of Euphorbia hirta against Callsobruchus chinensis. Asian Journal of Animal Science. 2010; 4(2):167-170.

[6] Febrianti, E., O. R. Helda, and M. I. Pramudi. (2021). Pengaruh Ekstrak Patikan Kebo (Euphorbia hirta Linn) TerhaDAP Serangan Hama Daun Sawi. *Jurnal Proteksi Tanaman Tropika*. 5 (01), 407–413.

[7] Hasnawati, N. (2019). Pengaruh Konsentrasi Ekstrak Serai Wangi (ESW) TerhaDAP Populasi dan Intensitas Serangan Kumbang Aulacophora similis Olivier. (Coleoptera: Chrysomelidae) Pada Tanaman Mentimun. (Skripsi) Universitas Brawijaya. Malang.

[8] Kholidi, J. A. (2016). Efektivitas Interval Penyemprotan dan Konsentrasi Pestisida Nabati Paitan (*Tithonia diversifolia*) TerhaDAP Intensitas Kerusakan dan Hasil Pada Tanaman Kailan (*Brassica oleracea* L.). Universitas Muhammadiyah Jember.

[9] Kiran S, Ahmad M, Bodlah I, Gulzar. (2015). A. Susceptibility of Diamondback Moth, *Plutella xylostella* (Lepidoptera: Plutellidae) to some Euphorbiaceae plant extracts under laboratory conditions. *Asian journal of Agriculture and Biology*. 3(4):145-149.

[10] Minarno, E. B., and K. Ika. (2011). Ketahanan Galur Kedelai (Glycine max L.) TerhaDAP Serangan Ulat Grayak (Spodoptera litura F.) Berdasarkan Karakteristik Trikoma. *El-Hayah*, 2(1), 7–14.

[11] Situngkir, O. B. (2018). Uji Efektifitas Beberapa Insektisida Nabati TerhaDAP Mortalitas Ulat Grayak (*Spodoptera litura* F.) (Lepidoptera; Noctuidae) di Laboratorium. (Skripsi) Universitas Sumatera Utara.

[12] Suputa, Cahyaniati., A. Kustaryati, M. Railan, U. H. Issusilaningtyas, and W. P. Mardiasih. (2006). Pedoman Identifikasi Hama Lalat Buah. Direktorat Perlindungan Tanaman Hortikultura. ISBN 979-3147-22-9.

[13] Toana, M. and Hibban. (2007). Pengaruh Konsentrasi Ekstrak Kulit Jeruk Nipis (*Citrus aurantifolia* S.) TerhaDAP Kepadatan Populasi dan Intensitas Serangan *Plutella xylostella* L. (Lepidoptera : Plutellidae) Pada Tanaman Kubis. *J Agroland*. 14 (3), 195-200.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Parameters affecting Tractor Fuel Consumption during Primary Tillage Operation in Uyo, Akwa Ibom State, Nigeria

P. Okoko and W. A. Olosunde

Department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo, Uyo, Nigeria

Received: 27 Feb 2023; Received in revised form: 27 Mar 2023; Accepted: 05 Apr 2023; Available online: 13 Apr 2023

Abstract— *Tractor fuel consumption is a vital parameter in management of farm machinery. Parameters affecting tractor fuel consumption in litres per hectare(L/ha) during ploughing operation in Uyo was investigated. The study was conducted at the University of Uyo teaching and research farm, Uyo in Akwa Ibom State, Nigeria. The soil in the study location was characterized as clay loam. Effects of operation parameters on fuel consumption for ploughing operation were investigated using One-Way Repeated Measures Analysis of Variance. The findings of the study indicate that at <0.05 significance level, operation parameters had significant effect on tractor fuel consumption during ploughing operation. The study had identified factors affecting tractor fuel operation during ploughing operation in the study location.*

Keywords— ***Ploughing, parameters, tractor, fuel consumption, clay loam soil***

I. INTRODUCTION

Land preparation is one of the most energy consuming operations in the field. Energy utilized in tillage is governed by such factors as soil type and conditions, depth of cut, operating speed and hitch geometry. Field practices have shown that land development constitutes the major cost of farm operation due to the high level of energy expended during tillage. Fuel consumption plays a significant role in the selection and management of tractors and equipment (Oyelade and Oni, 2018). Two of the common tillage implements in the South-South region of Nigeria are the disc plough and disc harrow. Tillage operations require the most energy and power spent on farms (Al-Suhaibani and Ghaly, 2010).

Soil tilling, according to Oni (1991), is the most intensive of all processes involved in crop production. Tillage of soil is considered to be one of the biggest farm operations (Al-Suhaibani and Ghaly, 2010). There are several tillage implements used by farmers for seedbed preparation. However, the selection of tillage implements to prepare seedbed and weed control depends on soil type and condition, crop residues and weed type (Upadyaya *et al.*, 1984).

The use of tractors plays an important role in agriculture (Mahmood and Gee-Clough, 1989). The application of machines to agricultural production has been one of the outstanding developments in agriculture. Tractors and farm machinery are important sources of modern technology (Singh, 2000., Xinan *et al.*, 2005). According to Panam et al., (2010), tractors are the fastest farm machines used by farmers for tillage operations instead of human tools and animal-drawn implements. Machinery contributes a major capital input cost in most farm businesses.

The objective of this study is to identify parameters that affect fuel consumption in tractors.

II. MATERIALS AND METHODS

Study Location

The study location for this research work was in the University of Uyo in Uyo local government area of Akwa Ibom state, Nigeria.

Tractor and Tillage Implement

The specification of tractor used for the study is presented in Table I. Tillage implement used for evaluating the parameters affecting tractor fuel consumption is 4-buttom disc plough. Its specification is presented in Table 2

Table. I: Specification of Tractor Used

Specification	Eicher 5660
Effective output (hp)	55
Type of engine	3-cylinder
Type of fuel	Diesel
Front tyres (size)	7.50-16
Rear tyres (size)	14.9-28
Fuel tank capacity(L)	60
Country of manufacture	India

Table. 2: Implements Specifications

S/N	Item	Disc plough
1	Type (hitching)	Fully mounted
2	Number of bottoms/discs	4
3	Type of disc blade	Plane concave
4	Disc diameter(cm)	48.7
5	Disc Spacing(cm)	53
6	Tilt Angle (˚)	20
7	Implement width (cm)	129
8	Disc Angle(˚)	45
9	Implement Weight(kg)	386

Soil Sampling and Experimental Procedure

At each of the sampling points, random spots were core sampled and augured at 0-30 cm depth with the aid of a dutch auger and bulked out to give a composite sample. The soil samples from different sampling points were, on each occasion, collected in polyethylene sample bags and labeled accordingly and the samples were taken to the laboratory for analysis. Laboratory methods of analysis were carried out on the soil samples for particle size distribution. The tractor was tested on an area of 0.5 hectare (50 m x 100 m) in a Randomized Complete Block Design (RCBD). Parameters measured during ploughing operation include draft, the width of cut, depth of cut, duration of operation, the speed of operation, field capacity, field efficiency, fuel consumption, wheel slip, soil moisture content, soil bulk density and soil cone index.

Parameters Tested

Implement Draft

The draft of implement was measured according to the tractor technique as described by Oyelade, 2016.

Duration of Operation

According to Oyelade and Oni (2018), the duration of operation measured in hr/ha is the time spent in completing the whole operation and they mathematically expressed it as:

$$X9 = \frac{1}{X5} \quad \text{.....(1)}$$

Where,

X9 = Duration of operation (hr/ha)

X5 = Effective field capacity (ha/hr)

Depth and width of cut

The depth and width of cut during field operation were measured using a steel rule and measuring tape

Speed of operation

The speed of operation for the tillage was determined using the equation below.

$$S = \frac{D}{T} \quad \text{... (2)}$$

Where;

S= speed of operation, km/hr

D =Distance travelled, m

T=Time taken to travel the distance, sec

Theoretical field capacity

Theoretical field capacity measured in ha/hr was expressed mathematically according to Oyelade and Oni (2018) as

$$G = \frac{E(3600)}{Ta} \quad \text{...(3)}$$

Where,

G = Theoretical field capacity ha/hr)

E = Area of field (ha)

Ta = Actual time taken in doing the main tillage work (sec)

Effective field capacity

Effective field capacity measured in ha/hr was expressed mathematically as

$$X5 = \frac{E(3600)}{Tt} \quad \text{... (4)}$$

Where,

X5 = Effective field capacity (ha/hr)

E = Area of field (ha)

Tt = Total time taken in completing the whole tillage operation (sec)

Field efficiency

Field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed in percentage. It was expressed mathematically as

$$H = \frac{X5}{G} \times 100 \quad \ldots(5)$$

Where,

H = Field efficiency (%)

Fuel consumption

The filling of fuel tank before the operation and then refilling after completing the operation method was used in the study. This method is a common method in the field for determining tractor fuel consumption in liters per hectare. This method was used by Ajav and Adewoyin, 2011., Ikpo and Ifem, 2005; Kudabo and Gbadamosi, 2012; Udo and Akubuo, 2004 and Oyelade and Oni, 2018 in determining tractor fuel consumption in liters per hectare. Fuel consumption measured in either L/ha or L/hr was expressed mathematically as

$$I = \frac{J}{E} \quad \ldots(6)$$

$$K = X5\ x\ I \quad \ldots(7)$$

Where,

I = Fuel consumption (L/ha)

J = Volume of fuel consumed (L)

E = Area of field (ha)

K = Fuel consumption (L/hr)

X5 = Effective field capacity (ha/hr)

Tractive efficiency

Tractive efficiency measured in percentage is the ratio of drawbar power to wheel power and was expressed mathematically as

$$Qt = \frac{Dp}{Qw} \times 100 \quad \ldots(8)$$

Where,

Qt = Tractive efficiency (5)

Dp = Drawbar power (kW)

Qw = Wheel power (kW), power losses in the transmission from engine to the wheels of, if 10%

is assumed, it can be written as

$$Qt = \frac{Dp}{0.9xQe} \times 100 \quad \ldots(9)$$

Where,

Qe = Engine power (kW)

Travel reduction (wheel slip)

In determining travel reduction (wheel slip), a mark was made on the tractor drive wheel with coloured tapes. This was used to measure the distance covered by the tractor drive wheel at every 10 revolutions under no load and the same revolution with a load on the same surface. The travel reduction (wheel slip) measured in percentage was expressed mathematically as:

$$L = \frac{M2-M1}{M2} \times 100 \quad \ldots(10)$$

Where,

L = Travel reduction (wheel slip, %)

M2 = Distance covered at 10 revolutions of the wheel at no load condition (m)

M1 = Distance covered at 10 revolutions of the wheel at load condition (m)

Soil Parameters

Moisture content of the soil

The research location for the tillage implement was subdivided into twenty-five subplots of 20 m by 10 m measurement. Soil samples were collected during the tillage experiment at three different points of 0 – 30 cm depth choosing randomly on each subplot to determine the average moisture content. The samples were weighed using a weighing balance, and the weight of each sample was recorded. Then the samples were placed in an oven maintained at 110^{0}C for 48 hours. The dried soil samples were reweighed, and the weight was again recorded. The moisture content was calculated on a dry weight basis according to the formula;

$$Moisture\ Content\ (M.C) = \frac{W_w - W_d}{W_d} \times 100 \quad \ldots(11)$$

Where,

W_w = weight of wet soil sample, g

W_d = weight of oven dry soil sample, g

Bulk density of soil

The procedure for soil sample collection as given for soil moisture content determination was the same for bulk density determination. The bulk density of the soil was determined according to the formula:

$$Bulk\ density\ (g/cm^3) = \frac{4M}{\pi\ D^2\ L} \quad \ldots(12)$$

Where,

M = Mass of the soil as contained in the core samples of oven dried soil, g

D = Diameter of cylindrical cone sample, cm

L = Length of the cylindrical cone sample, cm

Soil cone index

The soil cone index (CI) is the soil resistance to penetration and was measured using a cone penetrometer

Statistical Analysis

Results of measured parameters gathered from the experiment on a sandy loam soil during ploughing operation were subjected to Analysis of Variance (ANOVA) in investigating the measured parameters that contributed significantly to tractor fuel consumption in litres per hectare during ploughing operation. Using Version 3.1.1 of the R Software Package according to Oyelade and Oni, 2018 for statistical, computing and graphics, One-way Repeated Measures ANOVA was used to investigate the effects of ploughing operation parameters on tractor fuel consumption. As a result of this, the following hypothesis were drawn.

Hypothesis: Test of significance of ploughing operation parameters

Null hypothesis (H_0): Effects of ploughing operation parameters on tractor fuel consumption in litres per hectare are the same.

Alternative hypothesis (H_1): Effects of the ploughing operation parameters on tractor fuel consumption in litres per hectare are not the same.

Test statistic: ANOVA F-test

Decision rule: Reject H_0 in favour of H_1 at 0.05 level of significance if P-value < 0.05, otherwise do not reject H_0

III. RESULTS AND DISCUSSION

Soil Analysis

The result of the soil analysis test carried out in the study location is presented in Table 3.

Table. 3: Soil Textural Analysis

	Soil Composition			
	Sand (%)	**Clay (%)**	**Silt (%)**	**Classification**
University of Uyo	30	58	12	Clay loam

IV. EXPERIMENTAL TEST RESULTS

Table 4 presents the mean values of measured parameters of the 4-bottom disc ploughing operation. The table was subjected to One-way Repeated Measures ANOVA. The ANOVA result for effects of ploughing operation parameters on tractor fuel consumption is presented in Table 5.

Table. 4: Summary Table of Mean of Measured Parameter During Ploughing Operation

Treatment	**Values**
Width of cut (cm)	176.74
Depth of cut (c)	15.89
Draft (N)	4.97
Effective field capacity (ha/hr)	1.009
Tractive efficiency (%)	20.84
Field efficiency (%)	72.35
Travel reduction (Wheel slip) (%)	11.62
Duration of operation (hr/ha)	1.086
Speed of operation (km/hr)	7.50
Average moisture content (%)	9.29
Average bulk density(g/cm^3)	1.40
Average cone index(N/cm^2)	24.13
TOTAL	**346.825**

Table. 5: ANOVA Table for Effects of Ploughing Operation Parameters on Tractor Fuel Consumption

Source	Sum of Square	df	Mean Square	F-Value	P-Value
Parameters	89916.198	11	7165.113	156.94	< 2e-14
Residuals	1253.017	24	52.209		

Decision: Since P-value is < 2e-14 which is < 0.05, H_0 is rejected

Based on the ANOVA results presented in Table 5, one can comfortably deduce that the effects of the twelve ploughing operation parameters on tractor fuel consumption in litres per hectare in Uyo are not the same. In connection with this , therefore, it is important to conduct multiple comparison test using a Pair-wise test to ascertain which ploughing operation parameters are actually significantly different in terms of their effects on tractor fuel consumption. The result of the Pair-wise test is presented in Table 6

Table. 6: Pair-wise Comparison Result of Ploughing Operation Parameters

	X11	X12	X10	X8	X2	X3	X4	X6	X9	X5	X7
X12	0.72	-	-	-	-	-	-	-	-	-	-
X10	**0.00***	0.68	-	-	-	-	-	-	-	-	-
X8	0.18	0.72	**0.002***	-	-	-	-	-	-	-	-
X2	**0.046***	1.00	0.158	0.060	-	-	-	-	-	-	-
X3	0.14	0.73	0.053	0.132	**0.04***	-	-	-	-	-	-
X4	0.74	0.72	0.012	1.000	**0.04***	**0.03***	-	-	-	-	-
X6	**0.00***	0.13	0.006	**0.004***	**0.00***	**0.00***	**0.004***	-	-	-	-
X9	0.13	0.68	0.755	0.131	0.15	0.25	0.131	**0.011***	0.760	-	-
X5	0.74	0.86	0.865	0,760	1.00	0.75	0.750	0.151	0.865	0.86	-
X7	0.42	0.88	1.001	0.332	0.75	0.76	0.144	**0.034***	0.760	0.86	0.86
X1	0.13	0.32	0.129	0.136	0.21	0.13	0.321	0.623	0.142	0.14	0.197

*Significant at P < 0.05

Key: X1 = Width of cut (cm), X2 = Depth of cut (cm), X3 = Draft (N), X4 = Effective field capacity (ha/hr), X5 = Tractive efficiency (%), X6 = Field efficiency (%), X7 = Travel reduction (Wheel slip) (%), X8 = Duration of operation (hr/ha), X9 = Speed of operation (km/hr), X10 = Average moisture content (%), X11 = Average soil bulk density (g/cm^3), X12 = Average soil cone index (N/cm^2)

V. CONCLUSION

This study was carried out to investigate the factors affecting tractor fuel consumption during polughing (primary tillage) operation in Uyo, Akwa Ibom State, Nigeria. One-way Repeated Measures ANOVA was used to study the influence of ploughing operation parameters on tractor fuel consumption. The results obtained from the One-way Repeated Measures ANOVA indicate that ploughing operation parameters had significant effect on tractor fuel consumption.

REFERENCES

[1] Ajav, E. A and Adewoyi, A. O (2011). Theeffects of ploughing depth and speed on the Fuel consumption of some commonly used farm tractors in selected states of south Western Nigeria. Proceedings of the Nigerian Institution of Agricultural Engineers (NIAE), 32: 114-122.

[2] Al-Suhaibani, S. A and Ghaly, A. E (2010). Effect of ploughing depth of tillage and forward speed on the performance of a medium size chisel plough operating in a sandy loam soil. *American Journal of Agricultural and Biological Engineers.* 5(3):247-255

[3] Gee, G. W and Or, D (2002). "Particle size analysis" In: Dane, J. H., Toop, G. C (Eds), Methods of Soil

Analysis Part 4, SSSA. Book Series No. 5. Soil Sci. Society of AM., Madison, Wi, USA. 255-293

[4] Ikpo, C and Ifem, J. L. C (2005). Fuel consumption of tractors –Steyr 768 and 8075 during tillage operations in Makurdi, Benue State. Proceedings of the Nigerian Institute of Agricultural Engineers, 27: 60-63.

[5] Kudabo, E. A and Gbadamosi, L (2012). Effects of forward speed on the performance of a disc plough. *Journal of Science and Multidisciplinary Research.* 4: 25-32

[6] Mahmood, N and Gee-Clough, D (1989). Field performance of tractors in Pakistan. *Journal Agricultural Mechanization in Asia, Africa and Latin America*. 20(4):64-68

[7] Oni, K. C (1991). Trafic compaction and tillage effects on the performance of maize in sandy loam soil of Nigeria. *Journal of Agricultural Mechanization in Asia, Africa and Latin America*. 22(2):27-31

[8] Oyelade, O. A and Oni, K. C (2018). Factors influencing tractor fuel consumption during harrowing operation on a sandy loam soil. Proceedings of International Commission of Agricultural and BioSystems Engineering. 12th CIGR section VI International Symposium.

[9] Panam, U., Uchida, S and Inaba, S (2010). The economic potential of tractor hire business in Riau Province, Indonesia: A case study of small tractor use for small rice farms. *Agricultural Engineering International: CIGR Ejournal*. Manuscript MES 1591 (12):1-12

[10] Singh, G (2000). Modernization of agriculture in India (Part 1) – farm mechanization. Agricultural situation in India, Ministry of Agriculture, New Delhi.

[11] Udo, D. C and Akubuo, C. O (2004). Fuel consumption in tillage operation for sandy loam soil. Proceedings of the Nigerian Institution of Agricultural Engineers (NIAE) 26:74-83

[12] Upadhyaya, S. K., Williams, T. H., Kemble, L. J. and Collins, N. E. (1984). Energy requirements for chiselling in coastal plain soils. *Transactions of ASAE*, 28(8): 1643 – 1649.

[13] Xinam, D., Yuzhou, L., Suocheng, D and Xiusheng, Y (2005). Impact of resources and technology on farm production in Northwestern China. Agricultural Systems, 84:155-169.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Screening, characterization and molecular insights of rhamnolipid biosurfactant produced by *Pseudomonas aeruginosa* BS1

Nisha S. Nayak[1*], Dhruvi S. Joshi[2], Yesha S. Rathi[1]

[1]Disha Life Sciences Pvt. Ltd., Ahmedabad, Gujarat, India.
[2]Swarrnim Startup and Innovation University, Gandhinagar, Gujarat, India.
*****Corresponding author: nisha_nayak272@yahoo.co.in

Received: 26 Feb 2023; Received in revised form: 25 Mar 2023; Accepted: 03 Apr 2023; Available online: 13 Apr 2023

Abstract— *Biosurfactants are a group of heterogenous metabolites synthesized by a variety of microorganisms. They exhibit the properties of the surface tension reduction, emulsion stabilization, promote foaming, and specific activity at extreme temperatures, pH, and salinity. A bacterial strain was screened for its biosurfactant production in 250 ml MSM broth with crude oil as an inducer for 5 days. The screening activity performed by (i) drop collapse test, (ii) oil displacement test, (iii) emulsification index proved the presence of biosurfactant. TLC and FTIR analysis confirmed that the biosurfactant produced by the selected bacterial isolate is a rhamnolipid. The potential isolate was identified by 16S rRNA gene sequencing analysis and it was identified as Pseudomonas aeruginosa.*

Keywords— ***crude oil, emulsification index, rhamnolipid, TLC, FTIR, PCR***

I. INTRODUCTION

Biosurfactants are biologically derived surface-active substances that are primarily produced as secondary metabolites by filamentous fungus, yeast, and bacteria. Due to their special amphiphilic composition, which combines hydrophobic and hydrophilic parts, which increases the bioavailability of water and lowers the surface tension. This provides emulsification activity (Nayarisseri *et al*., 2018; Meliani and Bensoltane, 2014). The diverse structure of biosurfactants results from their different microbial origin, the substrate on which they are grown and cultivation conditions used (Santos *et al*., 2016). In recent years, there has been a substantial increase in the production of biosurfactants and their commercialization (Henkel and Hausmann, 2019).

Some properties of biosurfactants that make them unique from chemical surfactants include: reduction of surface and interfacial tension, low toxicity, high biodegradability, emulsification, selective performance, specific activity, possibility of production from cheap raw materials, antimicrobial properties, easier production and more variety (De Giani *et al*., 2021; Bagheri *et al*., 2013).

There are basically five classes of biosurfactants: (i) glycolipids, (ii) phospholipids and fatty acids, (iii) lipopeptides and lipoproteins, (iv) polymeric surfactants and (v) specific biosurfactants (Desai and Banat, 1997; Varjani and Upasani, 2017). The biosurfactant production is an important survival strategy by different microorganisms as it helps in uptake of hydrophobic substrates for surface-associated modes of motility (Chrzanowski *et al*., 2012). *Pseudomonas aeruginosa* is the preferred microorganism for the production of rhamnolipid type of biosurfactant utilizing glycerol, mannitol, fructose, glucose, and vegetable oils (Koch *et al*., 1991; Santos *et al*., 2002). Rhamnolipids are one of the most important glycolipid biosurfactants, which are produced by two bacterial species of *Pseudomonas aeruginosa* and *Burkholderia* (Fracchia *et al*., 2012).

Rhamnolipid has a high emulsion capacity and is often used in the pharmaceutical and environmental industries such as increasing oil recovery and bioremediation

(Suhandono *et al*., 2021). *Pseudomonas* species are the largest producers of rhamnolipids. They produce two different types of rhamnolipids that differ in the number of rhamnose sugars. Mono-rhamnolipids and di-rhamnolipids are the main rhamnolipids. These molecules have high surface activity and are used in various medical fields as antifungal, antibacterial and antiviral materials (Kaskatepe *et al*., 2015). Microorganisms especially bacteria represent an excellent source of biosurfactants, so that the isolation and characterization of the emulsifying capacity of biosurfactant molecules represents an important step for their future application in the areas of biotechnology (Singh *et al*., 2019; Volkering *et al*., 1997).

The present study involves: Screening, production and characterization of biosurfactant from *P. aeruginosa* BS1 using crude oil.

II. MATERIALS AND METHODS

2.1 Screening of biosurfactant producing bacteria

A bacterial strain belonging to *Pseudomonas aeruginosa* was procured from the preserved culture collection of Disha Life Sciences Pvt. Ltd. It was then screened for biosurfactant production in Minimal Salt Medium (MSM) (g/L) as described by Ohadi *et al*., (2017) with some modifications: $MgSO_4$, 0.1; KH_2PO_4, 0.5; NH_4Cl, 0.01; $FeSO_4.7H_2O$, 0.001; $NaHCO_3$, 1; and K_2HPO_4, 0.5, pH 7.0 with 0.1% crude oil (as an inducer) by the following methods.

2.1.1 Drop collapse test

Drop collapse test, as described by Jain *et al*., (1991), was performed to screen the biosurfactant production. Crude oil was applied to the solid glass surface of a microscope glass slide and 250 µL of the supernatant was placed on the oil-coated surface and drop size was observed after 1 min with the help of a magnifying glass. The result was considered to be positive when the diameter of the drop was increased by 1 mm from that which was produced by distilled water that was taken as the negative control (Youssef *et al*., 2004).

2.1.2 Oil displacement test

In oil displacement test (Safary *et al*., 2010), 40 µl of crude oil was placed to the surface of 40 ml of distilled water in a petri dish forming thin oil layer on it. After that, 10 µl of culture supernatant was gently placed on the centre of the oil layer. Clear zone formation by displacing oil indicates the presence of biosurfactant. The diameter of the clear zone on the oil surface was visualized under visible light and measured after 30 seconds, which was correlated to the surfactant activity, also known as an oil displacement activity.

2.1.3 Emulsification index (%EI)

Emulsion activity of the culture supernatant was detected by addition of 2 mL of crude oil to the equal volume of cell-free supernatant, mixed with a vortex for 2 min and allowed to stand for 24 hours at 35 ± 2 °C. The emulsification activity was observed after 24 h and it was calculated using the following formula (Khan *et al*., 2017):

$$\text{EI24 (\%)} = \frac{Total\ height\ of\ the\ emulsified\ layer}{Total\ height\ of\ the\ liquid\ layer} \times 100$$

2.2 Production and extraction

The production and extraction of biosurfactant was carried out according to Abbasi *et al*., (2012) with some modifications. The culture was inoculated in 300 ml Luria Bertini (LB) broth to which 2% (v/v) of crude oil was added. The culture was incubated at 37 °C for 5 days at 120 rpm with shaking conditions. After incubation, cells were removed from the culture broth by centrifugation at 10,000×g for 15 min at 4 °C. The cell free supernatant was acidified with 6 N HCL to pH 2 and stored overnight at 4 °C to enhance the precipitation of biosurfactant. The resulted precipitate was separated by centrifugation (15,000×g, 15 min, 4 °C) and extracted several times with ethyl acetate at room temperature. The solvent was completely evaporated by drying at room temperature. The crude biosurfactant was obtained as a viscous brown-coloured substance.

2.3 Identification of biosurfactant by TLC and FTIR

The rhamnolipids extracted were analysed by thin-layer chromatography (TLC) according to (Bhat *et al*., 2015) with few modifications. The TLC was carried out on silica 60 gel aluminium sheets (Loba, Mumbai, India) using the solvent system $CHCl_3/CH_3OH/CH_3COOH$ (81:17:2). When the solvent reached the top, the plate was removed and allowed to air dry. The plate was then kept in iodine vapour chamber for development of yellow spot to check the presence of lipids in biosurfactant.

The partially purified biosurfactant was characterized by Bruker Alpha II Fourier Transform Infrared spectrophotometer (FTIR) spectroscopy to find out functional groups. The range of spectra used was 4,000 cm^{-1} – 400 cm^{-1}.

2.4 Quantitative assay of carbohydrate

Phenol sulfuric acid method is used for detection of rhamnose-sugar(carbohydrate) in biosurfactant. The concentration of carbohydrates was determined by comparing it with D-glucose as a standard. The basic protocol of DuBois *et al*., (1956) was followed, with the modifications indicated below. The biosurfactant (10 µL) and phenol solution (80 µl) were taken and then 1 ml of

concentrated sulfuric acid was added slowly down the side of the tube. The tube was then incubated for 30 s at room temperature. The absorbance was read at 490 nm using distilled water as blank in a Double Beam Spectrophotometer (Systronics, Ahmedabad, India).

2.5 Identification of biosurfactant producing bacteria

Strain BS1 was identified by 16S rRNA gene sequence analysis. The molecular identification was carried out by amplification, sequencing and analysis of conserved 16S rRNA region. Genomic DNA was isolated from the pure culture and the quality of DNA was checked by gel electrophoresis on a 1% agarose gel. The PCR was performed using universal primers. The PCR products were sequenced and the obtained sequences were compared with the known ones in the National Centre for Biological Information (NCBI) database using Basic Local Alignment Search Tool (BLAST) and accession number was obtained by submission to NCBI GenBank.

2.6 Rhamnolipid producing gene screening by PCR

The PCR was carried out according to Pacwa-Płociniczak *et al*., (2014) with a few changes. The primers rhlA and rhlB were used to detect potential rhamnolipid synthesis by the BS1 strain. The PCR was run with a mixture containing 1 µl of the DNA template, 0.2 µM of each primer, 10× reaction buffer, 1.5 mM of $MgCl_2$, 200 µM of dNTP and 1 U of Taq DNA polymerase in a Thermal Cycler. PCR amplification was carried out as follows- denaturation at 95 °C for 3 min, and 30 cycles of 60 s, followed by annealing for 1 min at 56 °C and an extension step of 1.5 min at 72 °C and a final extension step of 10 min at 72 °C. The experiment included a control reaction mixture without added DNA.

III. RESULTS AND DISCUSSION

3.1 Screening of isolate for biosurfactant production

Sample (5 ml) was withdrawn at regular intervals (24 h) from the flask containing 250 ml MSM broth for 5 days to perform the screening tests. The results obtained after the screening tests are as follows:

Table 1: Screening of biosurfactant

Time (h)	Screening Test		
	Drop Collapse Test	Oil displacement Test (mm)	Emulsification index (%)
24	+	20 mm	40%
48	+	22 mm	48%
72	+	25 mm	52%
96	+	28 mm	60%
120	+	30 mm	72%

From the results obtained, it can be seen that the bacterial isolate gave positive results for the drop collapse test. Production of biosurfactant decreases the surface tension of the supernatant and as a result, the shape of the test droplet was larger as compared to the control (distilled water) as shown in Fig. 1(a). Oil displacement test is considered positive when a clear zone is formed as oil gets displaced by the presence of biosurfactant as depicted in Fig. 1(b). However, the extent of oil displacement differed considerably. There was a gradual increase in oil displacement activity from 20 mm to 30 mm at the end of 5 days. *Pseudomonas aeruginosa* ATCC-10145 a highly positive strain showed 8.0 cm of oil displacement (El-Sheshtawy and Doheim, 2014). Thavasi *et al*., (2011) reported positive biosurfactant producing bacteria using drop collapsed and oil displacement test, among which many isolates belonged to *Pseudomonas* sp.

Higher biosurfactant concentration in the culture medium was related to high emulsion capacity. The emulsification activity of biosurfactant also increased during incubation period. It was 40% after 24 hours and it reached 72% at the end of 120 hours. In the current study, crude oil was used but according to the previous works, *Pseudomonas* rhamnolipids can effectively emulsify and stabilize emulsions with various types of hydrocarbons and oils such as linseed oil, almond oil, mineral oil (Benincasa *et al*., 2004), diesel (Haba *et al*., 2003; Wei *et al*., 2005), kerosene, n-alkanes, aromatic compounds, coconut oil, and olive oil (Patel and Desai, 1997). Rahman *et al*., (2002) reported results for two *P. aeruginosa* strains. The strains showed emulsification index from 25% to 90% for oily phases diesel and kerosene.

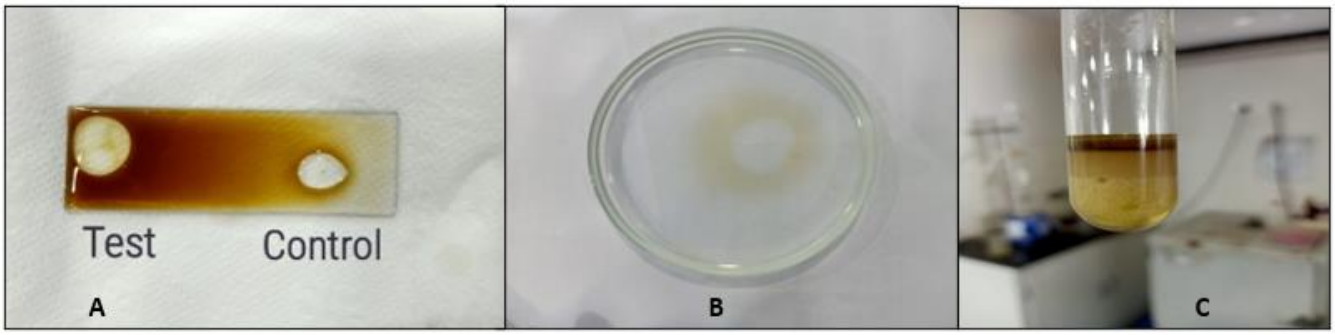


Fig. 1: Screening of biosurfactant production by Pseudomonas aeruginosa BS1 (A) Drop collapse test; (B) Oil displacement test; (C) Emulsification Index

3.2 Characterization of produced biosurfactant

Results of TLC showed yellow spots indicating the presence of lipids in the structure of produced biosurfactant. TLC of partially purified rhamnolipids recovered from cell-free supernatant of *P. aeruginosa* revealed three different spots with different R_f (retention factor) values. The first major spot (R_f = 0.69) was a mono-rhamnolipid whereas the second spot (R_f = 0.43) and third spot (R_f = 0.40) confirmed the presence of di-rhamnolipids. These results are as per the findings of Abdel-Mawgoud *et al*., (2007), where crude biosurfactant extract of *P. aeruginosa* BS20 showed two main spots with R_f values 0.4 and 0.68 representing di-rhamnolipids and mono-rhamnolipids respectively. Another study done by Thio *et al*., (2022) on *Pseudomonas* sp. showed two spots with R_f values of 0.68 and 0.38 during TLC which confirmed the lipid nature of biosurfactant.

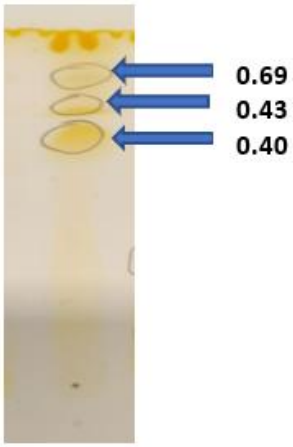


Fig. 2: Thin Layer Chromatography (TLC) of partially purified biosurfactant

The partially purified sample biosurfactant was checked for functional group by using FTIR. The prominent peak was found at 3382 cm^{-1} vibrations which indicates stretching for –CH and –CH_2. The strong stretching of C=O of the carbonyl group was observed at 1636 cm^{-1}. The FTIR spectra of biosurfactants from *P. aeruginosa* BS1 also revealed the presence of lipid moiety in the purified glycolipids showing peaks at 1014 cm^{-1} (Moussa *et al*., 2014). Similarly, the biosurfactant showed an intensity band at 1636 cm^{-1} indicated bending of the hydroxyl (-OH) group, which reflects the presence of the carboxylic acid functional group in the compound (Figure 3).

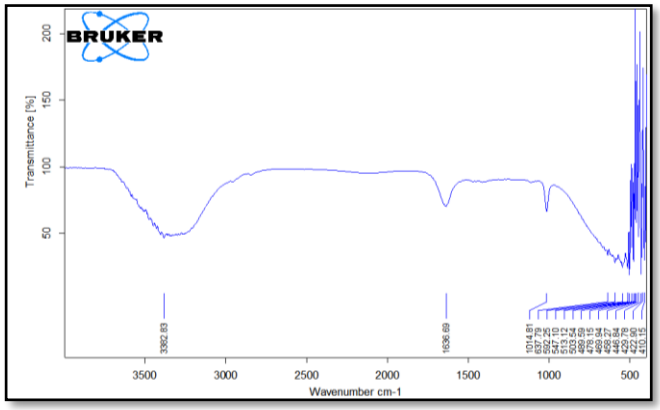


Fig. 3: FTIR of partially purified biosurfactant

3.3 Quantitative analysis for carbohydrate

The concentration of carbohydrate was 5.52 mg/ml as per the carbohydrate standard curve and O.D. taken at 490 nm. Abbasi *et al*., (2013) followed the same procedure and the biosurfactant obtained had 32% (w/w) carbohydrate content.

3.4 Identification of biosurfactant producing bacteria

After gene sequencing analysis, the obtained sequence was found to be *Pseudomonas aeruginosa* BS1 and accession no OQ568205.1 was obtained by submission of sequence to NCBI GenBank.

3.5 Rhamnolipid producing gene screening by PCR

The whole DNA was screened for presence of biosurfactant producing gene RhlA and RhlB by using PCR technique. The results of Gel electrophoresis showed the presence of

RhlB near 232 bp having in the genome which also indicates biosurfactant production property in bacteria.

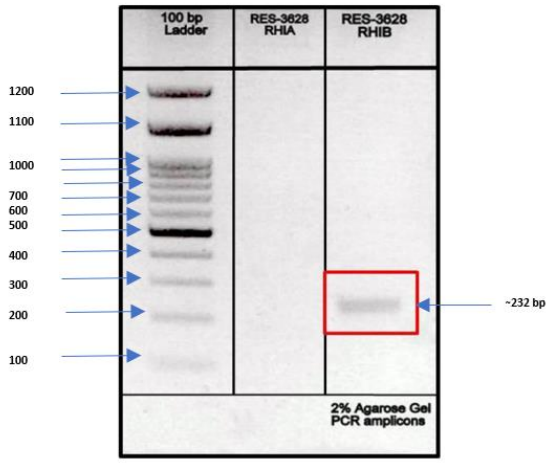


Fig. 3: Native-PAGE of RhlA and RhlB gene after PCR screening

IV. CONCLUSION

The present study was aimed at screening, production and characterization of a biosurfactant producing bacterial strain. Biosurfactant producing bacteria *Pseudomonas aeruginosa* was a potent producer which was confirmed by all major screening tests. Characterization of produced biosurfactant showed rhamnolipid nature based on TLC and FTIR results. More targeted studies to develop methods to scale up production of rhamnolipid biosurfactant and also explore new renewable resources as substrate for the bacterial strain for higher and efficient rhamnolipid production can be a way forward.

REFERENCES

[1] Abbasi, H., Hamedi, M. M., Lotfabad, T. B., Zahiri, H. S., Sharafi, H., Masoomi, F., ... & Noghabi, K. A. (2012). Biosurfactant-producing bacterium, Pseudomonas aeruginosa MA01 isolated from spoiled apples: physicochemical and structural characteristics of isolated biosurfactant. *Journal of bioscience and bioengineering*, *113*(2), 211-219.

[2] Abbasi, H., Sharafi, H., Alidost, L., Bodagh, A., Zahiri, H. S., & Noghabi, K. A. (2013). Response surface optimization of biosurfactant produced by Pseudomonas aeruginosa MA01 isolated from spoiled apples. *Preparative biochemistry & biotechnology*, *43*(4), 398–414.

[3] Abdel-Mawgoud, A. M., Aboulwafa, M. M., & Hassouna, N. A. H. (2007). Microbial production of surfactants: screening and identification of two promising isolates and their biosurfactants. *Egyptian Journal of Biotechnology*, *27*.

[4] Bagheri Lofabad, T., Partovi, M., & Bahmaei, M. (2013). Rhamnolipid biosurfactant production by Pseudomonas aeruginosa MR01 using vegetable oil refinery wastes. *New Cellular and Molecular Biotechnology Journal*, *3*(9), 91-99.

[5] Benincasa, M., Abalos, A., Oliveira, I., & Manresa, A. (2004). Chemical structure, surface properties and biological activities of the biosurfactant produced by Pseudomonas aeruginosa LBI from soapstock. *Antonie Van Leeuwenhoek*, *85*, 1-8.

[6] Bhat, R., Dayamani, K. J., Hathwar, S., Hegde, R., & Kush, A. (2015). Exploration on production of rhamnolipid biosurfactants using native Pseudomonas aeruginosa strains. *Journal of BioScience & Biotechnology*, *4*(2).

[7] Chrzanowski, Ł., Dziadas, M., Ławniczak, Ł., Cyplik, P., Białas, W., Szulc, A., ... & Jeleń, H. (2012). Biodegradation of rhamnolipids in liquid cultures: effect of biosurfactant dissipation on diesel fuel/B20 blend biodegradation efficiency and bacterial community composition. *Bioresource technology*, *111*, 328-335.

[8] De Giani, A., Zampolli, J., & Di Gennaro, P. (2021). Recent trends on biosurfactants with antimicrobial activity produced by bacteria associated with human health: Different perspectives on their properties, challenges, and potential applications. *Frontiers in microbiology*, *12*, 655150.

[9] Desai, J. D., & Banat, I. M. (1997). Microbial production of surfactants and their commercial potential. *Microbiology and Molecular biology reviews*, *61*(1), 47-64.

[10] DuBois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. T., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical chemistry*, *28*(3), 350-356.

[11] El-Sheshtawy, H. S., & Doheim, M. M. (2014). Selection of Pseudomonas aeruginosa for biosurfactant production and studies of its antimicrobial activity. *Egyptian journal of petroleum*, *23*(1), 1-6.

[12] Fracchia, L., Cavallo, M., Martinotti, M. G., & Banat, I. M. (2012). Biosurfactants and bioemulsifiers biomedical and related applications–present status and future potentials. *Biomedical science, engineering and technology*, *14*(1), 1-49.

[13] Haba, E., Abalos, A., Jauregui, O., Espuny, M. J., & Manresa, A. (2003). Use of liquid chromatography-mass spectroscopy for studying the composition and properties of rhamnolipids produced by different strains of Pseudomonas aeruginosa. *Journal of Surfactants and Detergents*, *6*, 155-161.

[14] Henkel, M., & Hausmann, R. (2019). Diversity and classification of microbial surfactants. In *Biobased surfactants* (pp. 41-63). AOCS Press.

[15] Jain, D. K., Collins-Thompson, D. L., Lee, H., & Trevors, J. T. (1991). A drop-collapsing test for screening surfactant-producing microorganisms. *Journal of Microbiological Methods*, *13*(4), 271-279.

[16] Kaskatepe, B., Yildiz, S., Gumustas, M., & Ozkan, S. A. (2015). Biosurfactant production by Pseudomonas aeruginosain kefir and fish meal. *Brazilian Journal of Microbiology*, *46*, 855-859.

[17] Khan, A. H. A., Tanveer, S., Alia, S., Anees, M., Sultan, A., Iqbal, M., & Yousaf, S. (2017). Role of nutrients in bacterial biosurfactant production and effect of biosurfactant

production on petroleum hydrocarbon biodegradation. *Ecological Engineering*, *104*, 158-164.

[18] Koch, A. K., Käppeli, O., Fiechter, A., & Reiser, J. (1991). Hydrocarbon assimilation and biosurfactant production in Pseudomonas aeruginosa mutants. *Journal of Bacteriology*, *173*(13), 4212-4219.

[19] Meliani, A., & Bensoltane, A. (2014). The ability of some Pseudomonas strains to produce biosurfactants. *Poult. Fish. Wildl. Sci*, *2*, 112.

[20] Moussa, T. A. A., Mohamed, M. S., & Samak, N. (2014). Production and characterization of di-rhamnolipid produced by Pseudomonas aeruginosa TMN. *Brazilian Journal of Chemical Engineering*, *31*, 867-880.

[21] Nayarisseri, A., Singh, P., & Singh, S. K. (2018). Screening, isolation and characterization of biosurfactant producing Bacillus subtilis strain ANSKLAB03. *Bioinformation*, *14*(6), 304.

[22] Ohadi, M., Dehghannoudeh, G., Shakibaie, M., Banat, I. M., Pournamdari, M., & Forootanfar, H. (2017). Isolation, characterization, and optimization of biosurfactant production by an oil-degrading Acinetobacter junii B6 isolated from an Iranian oil excavation site. *Biocatalysis and Agricultural Biotechnology*, *12*, 1-9.

[23] Pacwa-Płociniczak, M., Płaza, G. A., Poliwoda, A., & Piotrowska-Seget, Z. (2014). Characterization of hydrocarbon-degrading and biosurfactant-producing Pseudomonas sp. P-1 strain as a potential tool for bioremediation of petroleum-contaminated soil. *Environmental Science and Pollution Research*, *21*, 9385-9395.

[24] Patel, R. M., & Desai, A. J. (1997). Biosurfactant production by Pseudomonas aeruginosaGS3 from molasses. *Letters in Applied Microbiology*, *25*(2), 91-94.

[25] Rahman, K. S. M., Rahman, T. J., McClean, S., Marchant, R., & Banat, I. M. (2002). Rhamnolipid biosurfactant production by strains of Pseudomonas aeruginosa using low-cost raw materials. *Biotechnology progress*, *18*(6), 1277-1281.

[26] Safary, A., Ardakani, M. R., Suraki, A. A., Khiavi, M. A., & Motamedi, H. (2010). Isolation and characterization of biosurfactant producing bacteria from Caspian Sea. *Biotechnology*, *9*(3), 378-382.

[27] Santos, A. S., Sampaio, A. P. W., Vasquez, G. S., Anna, L. M. S., Pereira, N., & Freire, D. M. (2002). Evaluation of different carbon and nitrogen sources in production of rhamnolipids by a strain of Pseudomonas aeruginosa. In *Biotechnology for Fuels and Chemicals: The Twenty–Third Symposium* (pp. 1025-1035). Humana Press.

[28] Santos, D. K. F., Rufino, R. D., Luna, J. M., Santos, V. A., & Sarubbo, L. A. (2016). Biosurfactants: multifunctional biomolecules of the 21st century. *International journal of molecular sciences*, *17*(3), 401.

[29] Singh, P., Patil, Y., & Rale, V. (2019). Biosurfactant production: emerging trends and promising strategies. *Journal of applied microbiology*, *126*(1), 2-13.

[30] Suhandono, S., Kusuma, S. H., & Meitha, K. (2021). Characterization and production of rhamnolipid biosurfactant in recombinant escherichia coli using autoinduction medium and palm oil mill effluent. *Brazilian Archives of Biology and Technology*, *64*.

[31] Thavasi, R., Sharma, S., & Jayalakshmi, S. (2011). Evaluation of screening methods for the isolation of biosurfactant producing marine bacteria. *J Pet Environ Biotechnol S*, *1*(2), 1-7.

[32] Thio, C. W., Lim, W. H., Md. Shah, U. K., & Phang, L. Y. (2022). Palm kernel fatty acid distillate as substrate for rhamnolipids production using Pseudomonas sp. LM19. *Green Chemistry Letters and Reviews*, *15*(1), 83-92.

[33] Varjani, S. J., & Upasani, V. N. (2017). Critical review on biosurfactant analysis, purification and characterization using rhamnolipid as a model biosurfactant. *Bioresource technology*, *232*, 389-397.

[34] Volkering, F., Breure, A. M., & Rulkens, W. H. (1997). Microbiological aspects of surfactant use for biological soil remediation. *Biodegradation*, *8*, 401-417.

[35] Wei, Q. F., Mather, R. R., & Fotheringham, A. F. (2005). Oil removal from used sorbents using a biosurfactant. *Bioresource technology*, *96*(3), 331-334.

[36] Youssef, N. H., Duncan, K. E., Nagle, D. P., Savage, K. N., Knapp, R. M., & McInerney, M. J. (2004). Comparison of methods to detect biosurfactant production by diverse microorganisms. *Journal of microbiological methods*, *56*(3), 339-347.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Interconnectedness and the Value of Life: A Deep Ecological Analysis of 'Do Androids Dream of Electric Sheep?' by Philip K. Dick

Samira Mehdipour Shekakomi

Department of English Literature, Islamic Azad University of Science and Research Branch, Iran

Received: 11 Mar 2023; Received in revised form: 09 Apr 2023; Accepted: 18 Apr 2023; Available online: 27 Apr 2023

Abstract— *This article examines the ecological themes present in Philip K. Dick's "Do Androids Dream of Electric Sheep?" through the lens of Warwick Fox's deep ecology theory. The novel emphasizes the interconnectedness of all life, demonstrating the importance of recognizing our place within a larger ecological system. The absence of non-human life is portrayed as a contributing factor to the degradation of the environment, emphasizing the intrinsic value of non-human life in ecological systems. The consequences of anthropocentrism, including environmental destruction and a lack of empathy for non-human beings, are explored. The relationship between technology and ecology is also examined, with the potential for both degradation and restoration. Overall, the article suggests that recognizing the interconnectedness of all life and valuing non-human life are essential for the health and survival of the entire ecosystem.*

Keywords— ***Anthropocentrism, Artificial life, Biodiversity, Deep ecology, Dystopian future, Ecological systems, Environment, Intrinsic value, Interconnectedness, Non-human life, Philip K. Dick, Technology, Warwick Fox.***

I. INTRODUCTION

In "Do Androids Dream of Electric Sheep?", Philip K. Dick explores the complex relationship between humans and artificial life in a dystopian future. While the novel has been widely analyzed for its social and political commentary, this article takes a different approach by examining the ecological themes present in the text. By examining the interconnectedness of all life, the intrinsic value of non-human life, the consequences of anthropocentrism, and the relationship between technology and ecology through the lens of Warwick Fox's deep ecology theory.

II. THE INTERCONNECTEDNESS OF ALL LIFE

One of the key themes in "Do Androids Dream of Electric Sheep?" is the interconnectedness of all life. Using Warwick Fox's deep ecology theory as a lens, it becomes clear that the novel emphasizes the importance of recognizing the ways in which human beings and non-human entities are connected.

This interconnectedness is demonstrated through the relationship between humans and animals, as well as between humans and androids. For example, the empathy that characters such as Rick Deckard feel towards animals is contrasted with their lack of empathy towards androids, suggesting that the novel sees all forms of life as interconnected and deserving of respect. Furthermore, the way in which the environment is portrayed as a post-apocalyptic wasteland serves as a warning about the

potential consequences of neglecting the interconnectedness of all life. By highlighting the importance of recognizing our place within a larger, interdependent ecological system, the novel suggests that humans must begin to view themselves as part of a larger whole in order to avoid environmental catastrophe.

Warwick Fox in his book "Toward a Transpersonal Ecology: Developing New Foundations for Environmentalism" explains the interconnectedness of all life:

> "Deep ecology is based on a perception of the inherent worth of other beings, which is independent of their utility for human purposes. It recognizes the right of all beings to live and flourish, to the extent that such flourishing is compatible with the existence of other beings. It recognizes the inherent value of non-human life, as well as the value of human life, and emphasizes the importance of the interconnectedness of all life-forms in ecological systems."

III. THE INSTRINSIC VALUE OF NON-HUMAN LIFE

In "Do Androids Dream of Electric Sheep?", the absence of non-human life is portrayed as a contributing factor to the degradation of the environment. The novel suggests that the loss of biodiversity and the disappearance of non-human species has led to a decline in the health of the ecosystem as a whole.

This idea is significant because it suggests that the novel recognizes the intrinsic value of non-human life in ecological systems. That is, the novel suggests that non-human life has inherent value and that it is important to preserve it for its own sake, not just for its usefulness to humans. By showing the negative consequences of the absence of non-human life, the novel emphasizes the importance of recognizing and valuing the interconnectedness of all life-forms in ecological systems.

The novel suggests that the well-being of all living beings is interconnected and that the preservation of non-human life is essential for the health and survival of the entire ecosystem. This emphasis on the intrinsic value of non-human life is a central aspect of deep ecology, which recognizes the importance of the interconnectedness of all life-forms and the need to protect the natural world for its own sake, as well as for the well-being of humans.

IV. THE CONSEQUENCES OF ANTHROPOCENTRISM

Warwick Fox's deep ecology theory critiques anthropocentrism, the view that human beings are the most important or significant entities in the world. In "Do Androids Dream of Electric Sheep?", the consequences of anthropocentrism are explored through the portrayal of a dystopian future in which human beings have exploited and destroyed the natural world.

Here are some quotes from the novel that illustrate the consequences of anthropocentrism:

"The dust continued westward, blotting out the white sun and then the stars. This had happened before, but never so violently. Birds and animals had died off. All the fish had died and the rivers were poisonous. And so it was that the plague came to this area too." (Chapter 1)

"It had never occurred to him that the day might come when he would feel about an animal as an animal evidently felt about him." (Chapter 3)

"It was a major statement, a philosophical statement—the supreme statement that could be made now. A voice from the tomb of the world. He was awed. At the same time he was filled with a bursting excitement. Here was a creature who was not human, who saw reality in a completely different way." (Chapter 9)

These quotes suggest that the consequences of anthropocentrism include environmental destruction, loss of biodiversity, and a lack of empathy for non-human beings. By portraying these consequences in the novel, Philip K. Dick highlights the need to move beyond anthropocentrism and recognize the value of non-human life in ecological systems.

V. THE RELATIONSHIP BETWEEN TECHNOLOGY AND ECOLOGY

Warwick Fox's deep ecology theory emphasizes the importance of the relationship between technology and ecology. In "Do Androids Dream of Electric Sheep?", this relationship is explored through the portrayal of a dystopian future in which advanced technology has been used to create artificial animals and humans.

On the one hand, the technology in the novel has contributed to the degradation of the natural world. The widespread use of advanced technology has led to environmental destruction, loss of biodiversity, and a lack of connection with the natural world. For example, the use of artificial animals has led to a situation in which "nobody raises genuine animals anymore" (Chapter 1), and people are more concerned with owning expensive,

lifelike replicas of animals than with preserving real animals.

On the other hand, the technology in the novel also has the potential to contribute to ecological preservation and restoration. For example, the development of "mood organs" allows people to control their emotions and avoid negative feelings, which could lead to more harmonious relationships with other living beings. Additionally, the androids in the novel are capable of performing dangerous or unpleasant tasks that could otherwise harm living beings, such as radiation clean-up or waste disposal.

The relationship between technology and ecology in "Do Androids Dream of Electric Sheep?" is complex and multifaceted. While advanced technology has contributed to environmental degradation and a lack of connection with the natural world, it also has the potential to contribute to ecological preservation and restoration. By exploring this relationship, Philip K. Dick raises important questions about the role of technology in shaping our relationship with the natural world and the potential consequences of our choices.

Warwick Fox's deep ecology theory suggests that the relationship between technology and ecology is crucial for ecological preservation and restoration. "Do Androids Dream of Electric Sheep?" portrays this relationship as complex and multifaceted, highlighting the potential of technology both to contribute to environmental destruction and to facilitate ecological restoration.

VI. CONCLUSION

In conclusion, "Do Androids Dream of Electric Sheep?" by Philip K. Dick explores ecological themes such as interconnectedness, the intrinsic value of non-human life, the consequences of anthropocentrism, and the relationship between technology and ecology. Through the lens of Warwick Fox's deep ecology theory, the novel emphasizes the importance of recognizing the ways in which human beings and non-human entities are connected and the value of non-human life in ecological systems. The novel highlights the negative consequences of neglecting the interconnectedness of all life and the need to move beyond anthropocentrism to recognize the value of non-human life. Additionally, the relationship between technology and ecology is explored, with the novel warning about the potential negative impacts of advanced technology on the environment. Overall, "Do Androids Dream of Electric Sheep?" offers a deep ecological analysis of the relationship between humans, non-human life, and the natural world, emphasizing the need for a more interconnected and sustainable approach to ecological systems.

REFERENCES

[1] Dick, P. K. (1968). Do Androids Dream of Electric Sheep? Random House.

[2] Fox, W. (1995). Toward a transpersonal ecology: Developing new foundations for environmentalism. Shambhala.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

$Bi_{25}FeO_{40}$ microspheres loading on g-C_3N_4 for high efficiency pollutants photodegradation

Xuan Sang Nguyen

Environmental Engineering Institute, Viet Nam Maritime University, Vietnam

Received: 15 Mar 2023; Received in revised form: 15 Apr 2023; Accepted: 23 Apr 2023; Available online: 30 Apr 2023

Abstract— *$Bi_{25}FeO_{40}$/g-C_3N_4 composites were synthesized for dechlorination of 2-chlorophenol (2-CP). The characteristic of the obtained products was studied using the X-ray diffraction (XRD), (FESEM) scanning electron microscopy, UV-vis reflectance. The effects of g-C_3N_4 content, photocatalyst dosage, solution pH, H_2O_2 on the dechlorination efficiency were investigated, in addition to the reusability of the nanocomposites. The results showed that increasing content of $Bi_{25}FeO_{40}$ in nanocomposites, from 10 to 30 wt.%, greatly increased the dechlorination efficiency. $Bi_{25}FeO_{40}$/g-C_3N_4 20wt.% and initial pH below 6.0 was the optimal conditions for the catalytic dechlorination of 2-CP. About 94.5% of 2-CP were completely removed after 150 minutes reaction at initial pH value of 6.0. The composites were easily separated from the solution by an applied magnetic field. The removal efficiency of 2-CP slightly decreased to 90% when the catalyst was reused in 4 runs. Therefore, $Bi_{25}FeO_{40}$/g-C_3N_4 composites can be considered as a promising method for remediation of pollution by 2-CP.*

Keyword— ***$Bi_{25}FeO_{40}$; photo-Fenton; Cluster microspheres.***

I. INTRODUCTION

Recently, great attention has been paid for the morphology control of nanometer- and micrometer-size catalyst materials because of their interesting physical and chemical properties. Then, these materials can using widely in practice fields [1-3]. In this respect, a great number of remarkable approaches have been studied to controlling-synthesis the morphologies and facets exposed, wether in nanoscale or microscope [4, 5].

Recently, 2-chlorophenol is widely used in daily chemical and pharmaceutical industries. It is also a significatn intermediate of some medicines. Therefore, 2-CP causes the serious pollution in industrial wastewater. Some catalysts prepared from precious metals and their alloys have been applicated to remove 2-CP. However, noble metals are expensive cost. To solve this problem, catalysts based on metals and their alloys as Fe, Cu and Bi were developed due to their earth-abundant, low-cost and less toxic. For example, the magnetically recyclable Bi/$Bi_{25}FeO_{40}$-C nanocomposites were prepared via a one step hydrothermal method and exhibited high photocatalytic activity in hydrogen generation. Magnetic $Bi_{25}FeO_{40}$-graphene photocatalysts were fabricated by alkaline hydrothermal approach and showed enhanced catalytic activity for the removal of methylene blue (MB) under visible-light irradiation [6].

Due to the interesting characteristic, g-C_3N_4 is considered to be the most stable allotrope among various carbon nitrides under ambient conditions. Because of the two-dimensional frameworks of tri-s-triazine connected via tertiary amines structure , g-C_3N_4 possess high stable thermal and chemical stability. G-C_3N_4 is founded to be a visible-light-active polymeric semiconductor with a band gap of ~2.7 eV, corresponding to an optical wavelength of ~460 nm. Specially, it have an appropriate band structure for both water reduction and oxidation. As such, g-C_3N_4 is considered become the shining star in the field of photocatalysis.

In this work, $Bi_{25}FeO_{40}$/g-C_3N_4 composites were synthesised through a simple hydrogenthermal method. The catalyst activity of $Bi_{25}FeO_{40}$ photocatalysts were investigated by the photo-degradation 2-CP under visible light. The factors influential to the efficiency of the photo-dechlorination process are also studied and discussed in

detail as the effects of g-C_3N_4 content, photocatalyst dosage, solution pH. The result show that $Bi_{25}FeO_{40}$/g-C_3N_4 composites can be considered as a promising approach for 2-CP removal.

II. EXPERIMENTAL

2.1 Synthesis of composites.

Pure g-C_3N_4 powder was prepared using melamine as a precursor at 550 ^{0}C for 4h in a muffle furnace. The obtained products were washed several times with de-ionized water then grounded for further use. Microsphere $Bi_{25}FeO_{40}$ was synthesized via a normal hydrothermal process. In a typical procedure, a certain amount of $Fe(NO_3)_3 \cdot 9H_2O$ (2,04 g) and $Bi(NO_3)_3 \cdot 5H_2O$ (2,62 g) were dissolved in 60ml of deionized water under magnetic stirring. The precipitate was put into a Teflon-lined autoclave, followed by adding with 10 mL of sodium alginate solution (10 g/L), 4.5g of citric acid and a certain amount of KOH. After 30 min ultrasonic treatment, the mixture was transfered into a Teflon liner of 100mL capability. The autoclave was sealed and heated at 180°Cfor 12h and cooled to room temperature naturally. The resulting precipitant was recovered by filtration, followed by washing with distilled water three times, and drying at 80°C for 10h.

The Bi/g-C_3N_4 composite was prepared by simple impregnation method. A mount of 0.5 g $Bi_{25}FeO_{40}$ was added into 50 ml of ethanol under ultrasonic treatment for 40 min. Then, a certain amount of g-C_3N_4 added into the $Bi_{25}FeO_{40}$ suspension under vigorously stirring for 5 hours. The mixture was separated from the solution by an internal magnet, then washed and dried at 100^{0}C for 12h in an electric oven. The as-prepared composites were named x% Bi/g-C_3N_4 (x% denotes t mass percentages of g-C_3N_4 in as obtained-composites). In this work, Bi/g-C_3N_4 composite with 10 wt%, 20 wt% and 30 wt% of g-C_3N_4 were synthesized, respectively.

2.2 Characterization

X-ray diffraction (XRD analysis was carried out an X-ray powder diffractometer with Cu Kα radiation at 40 kV and 40 mA. The morphology and internal structure of the prepared samples were further checked by transmission electron microscopy (FESEM), using a JEM 2100F electron microscope operated at a voltage of 200 kV. UV–vis reflectance spectra of the powder catalysts were recorded by a Perkin Elmer spectrometer Lambda 35 using an RSAPE-20 reflectance spectroscopy accessory (Labsphere Inc., NorthSutton, NH). The PL spectra of products were measured by a transient fluorescence spectrometer (Shimadzu RF-5301PC).

2.3 The photo-degradation of 2-CP

The degradation experiments were carried out under single wavelength light (PL-LED 100F λ=410 nm). 2-CP were used as the model pollutant to evaluate the Fenton activity of the Bi/gC_3N_4 composites. In a typical process, 10 mg of Bi/gC_3N_4 composite was added into 100mL of the 2-CP (10mg/L) aqueous solution with countinuous stirring. Before illumination, the suspension was stiring in dark for 30 minutes to reach adsorption-desorption equilibrium. Then 0.1ml of the H_2O_2 aqueous solution (30%) was added to the reaction solution at the beginning of the illumination. About 5ml of the suspension were collected after a defined time and centrifuged to remove the photocatalyst for UV-vis spectrum measurement.

III. RESULT AND DISCUSSION

3.1 XRD analysis

Fig.1 shows X-ray diffaction pattens of g-C_3N_4, $Bi_{25}FeO_{40}$ and Bi/gC_3N_4 20% wt. The patterns showed the sharp and intense peaks indicating the photocatalysts were well crystallized. As shown in the Fig. 1, the XRD peaks of the $Bi_{25}FeO_{40}$ were observed agree with the sillenite-type structure (JCPDS 46-0416). The strong and sharp diffraction peaks signify exbihite the high crystallinity of $Bi_{25}FeO_{40}$. The two characteristic peaks of g-C_3N_4 at 13.28 and 27.33 can be indexed to (100) and (002) diffraction planes (JCPDS 87-1526) [7, 8]. Compared to pure g-C_3N_4, it can be seen clearly most peaks for $Bi_{25}FeO_{40}$/g-C_3N_4 indexing to the structure of $Bi_{25}FeO_{40}$. Because of the presence of $Bi_{25}FeO_{40}$, the peaks of g-C_3N_4 became weaker. The character of g-C_3N_4 could not be obtained in the XRD pattern of 20% Bi/g-C_3N_4 composite sample could be explained by the low adding content and well dispersion of g-C_3N_4 powders. However, g-C3N4 can still be found in the composites due of the appearance of the peak at 27^0. The results suggests the composites were formed between g-C_3N_4 and $Bi_{25}FeO_{40}$.

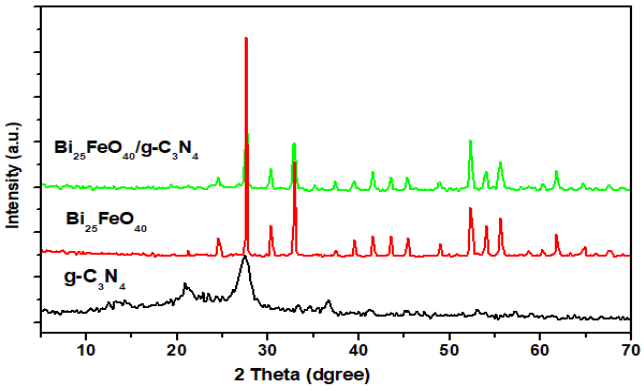


Fig. 1. XRD pattern of g-C_3N_4, $Bi_{25}FeO_{40}$ and $Bi_{25}FeO_{40}$/gC_3N_4 20% wt

3.2 SEM analysis

The surface properties of $Bi_{25}FeO_{40}$ and $Bi_{25}FeO_{40}$/g-C_3N_4 composite photocatalyst was observed using SEM method. The obtained results are depicted in Fig. 2. As shown in Fig. 2A, the material is composed of a large quantity of well-dispersed microspherical particles. These particles have uniform size and shape, most of which are spheres of 300-500 nm. From Fig. 2B, it is seen that the surface of the samples became rough when the g-C3N4 was modified with $Bi_{25}FeO_{40}$. The surface of $Bi_{25}FeO_{40}$ was cover by g-C3N4 particles. After loading with g-C_3N_4, accommodation of g-C3N4 on the surface of $Bi_{25}FeO_{40}$ lead to the formation of a tight heterostructure. In this case, two phases of g-C_3N_4 and $Bi_{25}FeO_{40}$ are clearly seen and close contact to form an intimate interface. This is similar to previous reports [9-11]. It is found that cavitations created in sonochemical technique play an important role in the preparation of heterostructure materials. This can promote the formation of the stable hybrid structure between g-C_3N_4 and $Bi_{25}FeO_{40}$ composite [12].

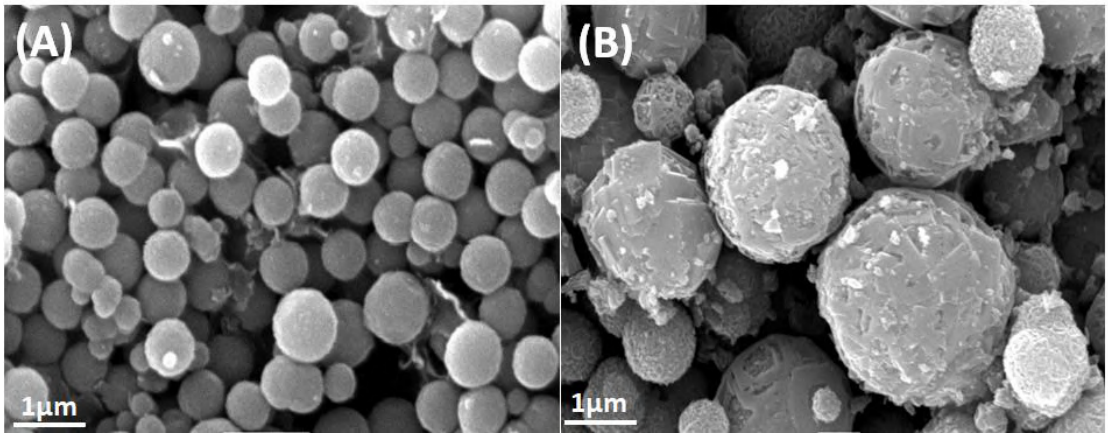


Fig. 2. SEM image of the as-prepared $Bi_{25}FeO_{40}$ microspheres and $Bi_{25}FeO_{40}$/g-C_3N_4 microspheres

3.4 Photo-degradation of 2-CP

The photocatalytic reaction of the $Bi_{25}FeO_{40}$/g-C_3N_4 catalysts were evaluated through the degradation of 2-chlorophenol (2-CP) in the presence of H_2O_2 with visible-light. The results of photocatalytic activities of the samples prepared at different conditions are shown in Fig. 3. When the photocatalyst is absence, no photodegradation can be observed. The photocatalytic activity of the Bi/g-C_3N_4 composite with visible light are further investigated by comparison with that of pure two-component. The Bi/g-C_3N_4 composite are much more photocatalytically efficient than pure $Bi_{25}FeO_{40}$ and pure g-C_3N_4. As shown in Fig.3a, about 94.5 % of 2-CP is photodegraded for 150 minutes of visible light irradiation while only 31% and 42% of 2-CP reduced with pure g-C_3N_4 and $Bi_{25}FeO_{40}$ microspheres used, respectively.

To understand the effect of g-C_3N_4 amount on $Bi_{25}FeO_{40}$/g-C_3N_4 composite, Bi/g-C_3N_4 10%, 20% and 30% wt composites were used for the photodegradation of 2-CP. From Fig. 3b, it can be observed that 94%, 87%, and 66% 2-CP was degraded in the present of g-CN/ZnFe 20%, 10% and 30%, respectively under the same time irradiation. It can be learned from the results that amount g-C_3N_4 introduced into the $Bi_{25}FeO_{40}$ is one of pivotal role for photocatalytic efficiency. When introduced g-C_3N_4 amount in the composites is over 30%, the photocatalytic activity is reduced. This can be explained that with suitable content g-C_3N_4 added, the interfacial interaction can be formed between g-C_3N_4 and $Bi_{25}FeO_{40}$ which resulting on the improved transfer and separation of photogenerated electron/hole pairs [13]. Whereas, increasing further content of g-C_3N_4 in the composite would form blocking on the reaction sites of $Bi_{25}FeO_{40}$, which can make their active sites reduced [14].

The excellent photocatalytic performance of $Bi_{25}FeO_{40}$/g-C_3N_4 composite can be attributed to their high crystalline and hibrid structure. The tight binding of g-C_3N_4 and $Bi_{25}FeO_{40}$ is suitable for the charge transfer between these two semiconductors and leads to a high separation rate of photogenerated electron-hole pairs while comparing to a physical mixture of two-component. As a result, these composites with a hybrid structure would result in an electric field at the interface, then improving the photocatalytic activity. The mineralization of 2-CP was also investigated as depicted in Figure 3c. The results reveal that the TOC removal of 2-CP using $Bi_{25}FeO_{40}$/g-C_3N_4 composites as catalysts achieved about 74 %. The results suggest that as-synthesized cluster microspheres show high capacity for the mineralization of 2-CP pollutants.

Effect of catalyst amount and pH in the range of 2 to 8 on 2-CP photo-degradation efficiency was also valued as depicted in Fig. 4. The results show that the degradation rate

of 2-CP improved with an increase in catalyst amount, as shown in Fig. 4a. However in higher catalyst dosage, the 2-CP removal percentage slightly decreased. Based on the experiment, 10 mg/L of the as-prepared composite is optimum dose for the 2-CP photo-dechlorination. The experiment results on the effect of pH reveal that the optimum pH was 6.0 (see at Fig. 4b). With pH below 6.0, in high H^+ concentration, the formation of stable oxonium ion $[H_3O_2]^+$ makes hydrogen peroxide more stable and then decreases its activity with ferrous ions. Moreover, the formation of Fe(II) complexes and ferric oxyhydroxides precipitation at a pH above 5.8 are probably reasons for efficiency decreases in the 2-CP removal processes.

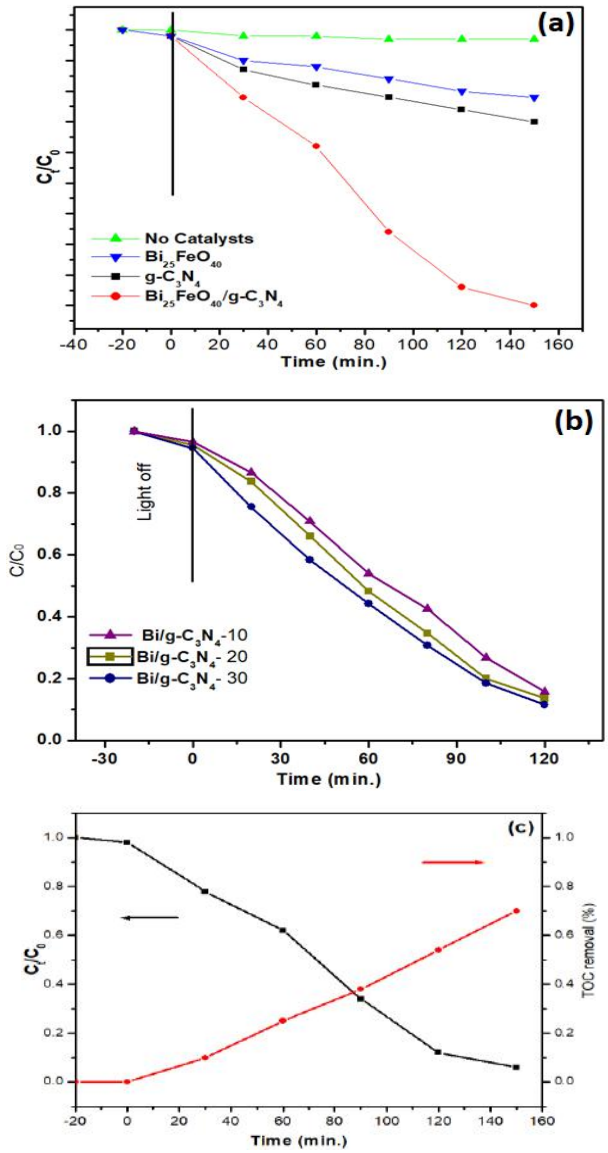


Fig. 3. (a) The 2-CP photo-degradation with different photocatalysts under visible light; (b) The 2-CP photo-degradation with Bi/gC_3N_4 composites of 10,20,30 wt%. (c) The mineralization of 2-CP using $Bi_{25}FeO_{40}$/g-C_3N_4 composite under visible light.

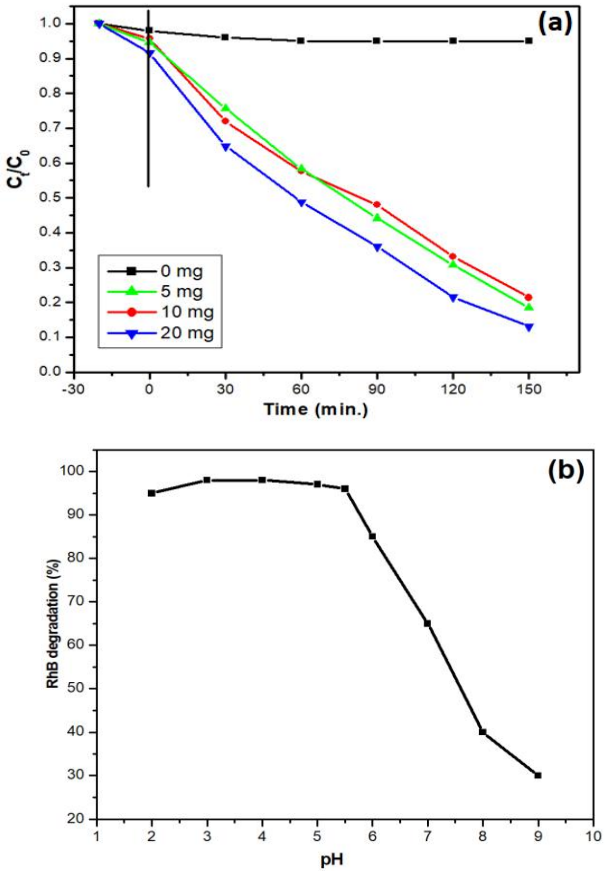


Fig. 4. The effect of (a) catalyst amount and (b) pH on 2-CP removal %

As known, the Fenton reaction is one of the most effective advanced oxidation processes for wastewater treatment in which the active hydroxyl radicals generated by reaction between Fe^{2+} and H_2O_2. It is reported that the presence of Fe^{2+} in the oxide plays an important role for the activation of H_2O_2[15, 16]. With the present of both visible light and H_2O_2, active hydroxyl radicals will be generated by main reactions following:

$$H_2O_2 + Fe\ (II) \rightarrow Fe\ (III) + {}^{\bullet}OH + OH^- \quad (3)$$

$$Fe\ (III) + e^- \rightarrow Fe\ (II) \quad (4)$$

Then more •OH can be produced resulting in a reaction between regenerated Fe(II) with H_2O_2 (Eq. (1)). Therefore, the kinetics of the reaction between ·OH and 2-CP is improved remarkably via visible light irradiation[16]. Moreover, the improvement of the photo-Fenton reaction of the as-prepared composite could be ascribed to the electron transfer process accelerated. As a result, the interface between Fe^{3+} and H_2O_2 improved, which result in more ·OH radical from high rate of decomposition H_2O_2 [17]. Furthermore, the crystalline structure and hybrid structure are important factors that could improve the photocatalytic perform of the as-obtained Bi/g-C_3N_4.

To investigate the stability of the Bi/g-C_3N_4 composites, the recycle tests were conducted in the oxidation process under Vis light irradiation. The results reveal that the as-obtained composite was easily collected by an internal magnet and the 2-CP degradation effectively has no significant change during the 4th successive cycles, demonstrating the high stability of the composite (Fig. 5). The chracteristic plays a very important role in application for water treatment at industry scale. The high photocatalytic activity, the stability and the easily separation suggest that the Bi/g-C_3N_4 can be promising candidates for the 2-CP dechloronation application.

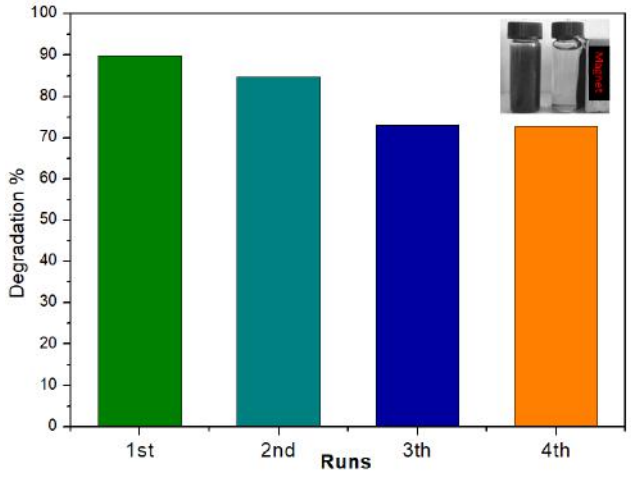


Fig. 5. The stability of the Bi/g-C_3N_4 composites after 4 recycles

IV. CONCLUSION

A series of magnetic separable $Bi_{25}FeO_{40}$/g-C_3N4 composite was successfully prepared by simple solvothermal method. The optimized weight ratio of g-C_3N_4 and $Bi_{25}FeO_{40}$ was observed. The results showed that $Bi_{25}FeO_{40}$/g-CN composite with added 20% g-C_3N_4 exposed the highest activity for 2-CP dechlorination under visible light irradiation. The improved photocatalytic activity of 20% Bi/g-CN can be attributed to their high crystalline and hibrid structure. The tight binding of g-C_3N_4 and $Bi_{25}FeO_{40}$ is suitable for the charge transfer between these two semiconductors and leads to a high separation rate of photogenerated electron-hole pairs while comparing to a physical mixture of two-component. As a result, these composites with a hybrid structure would result in an electric field at the interface, then improving the photocatalytic activity. Specially, Bi/g-C_3N_4 can be collected easily by using an external magnetic field and exhibite the high stability after 4 runs. These properties of the Bi/g-C_3N_4 composites as prepare could be a promising photokklcatalyst for the degradation pharmaceutical contaminants.

REFERENCES

[1] M.I. Ahsaan Bari, Ali Haider, Anwar Ul-Hamid, Junaid Haider, Iram Shahzadi, Ghazanfar Nazir, Anum Shahzadi, M. Imranh, Abdul Ghaffari, Evaluation of bactericidal potential and catalytic dye degradation of multiple morphology based chitosan/polyvinylpyrrolidone-doped bismuth oxide nanostructures, Nanoscale Adv., 2022,, 4 (2022) 2713-2728.

[2] S. Garg, M. Yadav, A. Chandra, K. Hernadi, A Review on BiOX (X= Cl, Br and I) Nano-/Microstructures for Their Photocatalytic Applications, J Nanosci Nanotechnol, 19 (2019) 280-294.

[3] N.A. Abdelwahab, E.M.H. Morsy, Synthesis and characterization of methyl pyrazolone functionalized magnetic chitosan composite for visible light photocatalytic degradation of methylene blue, Int J Biol Macromol, 108 (2018) 1035-1044.

[4] L. Luo, H. Lin, L. Li, T.I. Smirnova, P.A. Maggard, Copper-organic/octamolybdates: structures, bandgap sizes, and photocatalytic activities, Inorg Chem, 53 (2014) 3464-3470.

[5] U. Alam, A. Khan, D. Bahnemann, M. Muneer, Synthesis of iron and copper cluster-grafted zinc oxide nanorod with enhanced visible-light-induced photocatalytic activity, J Colloid Interface Sci, 509 (2018) 68-72.

[6] M.A. Basith, R. Ahsan, I. Zarin, M.A. Jalil, Enhanced photocatalytic dye degradation and hydrogen production ability of $Bi_{25}FeO_{40}$-rGO nanocomposite and mechanism insight, Sci Rep, 8 (2018) 11090.

[7] J. Yang, H. Chen, J. Gao, T. Yan, F. Zhou, S. Cui, W. Bi, Synthesis of Fe_3O_4/g-C_3N_4 nanocomposites and their application in the photodegradation of 2,4,6-trichlorophenol under visible light, Materials Letters, 164 (2016) 183-189.

[8] J. Ma, Q. Yang, Y. Wen, W. Liu, Fe-g-C_3N_4/graphitized mesoporous carbon composite as an effective Fenton-like catalyst in a wide pH range, Applied Catalysis B: Environmental, 201 (2017) 232-240.

[9] X. Wang, W. Mao, J. Zhang, Y. Han, C. Quan, Q. Zhang, T. Yang, J. Yang, X. Li, W. Huang, Facile fabrication of highly efficient g-C_3N_4/$BiFeO_3$ nanocomposites with enhanced visible light photocatalytic activities, J Colloid Interface Sci, 448 (2015) 17-23.

[10] T.S. Ahooie, N. Azizi, I. Yavari, M.M. Hashemi, Magnetically separable and recyclable g-C3N4 nanocomposite catalyzed one-pot synthesis of substituted imidazoles, Journal of the Iranian Chemical Society, 15 (2018) 855-862.

[11] K. Vignesh, A. Suganthi, B.-K. Min, M. Kang, Photocatalytic activity of magnetically recoverable $MnFe_2O_4$/g-C3N4/TiO_2 nanocomposite under simulated solar light irradiation, Journal of Molecular Catalysis A: Chemical, 395 (2014) 373-383.

[12] M. Masjedi-Arani, M. Salavati-Niasari, Cd_2SiO_4/Graphene nanocomposite: Ultrasonic assisted synthesis, characterization and electrochemical hydrogen storage application, Ultrason Sonochem, 43 (2018) 136-145.

[13] Y. He, L. Zhang, M. Fan, X. Wang, M.L. Walbridge, Q. Nong, Y. Wu, L. Zhao, Z-scheme SnO_{2-x}/g-C_3N_4 composite as an efficient photocatalyst for dye degradation and photocatalytic

CO2 reduction, Solar Energy Materials and Solar Cells, 137 (2015) 175-184.
[14] S. Huang, Y. Xu, M. Xie, H. Xu, M. He, J. Xia, L. Huang, H. Li, Synthesis of magnetic $CoFe_2O_4$/g-C_3N_4 composite and its enhancement of photocatalytic ability under visible-light, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 478 (2015) 71-80.
[15] X.-L. Cheng, J.-S. Jiang, D.-M. Jiang, Z.-J. Zhao, Synthesis of Rhombic Dodecahedral Fe_3O_4 Nanocrystals with Exposed High-Energy {110} Facets and Their Peroxidase-like Activity and Lithium Storage Properties, The Journal of Physical Chemistry C, 118 (2014) 12588-12598.
[16] X. Feng, G.Y. Mao, F.X. Bu, X.L. Cheng, D.M. Jiang, J.S. Jiang, Controlled synthesis of monodisperse CoFe2O4 nanoparticles by the phase transfer method and their catalytic activity on methylene blue discoloration with H_2O_2, Journal of Magnetism and Magnetic Materials, 343 (2013) 126-132.
[17] P. Alimard, Fabrication and kinetic study of Nd-Ce doped Fe_3O_4-chitosan nanocomposite as catalyst in Fenton dye degradation, Polyhedron, 171 (2019) 98-107.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Quality analysis of *Areca catechu* L varieties from Mekong delta, in VietNam

Lang Nguyen Thi*, Hieu Bui Chi, Khang Minh Le, Phuoc Trong Nguyen

High Agricultural Technology Research Institute for Mekong delta
Web: hatri.org
*Corresponding author

Received: 11 Mar 2023; Received in revised form: 16 Apr 2023; Accepted: 22 Apr 2023; Available online: 30 Apr 2023

Abstract— *The areca nut palm (Areca catechu L., Arecaceae family) is an economically important palm species in the World providing livelihood options to millions of farmers. The objectives of this study were to extract from areca nut to determine the The phenolic content (TPC) , The flavonoid content (TFC) and Anthocyanin content (TAC) content of 8 samples areca nut in the Mekong Delta .TPC of different sample differed significantly ($p < 0.05$). The TPC measured in areca nut was significantly higher (135.78-162.27 mg). There were significant differences in the flavonoid content in areca nut ($p < 0.05$). The Anthocyanin contents in areca nut were in the range of (23.55-35.55mg). The contents of TFC of different arecanut palm sites were significantly different ($p < 0.05$) The TFC measured was significantly higher (365.71–495.12mg) . The trend of flavonoid content of different sites was similar to that of total phenolic content .Alkaloid levels in 8 Areca Nut at difference sites analysis .The content associated Alkaloid in eight varieties with different genotypes such as Guvacine ,arecoline , Arecaidine and arecoline in hoblies in different districts of Mekong were compared. The DPPH radical-scavenging rate significantly varied in different sites (34.6 to 66.9% $p < 0.05$). According to the differences of functional substances among varieties, it can provide guidance for consumers and theoretical basis for the production of healthy food.*

Keywords— ***extraction, phenolic content (TPC), flavonoid content (TFC), Anthocyanin content, Alkaloid***

I. INTRODUCTION

Although, areca nut palm is a tree that farmers in the Mekong Delta grow in a comnination with other fruit trees, it is just an interesting complementary occupation for farmers in that Mekong Delta region. The amount of areca palm produced is not enough to meet the demand of both domestic and foreign markets because areca nuts are an important raw material of many industries continuously today. Areca nut has been used in various kinds of traditional medications for the treatment of diseases such as, schizophrenia and glaucoma and it is also known to be a stimulant and aids in digestion (Rama et al., 2016). Extensive investigations demonstrated that AS possessed many pharmacological activities, such as antioxidant activity, anti-bacterial activity, anti-hypoglycemic activity, anti-inflammatory activity, anti-parasitic activity, and activity for promoting digestive functions, etc. (Shen et al., 2017; Peng et al., 2015). Particularly, these health benefits are related to the phyto-chemical constituents of the AS extracts, including phenolics, flavonoids and alkaloids, etc. (Sazwi et al., 2013).Polyphenols are very important plant constituents and they exert antioxidant activity by inactivating lipid free radicals or preventing decomposition of hydroperoxides into free radicals(Maisuthisakul et al.,2012). However, polyphenols also possess pro-oxidant efect under certain conditions, such as high concentrations, high pH and the presence of redox-active transition metals(Antonio et al.,2015). The pro-oxidant activity of catechins at non-cytotoxic levels have been used as chemosensitizer for the treatment of cancer(Antonio et al.,2015). However, at high concentrations, certain polyphenols, such as catechins could exhibit cytotoxicity to normal cells (Elbling, et al .,2015). Thus, moderate amounts

of polyphenols could protect against diseases associated with oxidative stress such as cancer, coronary heart disease, infammation via mechanisms like antioxidant activity and neutralisation/modulation of human/bacterial/viral proteins/enzymes(Petti et al.,2009). In the recent years, the health benefits of the pigmented rice varieties have reported due to the presence of bioactive compounds. The phytochemical constituents (total phenolic, flavonoid and anthocyanin content) and individual phenolics and flavonoids of the extracts of sixteen genotypes of pigmented rice bran were evaluated using spectrophotometric and ultra-high performance liquid chromatography method. Antioxidative properties of the free and bound fractions were evaluated using nitric oxide and 1,1-diphenyl-2-picrylhydrazyl scavenging assays. Extracts were evaluated for antiproliferative activity against breast cancer cell lines (MCF-7 and MDA-MB-231) using the MTT assay(Ali et al .,2018). Phenolics, one of the most abundant groups of phytochemicals in whole grains, are considered natural antioxidants, which act as radical scavengers to decrease the incidence of oxidative stress-induced damage to large biological molecules, such as lipids, proteins, and DNA (Slavin .2004).

Therefore, the local agricultural sector needs to support farmers to improve varieties in agricultural production. Changing economic and social conditions, including the limited capabilities of farmers, have caused traditional agricultural production to change to more commercial production.

The predicting trends of agricultural product will allow to make right decision in economy nowadays. The right decision making about targeting and direction policies should be on the accurate information and current database and knowledge from inside and outside the country. This study would address suggestion for utilization of quantify flavonoids and polyphenols between 8 different sample *Areca catechu* L varieties from Mekong delta . Polyphenols and flavonoids and the mechanism of *Areca catechu* L growth and development from the limited description of previous works. Our studies have enriched the active compounds of areca nut and laid a solid foundation to improve the active compounds for the type of of Areca catechu L (areca nut)served as functional oral drugs for Vietnam.

II. METHODS AND MATERIALS

Sample Collection

Areca nut samples were collected from different districts of Mekong delta (Giong Trom, Ba Tri, Mo Cay(Ben Tre Province); Cai lay(Tien Giang) ; Tra Cu(Tra Vinh) ; Cai Rang, O Mon(CanTho city) and Binh Minh(Vinh Long)

Fresh seeds were taken from areca nuts and dried at 60 °C for 72 h to obtain a stable weight. They were chopped and ground by roller mill and then passed through a 14-mesh sieve before extracted.

Extraction of Polyphenol from Areca Seed

Maximum polyphenols (407.47 mg GAE g-1), total antioxidant activity with minimum arecoline (1.73 mg g-1 of sample) was achieved by using 80% acetone at pH 4 for 90 min with 10% w/v substrate under shaking conditions (chavan and singhal, 2013). To determine the antioxidant compounds, the optimum extraction conditions were used. 5 g of the finely powdered and dried areca seed sample was extracted using 55 ml of 70% ethanol at 70°C for 120 min by reflux. The extracts were filtered through Whatman No. 4 paper under reduced pressure, and then lyophilized by LGZ-10D Freezer Dryer. All the samples were redissolved

in 70% ethanol at a concentration of 5.0 mg/ml and analyzed for their content of polyphenols.

Determination of Polyphenol Content

Determination of total phenolic content (TPC) :TPC was determined by modified FC method.21 The extracts (0.5 ml; 1mg/ml stock solution) were mixed with 0.5 ml of distilled water and 1ml of FC reagent (pre-diluted, 10 times, with distilled water) and incubated for 5 min at room temperature (27± 2°C). After incubation, 2 ml of 700 mM sodium carbonate was added in the reaction mixtures, mixed and kept in dark for 45 min at room temperature. The absorbances of the samples were measured at 765 nm using a UV–Vis spectrophotometer (CECIL, CE 7200; Cambridge, UK). A calibration curve was prepared using standard solutions of gallic acid ranging from10 to 80 µg/ml (r2 =0.983). The amount of phenolics in different extracts was calculated from the calibration curve and was expressed as mg gallic acid equivalent (GAE) per gm of FL.

Estimation of total anthocyanin content (TAC)

Different areca nut samples (50 mg) were extracted with methanol/HCl (99:1 v/v) solute on at 4 °C for overnight. The observation of each sample were measured at 530 and 657 nm using a spectrophotometer. (UV-2120 Optizen, Mecasys, Korea), and relative anthocyanin levels were determined using the following formula:

$$\text{TAC= optical density (OD)530nm } -(0.25\times \text{ OD 657m})\times \text{ extraction volume (mL)}\times 1/\text{weight of sample (g)} \quad (1)$$

Cyanidin 3-glucoside was used as a standard and results were expressed as milligrams of cyanidin 3-glucoside equivalents (Cy3-GE)/100 gDM.

Determination of Flavonoid Content

Currently, the determination of TFC was depended on the aluminium chloride colorimetric method described by(Qiu, et al 2010). Briefly, a 50 µL supernatant was mixed with 100 µL distilled water. Then, 5% $NaNO_2$ was added into the mixture and incubated for 5 min. Subsequently, 10% $AlCl_3$ $6H_2O$ solution was drawn and added to the mixture for incubation for 3 min. Finally, 60 µL 4%NaOH was added to the termination reaction. The samples were read at 510 nm. Absolute methanol was used as the control, while a standard rutin curve was used to calculate the content of TFC. Results were recorded as mg of RE/100 g DW.

***Determination of DPPH* (1,1-Diphenyl-2-picrylhydrazyl) assay** Radical Scavenging Activity

The method by (Ghasemzadeh và ctv.,2015), was used with slight modifications to assess DPPH. The mixtures were shaken vigorously, and the sample was taken then incubated for 30 min in the dark. Mixture was measured at 517 nm.

$$\text{DPPH radical scavenging effect (\%)}=1-\text{Asample}-\text{Abackground}\text{Acontrol}\times 100\%\text{DPPH radical scavenging effect (\%)}=1-\text{Asample}-\text{Abackground}\text{Acontrol}\times 100\% \quad (2)$$

where A_{sample}, $A_{control}$, and $A_{background}$ refer to sample (sample and DPPH), control (without sample), and background (without sample), respectively.

Statistical Analyses

All measurements in this study were presented as means ± standard deviations. Each antioxidant activity assay was carried out three times from the same extracts in order to determine their reproducibility. Statistical differences and principal component analysis were analyzed with SPSS 25 (SPSS Inc., Chicago, IL, USA) (Li et al .2021). Canonical correspondence analysis and networks were conducted with Origin software.

III. RESULT AND DISCUSSION

3.1. The phenolic content (TPC) , The flavonoid content (TFC) and **Anthocyanin** (TAC) content of 8 samples areca nut in the Mekong Delta :TPC of different sample differed significantly ($p < 0.05$). The TPC measured in areca nut was significantly higher (135.78-162.27mg). The difference in the total phenolic content between varieties can be attributed to differences in genotype.

This may indicate that is shown in Table 1.

Polyphenolic content in areca nut components. Our study shows that phenolic acids were mostly detected in seed samples. The highest TPC content was observed in at Giong Trom and Tra Cu (162.27-161.45mg) respectively.

TAC content varied in different districts. High concentration of TAC content was observed in Tra Cu (35.25mg followed by Giong Trom (33.15mg) and less concentration of TAC was observed in Omon (23.55mg).

The contents of TFC hoblies in different districts of Giong Trom were compared (Table 1). There was a significant difference in TFC content between among hoblies of Mekong delta district. Giong Trom(Ben Tre) and Tra Cu(Tra Vinh) had higher concentration of TFC (495.12 and485.54 mg) compare to the other hoblies. Low

concentration of TFC was determined in the Binh Minh (Vinh Long) (411.85mg) and Omon (365.71mg) district.

Table 1: TPC, TAC, TFC content (mg/100) in Different at samples

Sites	TPC	TAC	TFC
Giong Trom(Ben Tre)	162.27a	33.15a	495.12a
MO Cay(Ben Tre)	142.5c	25.47b	444.74b
Ba Tri(Ben Tre)	154.5b	30.28a	412.26c
Cai Rang(Can Tho)	135.78d	30.27a	456.33b
O mon (Can Tho)	141.12c	23.55b	365.71d
Cai Lay(Tien Giang)	157.54b	32.22a	412.26c
Tra Cu(Tra Vinh)	161.45a	35.25a	485.54a
Binh Minh (Vinh Long)	158.44b	31.25a	411.85c

3.2. Alkaloid Levels **in 8** Areca Nut **varieties** :The content of free and associated Alkaloid in eight varieties with different genotypes of is presented in Table 2. The total Alkaloid .

Guvacine content varied in different Mekong districts. High concentration of **Guvacine** content was observed in Mo cay (2.60 ppm) followed by Giong Trom and (Tra Cu) Tra Vinh (2.48 ppm) and less concentration of **Guvacine** was observed in Ba Tri (1.79.ppm).

The contents of arecoline in hoblies in different districts of Giong Trom were compared (Table 2). There was a significant difference in arecoline content between among Mekong district. Giong trom (Ben Tre)had higher concentration of arecoline (2.2 ppm) compare to the other district . Low concentration of arecoline was determined in the BaTri (0.91ppm) and (1.2ppm) of O mon district.

The contents of **Arecaidine** in hoblies in different districts of Giong Trom were compared (Table 2). There was a significant difference in **Arecaidine** content between among Mekong district. Giong trom (Ben Tre)had higher concentration of arecoline (0.5 ppm) compare to the other district . Low concentration of arecoline was determined in the BaTri (0.18 ppm) and (0.18ppm) of Binh Minh districtof Vinh Long Province

The contents of arecoline in hoblies in different districts of Giong Trom were compared (Table 2). There was a significant difference in arecoline content between among Mekong district. Giong trom (Ben Tre)had higher concentration of arecoline (2.2 ppm) compare to the other district . Low concentration of arecoline was determined in the BaTri (0.91ppm) and (1.2ppm) of O mon district.

Table 2. Alkaloid Levels Measured in Areca Nut-Containing Products

lines	Guvacine (ppm)	Arecaidine (ppm)	Guvacoline (ppm)	Arecoline (ppm)	total alkaloids
Giong Trom(Ben Tre)	2.48b	0.50a	0.99a	2.22a	6.19a
MO Cay(Ben Tre)	2.61a	0.24c	0.87b	2.02a	5.74b
Ba Tri(Ben Tre)	1.79d	0.18d	0.32c	0.91c	3.19d
Cai Rang(Can Tho)	2.43b	0.28c	0.34c	1.36b	4.4c
O mon (Can Tho)	2.55b	0.41b	0.24d	1.2b	4.4c
Cai Lay(Tien Giang)	2.12c	0.15d	0.32c	1.25b	3.84d
Tra Cu(Tra Vinh)	2.48b	0.15d	0.98a	2.15a	5.84b
Binh Minh (Vinh Long)	1.89d	0.18d	0.32c	1.91b	4.3c

3.3./DPPH activity Free radicals are an intermediate metabolite of various biochemical reactions in human life activities. It has high chemical activity and is an effective defense system of the human body. However, the

excessive accumulation of free radicals that cannot be scavenged in time will attack life macromolecules and various organelles, and cause interhuman damage at the molecular, cellular and tissue level, which can further accelerate the human aging process and cause various chronic diseases (Akbari et al, 2022).Various mechanisms, such as free radical scavenging, capacity reduction, metal ions, and lipid peroxidation inhibition, have been studied to explain how areca nut extract can be used as an antioxidant (Ghasemzadeh et al.,2015). DPPH radical scavenging tests are based on the transfer of electrons from the molecule of the donor radical to the corresponding radical. The DPPH method is the simplest method for measuring the ability of antioxidants to block free radicals. DPPH thoroughly scavenged the effects of all extracts in areca nut increased with increasing concentration (Figure 2). The rate of DPPH significantly , areca nut (34.6 to 66.9%, $p < 0.05$). Areca nut of Cai Rang (Can tho) has the lowest antioxidant capacity for removing DPPH radicals and is significantly different from other sites ($p < 0.05$). The 8- sites extract demonstrated the highest DPPH activity, followed by areca nut extraction. DPPH activity of different sites of areca nut ranges from 34.6 to 66.9%, (figure 2)

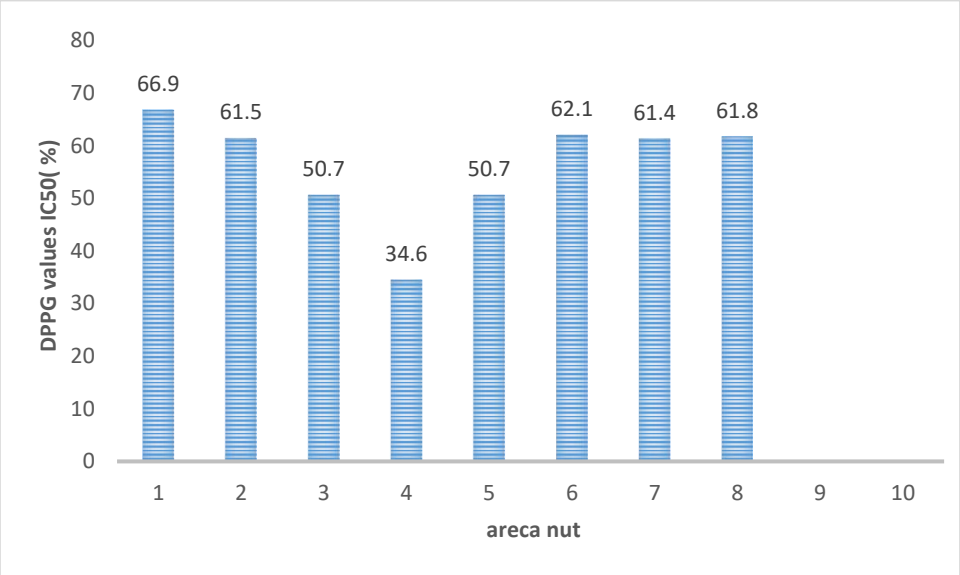


Fig.2: Antioxidant activity represented by $DPPH_{IC50}$ for different sites of areca nut. $DPPH_{IC50}$ value is an effective sample concentration at which DPPH radicals were scavenged by 50%.

IV. DISCUSSION

In our present investigation, we firstly studied TPC, TAC, TFC content (ppm) in Different at samples the from areca nut, and found that the three alkaloids including arecoline, guvacoline and homoarecoline, were predicted to possess good for properties, indicating that these alkaloids may possess good oral absorption and bioavailability. Nowadays, it is well known that an ideal candidate drug should possess some good characteristics of absorptive property and bioavailability besides pharmacological activity (Duchowicz et al .,2007).Guvacine is the most abundant of the four alkaloids measured, regardless of product type, contradicts the prevailing assertion in the literature that arecoline is the primary alkaloid in areca nuts te same with (Shih et al 2010). The results of the analyses revealed substantial variations in the levels of alkaloids across the tested products, with guvacine being the most abundant (1.39-8.16 mg/g), followed by arecoline (0.64-2.22 mg/g), arecaidine (0.14-1.70 mg/g) and guvacoline (0.17-0.99 mg/g). Substantial differences in the relative contribution of individual alkaloids to the total alkaloid content were also observed among the different products. (Vipin et al .,2017).In addition, Franke *et al*.2015 analyzed the aqueous extract of young and mature areca nuts and found significant differences in the total alkaloids and relative levels of individual alkaloids between them. Lower level of total alkaloids was observed in the young green nut compared to the mature nut, with arecoline being the major alkaloid. In the mature nut, however, guvacine was the major alkaloid with almost 3-fold higher concentration than arecoline, which is consistent with our data. For these observations suggest that the alkaloids contribution of differences sites .

V. CONCLUSIONS

Looking at a series of analytical results, the determination of polyphenols in areca nut extract aims to determine the quantitative profile of the quality of areca nut. Significant strides have been made in elucidating the

chemical structure of these bioactive compounds but while mass spectrometry based techniques certainly represent a powerful tool for defining areca nut phenolic profiles, We strongly believe that the research efforts undertaken to date constitute an excellent starting point towards the development of analytical tools aimed at investigating the phenolic, The flavonoid and Anthocyanin fraction of areca nut for demand in medicinal chemistry.

Studies related to antioxidant components may provide pharmacologic importance signifying ethnomedicinal uses of the plant species. The next need research for the geographic areas of raw plant material should also be analyzed and compared in the future research. Since the environmental factors e.g., nutrients and mineral in soil are also effect on the quality and quantity of phytochemical compounds in some species of medicinal plant and areca nut.

REFERENCES

[1] Antonio, J., León-González, C. A., Valérie, B. & Schini-Kerth, A. Pro-oxidant activity of polyphenols and its implication on cancer chemoprevention and chemotherapy. Biochem Pharmacol. 98, 371–380 (2015).

[2] Akbari, B., Baghaei-Yazdi, N., Bahmaie, M., Abhari, F. M. (2022). The role of plant-derived natural antioxidants in reduction of oxidative stress. *Biofactors* 48, 611–633.

[3] Ali Ghasemzadeh, Mohamad Taghi Karbalaii, Hawa Z. E. Jaafar & Asmah Rahmat 2018. Phytochemical constituents, antioxidant activity, and antiproliferative properties of black, red, and brown rice bran.*Chemistry Central Journal* volume 12, Article number: 17 (2018)

[4] Duchowicz PR, Talevi A, Bellera C, Bruno-Blanch LE, Castro EA. Appliation of descriptors based on Lipinski's rule in the QSPR study of aqueous solubilities. Bioorg Med Chem 2007; 15: 3711-3719.

[5] Deb, N., Majumdar, P., Ghosh, A.K. 2013. Pharmacognostic and phytochemical evaluation of the rhizomes of Curcuma longa L. J. Pharma. Sci. Tech. 2: 81–86.

[6] Elbling, L. et al. Green tea extract and (-)-epigallocatechin-3-gallate, the major tea catechin exert oxidant but lack antioxidant activities. FASEB J. 19, 807–809 (2015).

[7] Franke AA, Mendez AJ, Lai JF, Arat-Cabading C, Li X, Custer LJ. Composition of betel specific chemicals in saliva during betel chewing for the identification of biomarkers. *Food Chem Toxicol.* 2015;80:241–246. [PMC free article] [PubMed] [Google Scholar]

[8] Ghasemzadeh A, Jaafar HZ, Rahmat A (2015) Phytochemical constituents and biological activities of diferent extracts of Strobilanthes crispus (L.) Bremek leaves grown in diferent locations of Malaysia. BMC complement Altern Med 15(1):422.

[9] ICAR central . Arecanut and human Heath.2021. Plantion crops research Insitute Kasaragod 671124 Kerala,

[10] Li, W.; Wen, L.; Chen, Z.; Zhang, Z.; Pang, X.; Deng, Z.; Guo, Y. Study on metabolic variation in whole grains of four proso millet varieties reveals metabolites important for antioxidant properties and quality traits. *Food Chem.* 2021, *357*, 129791. [Google Scholar] [CrossRef

[11] Maisuthisakul, P., Suttajit, M. & Pongsawatmanit, R. Assessment of phenolic content and free radical-scavenging capacity of some thai indigenous plants. Food Chem. 2, 1409–1428 (2007)

[12] Petti, S. & Scully, C. Polyphenols, oral health and disease: A review. J. Dent. 37(6), 413–423 (2009).

[13] Peng Wei , Yu-Jie Liu , Na Wu , Tao Sun , Xiao-Yan He , Yong-Xiang Gao , Chun-Jie Wu.2015.Areca catechu L. (Arecaceae): a review of its traditional uses, botany, phytochemistry, pharmacology and toxicology. PMID: 25681543 DOI: 10.1016/j.jep.2015.02.010.

[14] Price M L, A E Hagerman, L G Butler .1980. Tannin content of cowpeas, chickpeas, pigeon peas, and mung beans. 1980 Mar-Apr;28(2):459-61. doi: 10.1021/jf60228a047.

[15] Rama, B.P., Savitri, V.H., Laxmi, P.G., Jenitta, E.P. 2016. A Study on the phytochemical analysis, silver nanoparticle synthesis and antibacterial activity from seed extract of Areca catechu L. Int. J. Biochem. Res. Rev. 9: 1–9.

[16] Sazwi Nordin Nur, Thurairajah Nalina, Zubaidah Haji Abdul Rahim [1].2013. Antioxidant and cytoprotective activities of Piper betle, Areca catechu, Uncaria gambir and betel quid with and without calcium hydroxide. BMC Complement Altern Med . doi: 10.1186/1472-6882-13-351.

[17] Slavin J (2004) Whole grains and human health. Nutr Res Rev 17(01):99–110

[18] ShenXiaojun, Weibo Chen, Yajun Zheng, Xintao Lei, Minm in Tang, Hui Wang, Fei Song .2017.Chemical composition, antibacterial and antioxidant activities of hydrosols from different parts of *Areca catechu* L. and *Cocos nucifera* L. Industrial Crops and Products

[19] Volume 96, February 2017, Pages 110-119.

[20] Shih YT, Chen PS, Wu CH, Tseng YT, Wu YC, Lo YC. Arecoline, a major alkaloid of the areca nut, causes neurotoxicity through enhancement of oxidative stress and suppression of the antioxidant protective system. *Free Radic Biol Med.* 2010;49:1471–1479. [PubMed] [Google Scholar

[21] Qiu, Y.; Liu, Q.; Beta, T. Antioxidant properties of commercial wild rice and analysis of soluble and insoluble phenolic acids. *Food Chem.* 2010, *121*, 140–147. [Google Scholar] [CrossRef]

[22] Vipin Jain, Apurva Garg, Mark Parascandola, Pankaj Chaturvedi, Samir S. Khariwala, and Irina Stepanov.2017.Analysis of Alkaloids in Areca Nut-Containing Products by Liquid Chromatography-Tandem Mass-Spectrometry.J Agric Food Chem. 2017 Mar 8; 65(9): 1977–1983.

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Peer Reviewed

Experimental study of the characterization of household waste in Bamako, Mali

Étude expérimentale de la caractérisation des ordures ménagères de Bamako au Mali

Mohamadou Adamou[1*], Mohamed S Maiga[1] , Oumar Cissé[2] , Joseph Amadomon Sagara[3] et Yaya Ouattara[1]

[1]Institut des Sciences Appliquées/Université des Sciences, des Techniques et des Technologies de Bamako – Mali
[2]Institut Africain de Gestion Urbaine de Dakar -Sénégal
[3]Consultant Indépendant
*Auteur correspondant : Mohamadou ADAMOU ; adamou14@outlook.com

Received: 05 Mar 2023; Received in revised form: 11 Apr 2023; Accepted: 20 Apr 2023; Available online: 30 Apr 2023

Abstract— *In Bamako, the flow of household waste and its typology are little known. In order to set up a sustainable management system for the city's garbage, it is nevertheless important to know the quantities, natures and dimensions of the objects that make up the garbage. This study, which began in 2017, consisted of characterizing the garbage collected at the household level in Bamako using the MODECOM method modified to adapt it to the Malian context. The objective of this study was to propose a method intended to obtain solid results on the characteristics of household waste produced in Bamako in order to build adapted collection and recovery strategies. The results, obtained from a sample of 270 households in the 6 communes of Bamako and 3 neighborhoods of different socio-economic levels per commune, showed that the average ratio of household waste produced in Bamako is about 0.28 Kg per inhabitant per day. The category of fines is the most important, with an average daily production of 2.45 kg for a household with an average of 20.5 inhabitants. Putrescibles come in second place. Their production represents 41% of the average amount of garbage generated in a high standard household. It represents the main biodegradable category of garbage. Fines, which are mostly sand, charcoal and ash, accounted for 37 percent of the waste generated by households of the same type. The particle size sorting, which can help to choose suitable industrial sorting tools, shows that the fraction of medium-sized garbage is the most abundant. The data from the characterization of garbage would allow the development of all forms of garbage management strategies, especially for its collection and recovery.*

Keywords— ***Bamako, characterization, experimental study, household waste.***

Résumé— *À Bamako, le flux des ordures ménagères et leur typologie sont peu connus. Pour mettre en place un système de gestion durable des ordures de la ville, il est pourtant important de connaitre les quantités, les natures et la dimension des objets qui les composent. Cette étude, qui a débuté en 2017, a consisté à caractériser les ordures collectées au niveau des ménages à Bamako selon la méthode MODECOM modifiée pour l'adapter au contexte malien. L'objectif de cette étude était de proposer une méthode destinée à obtenir des résultats solides sur les caractéristiques des ordures ménagères produites à Bamako afin de construire des stratégies de collecte et de valorisation adaptées. Les résultats, obtenus à partir d'un échantillon de 270*

ménages des 6 communes de Bamako et de 3 quartiers de niveaux socio-économiques différents par commune, ont montré que le ratio moyen d'ordures ménagères produites à Bamako est d'environ 0,28 Kg par habitant et par jour. La catégorie des fines est la plus importante avec une production moyenne journalière de 2,45 Kg pour un ménage constitué en moyenne de 20,5 habitants. Les putrescibles viennent en deuxième position. Leur production représente 41% de la quantité moyenne des ordures générées au niveau d'un ménage de haut standing. Elle représente la principale catégorie biodégradable des ordures. Les fines composées a priori en majorité de sables, de charbon de bois et de cendre représentaient 37% de la production des ménages du même type. Le tri granulométrique, qui peut permettre de choisir des outils industriels de tri adaptés, montre que la fraction des ordures de taille moyenne est la plus abondante. Les données de la caractérisation des ordures permettraient l'élaboration de toutes les formes de stratégies de gestion des ordures, en particulier pour leur collecte et leur valorisation.

Mots clés— ***Bamako, caractérisation, étude expérimentale, ordures ménagères***

I. INTRODUCTION

Les déchets sont produits de façon quotidienne et illimitée par les populations à travers leurs activités familiales, économiques et industrielles. Les ordures ménagères solides sont des déchets issus des activités des ménages (ADEME, 2009). Les densités d'ordures générées dans les pays dépendent des habitudes de consommation des ménages. Il existe une grande disparité entre les quantités d'ordures ménagères produites par les habitants. La densité des déchets urbains est estimée au Maroc à 0,35 ; en Tunisie à 0,30 (Zurbrug et Ahmed, 1999 ; Wicker, 2000 ; Charnay, 2005). À Dakar à peu près 2000 tonnes d'ordures ménagères sont collectées par jour (Cissé, 2015). Les ordures ménagères sont des mélanges très complexes.

Incontestablement, les ordures ménagères de Bamako sont aussi des mélanges très hétérogènes. On trouve en leur sein toutes sortes de détritus et de résidus comme les restes de cuisine, plastiques, papiers, cartons, cendres, sables, poussières, charbon, feuilles, bois, os, etc. Selon l'Institut Nationale de la Statistique du Mali (2021), la quantité moyenne de ces ordures déposées dans les décharges à Bamako est estimée à 3209 m^3. Parmi les facteurs qui influencent la forte production d'ordures à Bamako, on peut citer le caractère démographique de la ville. La population de Bamako est estimée à 2 millions d'habitants[1]. La croissance annuelle de cette population serait d'environ 5% (Banque Mondiale-Mali, (2011).

Une stratégie durable de gestion doit prendre en compte obligatoirement les aspects sociodémographiques de la ville.

Selon le décret[2] fixant les modalités de gestion des déchets solides « la gestion des ordures ménagères solides reste un défi majeur pour les acteurs du secteur. « …Elle nécessite la conjugaison d'efforts multiples de la part des populations et a pour objet de prévenir et de réduire le volume des déchets solides et leur nocivité ; valoriser les déchets solides par le recyclage et remettre en état les sites contaminés ; lutter contre les effets nocifs des déchets solides »[2].

Des technologies ou pratiques innovantes sont nécessaires pour une gestion efficace des ordures ménagères à Bamako, ce qui n'est pas le cas actuellement.

Une connaissance de la composition et de la densité des ordures ménagères permettrait de mieux choisir les options de gestion des ordures. Cependant, on constate une insuffisance des données actualisées concernant la typologie, la composition et le flux des ordures ménagères de la ville de Bamako.

En effet, peu d'informations récentes existent sur la composition réelle des ordures ménagères produites dans la ville de Bamako. Et une estimation quantitative des ordures produites en tenant compte de tous les facteurs influençant cette production n'est pas fréquemment réalisée.

Suite à une analyse de la situation actuelle de la gestion des ordures ménagères dans la ville de Bamako, les enjeux détaillés justifiaient l'importance de cette étude. Elle se propose ainsi de caractériser les ordures produites par les ménages en déterminant leur flux et en quantifiant les différentes catégories et fractions qui les composent.

II. MATÉRIELS ET MÉTHODES

La caractérisation des ordures a été réalisée au niveau des ménages selon le standing de vie de ces derniers avec la méthode de MODECOM [3] adaptée aux réalités socioéconomiques et culturelles du Mali.

[1] RGPH, 2011

[2] Décret n° 01 – 394. 2001 PRM du 06 septembre 2001

[3] AFNOR, 2013. MODECOM : méthode de caractérisation des ordures ménagères, 2ème édition. Éditions ADEME

2.1. Matériels

Les matériels utilisés pour l'échantillonnage des ordures ménagères au niveau des communes du district de Bamako sont composés : d'un appareil photo, fiches d'identification des ménages, GPS type "Garmin" (GPSmap76CSx), liste des communes selon les standings de vie, rouleaux de sacs poubelles de 100 L et 500 L, pelles, balais, stylos, équipements de protection individuelle, une trousse de secours, les ordures, une table de tri avec 3 cribles de 100, 20 et 10 mm, une balance, des seaux en plastiques, des gants et un véhicule de transport (moto tricycle).

2.2. Méthodes

2.2.1. Échantillonnage des ordures ménagères

L'échantillonnage des ordures au niveau des ménages a été effectué selon la méthode probabiliste basée sur la sélection aléatoire d'unités de population. Il a débuté tout d'abord par le zonage puis par l'identification des ménages selon un standing de vie. Ces deux étapes ont été suivies par les activités de collecte des ordures ménagères au niveau des communes.

Zonage et identification des ménages : les informations préalablement collectées lors d'une enquête descriptive sur la pratique de la gestion des ordures réalisée en 2017 à Bamako ont permis d'effectuer un zonage. Le zonage a consisté à identifier les différents ménages au niveau des six (6) communes de la capitale dans lesquels les ordures ont été collectées en fonction du standing de vie de ceux-ci.

Trois quartiers ont été choisis dans chaque commune, des ménages ont été sélectionnés selon leur standing de vie. Le type d'habitation, une estimation du revenu mensuel des ménages, le niveau d'instruction des chefs de famille sont des critères qui ont servi de base pour déterminer le standing de vie.

Au niveau de chaque quartier des communes du district, cinq (5) ménages de bas standing, cinq (5) ménages de moyen standing et cinq (5) ménages de haut standing ont été identifiés et sélectionnés pour la collecte des ordures par la technique de porte à porte.

Tableau 1 : liste des communes et quartiers selon les standings de vie

Commune I	HS[4]= Djelibougou	**Commune IV**	HS= ACI 2000
	MS[5]= Boulkasonbougou		MS= Sébénikoro
	BS[6]= Bankoni		BS= Lafiabougou
Commune II	HS= Quinzambougou	**Commune V**	HS= Kalabancoura ACI
	MS= Missira		MS= Garantiguibougou
	BS= Bozola		BS= Sabalibougou
Commune III	HS= Badiala II	**Commune VI**	HS= Faladjé
	MS= N'tomikorobougou		MS= Magnambougou
	BS= Koulouba		BS= Niamakoro

Périodes de la collecte : la campagne de collecte et de caractérisation physique des ordures ménagères a débuté le 01/08/ 2018 juste après l'enquête auprès des ménages sur la gestion des ordures et a pris fin le 22/02/2019.

L'équipe a réalisé des échantillonnages au niveau des communes I, IV et V pendant une saison pluvieuse et dans les autres communes (II, III et VI) pendant une saison sèche. Le choix des communes par rapport aux saisons a été fait en fonction des conditions de planification de la campagne.

Dépôt des sacs-poubelle : pour le dépôt des sacs poubelle, l'équipe est accompagnée d'un facilitateur dans les ménages des quartiers pour demander leur adhésion au projet.

Avec l'accord de participation des ménages au projet un membre de l'équipe expliquait aux interlocuteurs le déroulement des activités. Ensuite, l'équipe déposait les sacs-plastiques au niveau des ménages. Après 2 jours de production à compter du jour qui suit le dépôt des sacs, elle effectuait le ramassage et le transport des échantillons d'ordures ménagères.

2.2.2. Tris par taille et par catégorie

La caractérisation physique a été faite selon la taille et la typologie des ordures. Le tri (sur ordures humides) et la

[4] Haut standing
[5] Moyen standing
[6] Bas standing

classification des ordures en catégories[7] ont été réalisés selon la norme NF X 30-408.

Pesée des ordures après réception des échantillons à l'atelier : le contenu de chaque sac d'ordures échantillonnées a été pesé avant les tris et les données enregistrées dans un cahier. La pesée avait pour but de déterminer le poids journalier des ordures produites dans les ménages.

***Tri par catégories* :** une sélection des catégories à trier (sous catégories incluses) a été faite sur la base de la typologie des ordures, potentiellement produite par les ménages et identifiée lors de l'enquête sur les pratiques de gestion des ordures dans les ménages à Bamako. De ce fait, toutes les catégories et sous-catégories définies dans la liste de MODECOM ne sont pas triées.

Les ordures ménagères ont été séparées lors des tris dans des seaux portant les initiales des catégories concernées. Chaque catégorie a été pesée et les données enregistrées. Les catégories triées étaient : les putrescibles, papiers, cartons, composites, textiles, plastiques, combustibles non classés (CNC), verres, métaux, incombustibles non classés (INC), DMS (déchets ménagers spéciaux) et les fines.

Tri granulométrique (par taille) : les tris granulométriques des ordures ménagères, ont été effectués sur une table de tri composé de plusieurs cribles. Avant les criblages, les hétéroclites (objets de grande taille et rares) ont été d'abord triées et pesées. Après les ordures ont été déversées dans le premier palier de la table de tri (crible de taille 100 mm). Ce palier était déposé sur un deuxième palier comportant un crible de 20 mm de diamètre, lui-même installé sur un autre palier perforé de maillons de 10 mm de diamètre. Un dernier palier de récupération est installé en dessous du crible de 10 mm pour la récupération des ordures fines.

Au cours du tri, cinq (5) fractions ont ainsi été triées. Il s'agissait : des hétéroclites, la fraction >100 mm, la fraction <100,20>, la fraction <20,10> et la fraction <10 mm. Chaque fraction à la fin a fait l'objet d'une pesée.

Fig.1 : criblage des ordures sur la table de tri

Détermination du Ratio : le ratio (r) est la quantité moyenne d'ordures ménagères en kilogramme produite par habitant et par jour au niveau des ménages des communes de la ville. Donc les calculs ont été effectués sur la quantité moyenne d'ordures au niveau de chaque commune, la population moyenne des habitants ayant produit les ordures au niveau de chaque commune et le nombre des jours (2 jours) correspondant à la période de production des ordures au niveau des ménages.

La formule suivante (1) a été utilisée pour déterminer le ratio :

$$r = Q * P^{-1} * n^{-1}$$

Où :

r : ratio en kg/hab/j

Q : quantité totale d'ordures ménagères en kg P : population de référence ayant produit la quantité Q d'ordures en hab

n : nombre de jours correspondant à la production de la quantité Q d'ordures ménagères

III. RÉSULTATS ET DISCUSSION

3.1. Résultats

3.1.1. Quantités moyennes des catégories d'ordures générées par les ménages par jour par habitants pour chaque commune

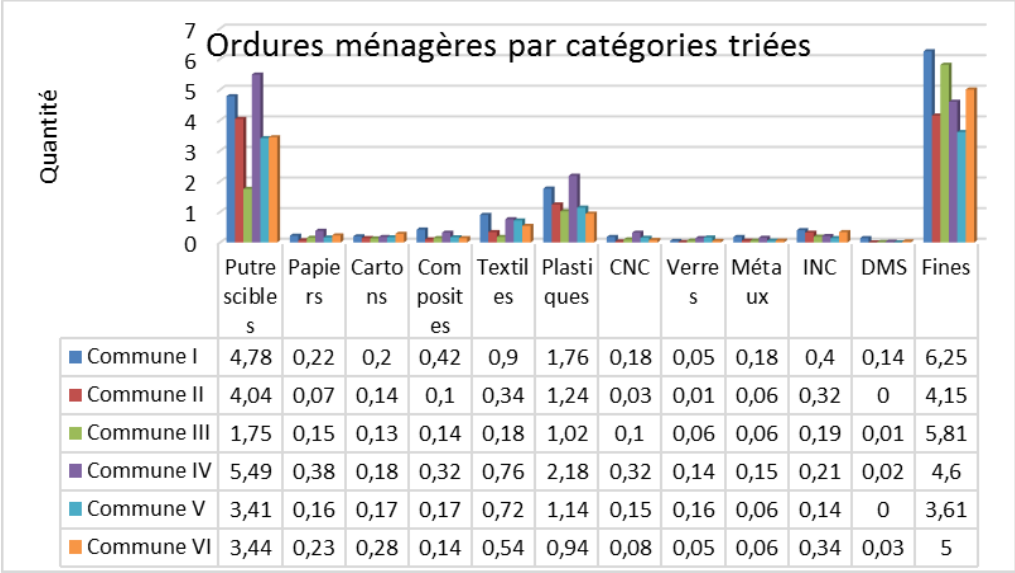
Les productions moyennes journalières des catégories d'ordures générées par les ménages en fonction du nombre d'habitants sont différentes d'une commune à une autre. Toutefois, on constate que les ordures ménagères de la catégorie des fines étaient les plus générées dans les communes avec une moyenne journalière de 2,45

[7] Catégories d'après MODECOM (Ademe, 1993)

Kg/ménage par (moyenne de 20,5 habitants). Les putrescibles étaient la deuxième catégorie

la plus importante avec une production quotidienne moyenne de 1,91 kg par le même nombre d'habitants.

Les fines étaient les plus générées dans toutes les communes du district à l'exception de la commune IV. En commune V, les fines représentaient 37,97% de la production légèrement supérieures à celle des putrescibles (33,05%). Les textiles constituaient la troisième production la plus importante dans cette commune. Les ordures ménagères de la catégorie des plastiques formaient la troisième catégorie la plus générée dans le district de Bamako. Quant aux déchets ménagers spéciaux, elles étaient rarement identifiables dans les poubelles.



	Putrescibles	Papiers	Cartons	Composites	Textiles	Plastiques	CNC	Verres	Métaux	INC	DMS	Fines
Commune I	4,78	0,22	0,2	0,42	0,9	1,76	0,18	0,05	0,18	0,4	0,14	6,25
Commune II	4,04	0,07	0,14	0,1	0,34	1,24	0,03	0,01	0,06	0,32	0	4,15
Commune III	1,75	0,15	0,13	0,14	0,18	1,02	0,1	0,06	0,06	0,19	0,01	5,81
Commune IV	5,49	0,38	0,18	0,32	0,76	2,18	0,32	0,14	0,15	0,21	0,02	4,6
Commune V	3,41	0,16	0,17	0,17	0,72	1,14	0,15	0,16	0,06	0,14	0	3,61
Commune VI	3,44	0,23	0,28	0,14	0,54	0,94	0,08	0,05	0,06	0,34	0,03	5

Fig.2 : récapitulatif des quantités moyennes des catégories d'ordures générées par les ménages en 2 jours en fonction du nombre d'habitants au niveau des communes

3.1.2. Ratios des ordures générées par habitant par jour en Kg par commune

Les ratios sont les quantités d'ordures générées par un habitant d'un ménage par jour en Kg dans les différentes communes du district de Bamako. Les ratios des ordures ménagères dans les communes du district de Bamako variaient entre 0,23 à 0,33 Kg/hbt/jour. Le ratio moyen d'ordures ménagères à Bamako était d'environ 0,28 Kg par habitant par jour. Le ratio d'ordures ménagères en commune IV était le plus élevé par rapport à ceux des autres communes de Bamako. En commune I le ratio des ordures générées était de 0,31 Kg/hbt/jour. Les fines représentaient la catégorie la plus générée soit 36% de la production totale de la commune.

En commune III, une personne par ménage produisait environ 0,23 Kg/hbt/jour, c'était la plus faible production.

Tableau 2 : Ratios des OM par commune

Ratios des OM par commune en Kg/hbt/jour			
Communes	Production moyenne d'ordures générées par un ménage dans une commune (en Kg) pendant les 2 jours	Habitants par ménage	Ratios Kg/hbt/jour
Commune I	15,51	24	0,31
Commune II	10,52	17	0,30
Commune III	9,63	20	0,23
Commune IV	14,78	22	0,33
Commune V	9,92	18	0,26
Commune VI	11,16	21	0,26

Moyennes	11,92	20	0,28

3.1.3. *Répartition des catégories d'ordures ménagères en fonction des standings de vie des ménages*

Répartition des catégories d'ordures ménagères en fonction des hauts standings de vie des communes après tri par catégorie (figure 3)

Au niveau des hauts standings de vie (figure 3a) les ordures ménagères des catégories des putrescibles et fines étaient les plus générées par les activités des ménages. La production des putrescibles représentait 41% de la quantité moyenne des ordures générées au niveau d'un ménage de haut standing. Les fines représentaient 37% de la production des ménages du même type.

La catégorie des plastiques représentait 9% de la production suivie des textiles (3%). Les composites, les INC et les cartons formaient chacun 2% de la production moyenne totale.

Les métaux, les papiers, les CNC et les verres étaient en général peu identifiables dans les contenus des poubelles des ménages à haut standing de vie. Les DMS étaient rarement produits par les habitants de ces ménages.

Répartition des catégories d'ordures ménagères en fonction des Bas Standings de vie des communes après le tri par catégorie (figure 3)

Dans les ménages de bas standing (figure 3b), les ordures ménagères de la catégorie des fines étaient les plus générées, avec une production moyenne de 44% devant les putrescibles dont la production moyenne représentait 24% de la production moyenne totale.

Les plastiques constituaient la troisième catégorie générée en grande quantité (14%). Les catégories des textiles, des INC, des papiers et des composites représentaient respectivement 6%, 4%, 2% et 2% de la production moyenne totale. Les verres, les métaux, les CNC et cartons représentaient les quatre derniers (4%) de la production.

Les fines représentaient la catégorie la plus retrouvée dans les poubelles au niveau des moyens standings (figure 3c) et des bas standings.

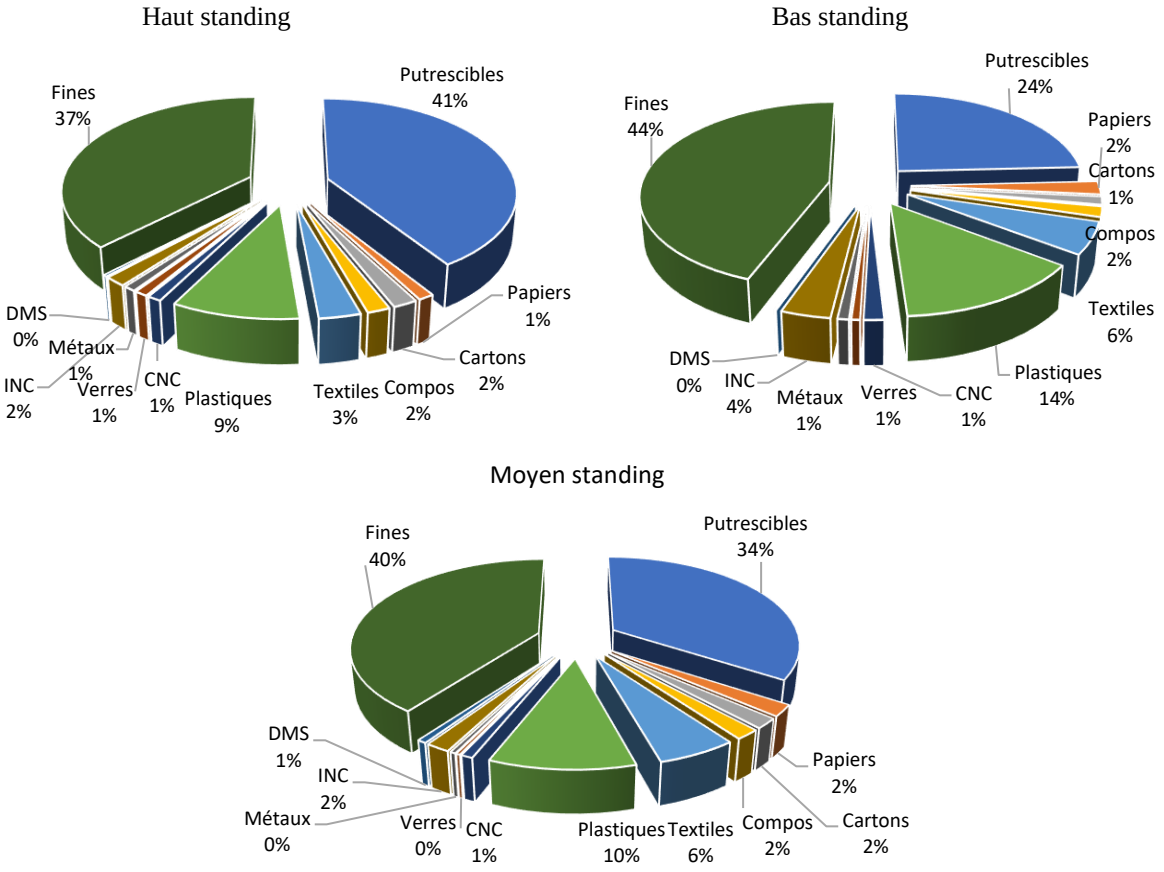


Fig.3 : pourcentage des ordures des ménages à haut standing, moyen standing et bas standing

3.1.4. Récapitulatif des résultats du tri par granulométrie

Les différentes fractions (fig. 4) étaient constituées d'un mélange de catégories d'ordures ménagères triées pour connaitre leur taille.

La fraction la moins abondante après la pesée pendant le tri au niveau de toutes les communes du district de Bamako était les hétéroclites.

La fraction (α) entre 20 mm et 100 mm était la plus abondante dans les communes du district de Bamako à l'exception de la commune VI où celle des fines a légèrement dépassé la fraction des objets de taille moyenne (20 mm < α < 100 mm).

La fraction des fines en commune VI était la plus abondante alors qu'en commune II, elle représentait à peu près 1,4% de la production moyenne.

En Commune III, la fraction moyenne était composée d'importantes quantités de cailloux, de restes d'aliments et d'objets de tous genres. En effet, les fractions moyennes (20 mm < α < 100 mm) représentaient 44,24% du total sachant bien que le nombre moyen de personnes dans un ménage en commune III était de 20.

En commune IV, la fraction des fines (*<10 mm)* était faiblement générée, elle représentait moins de 4% de la production moyenne. Elle était essentiellement composée de sable et de cendre de bois de chauffe. Les fractions très fines passaient facilement à travers les mailles de la table de tri (20 mm < α < 100 mm).

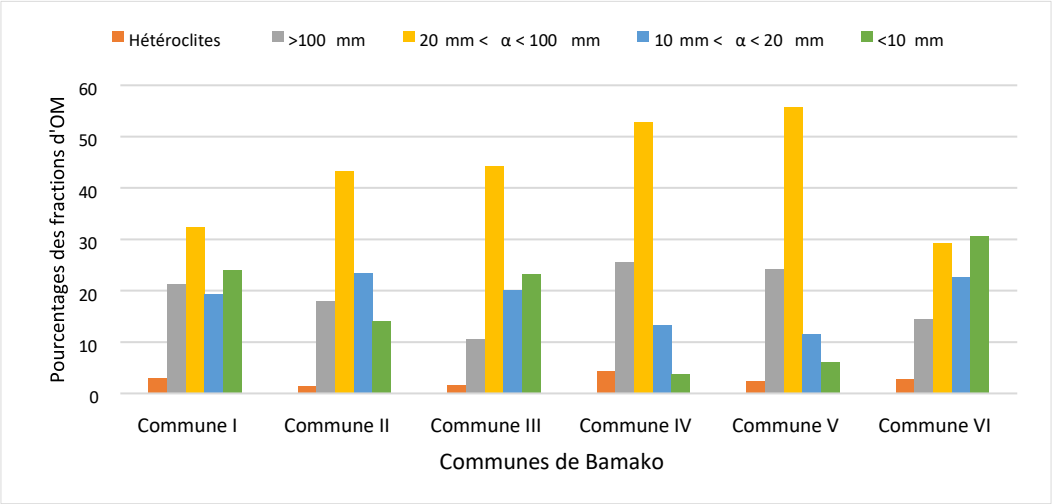


Fig.4 : pourcentage des fractions d'ordures ménagères par commune

3.1.5. Évolution de la production d'ordures ménagères à partir d'une extrapolation de la population

La production journalière d'ordures ménagères sur 3 ans de la capitale du Mali a été estimée à partir de l'extrapolation de la population en fonction des années de recensement 1998 et 2009[8] désagrégé par temps journalier. Puis on a estimé de la population par mois au cours de chaque année.

Les valeurs des populations de chaque mois de l'année concernée ont été multipliées par le ratio moyen d'OM en Kg/hbt/jour pour trouver les quantités journalières d'ordures ménagères générées dans la ville.

Le 01/01/2015, la production des ordures est estimée à 694 tonnes par une population de 2480487 habitants. À partir du 31/12/2017 la production journalière projetée est estimée à 812.

Tableau 3 : exemple de l'évolution de l'accroissement mensuel des ordures ménagères entre 01/01/2017 à 01/12/2017

Dates	Populations du district	Ratio moyen d'OM en Kg/hbt/jour	Quantités d'ordures ménagères du district produites (T)
01/01/2017	2755036	0,28	771
01/02/2017	2767645	0,28	774
01/03/2017	2779034	0,28	778

[8] RPGH 2009

01/04/2017	2791644	0,28	781
01/05/2017	2803847	0,28	785
01/06/2017	2816456	0,28	788
01/07/2017	2828659	0,28	792
01/08/2017	2841268	0,28	795
01/09/2017	2853878	0,28	799
01/10/2017	2866081	0,28	802
01/11/2017	2878690	0,28	806
01/12/2017	2890893	0,28	809
31/12/2017	2903096	0,28	812

3.2. Discussion

Les caractères biophysiques, socioéconomiques et climatiques du milieu d'étude sont différents des milieux pour lesquels le MODECOM a été proposé, ce qui a servi de motivation pour l'adapter au contexte local. L'enquête sur les pratiques de la gestion actuelle des ordures ménagères à Bamako a fourni assez d'informations pour le choix des méthodes et matériels utilisés.

Ce travail de caractérisation a concerné les ordures collectées directement au niveau de ménages par la technique de porte à porte. La méthode de collecte d'ordures de Ngnikam et *al*. (2017) qui ont stratifié la ville de Yaoundé en 5 classes socioéconomiques et celle de Cissé, (2015) qui a subdivisé la ville de Dakar en secteurs et circuits de collecte, sont différentes de celle utilisée à Bamako. À Bamako, la méthode de zonage a été faite en fonction de la configuration administrative de la ville. Au niveau de chaque commune, des ménages ont été choisis selon leur standing de vie. Nous n'avons pas eu le besoin d'effectuer un quartage comme le recommande la norme AFNOR X 30-408 car, les quantités collectées à Bamako étaient moins importantes. Cela a donné plus de précision concernant la quantification des différentes catégories d'ordures.

Le tri a été fait à l'atelier sur les ordures brutes récupérées instantanément au niveau des ménages. Elles n'ont, ni été séchées ni conservées après la collecte, cela nous a permis d'obtenir des informations sur les caractéristiques réelles des échantillons.

Cette étude est l'une des premières qui a permis de quantifier les ordures ménagères générées à Bamako par pesée. Ainsi, des quantités moyennes d'ordures par commune ont été appréciées.

Dans le district de Bamako, la production moyenne d'ordures ménagères est estimée à 0,28 Kg/hbt/jour, approximativement égale à la production moyenne d'ordures à Nouakchott (0,21 Kg/hbt/jour) et inférieur à la production moyenne à Ouagadougou (0,62 Kg/hbt/jour) (Charnay, 2005 ; Aloueimine, 2006).

On estime que les ménages produisent beaucoup d'ordures pendant les weekends plus précisément les dimanches. À Bamako, les dimanches sont des jours de cérémonie tels que les mariages, les baptêmes et autres évènements familiaux.

Le pourcentage massique de fines composées principalement de sables n'est pas négligeable à cause des modes de construction surtout et de l'état des rues sablonneuses.

En effet, on a constaté que la catégorie des ordures ménagères fines était la plus générée par les activités des habitants. Le sable qui est le composant principal des fines se mélange facilement aux autres déchets en augmentant ainsi le poids des déchets. Cette catégorie rend plus difficile l'élimination des ordures. Le remplissage rapide des décharges est fortement dû aux matières fines. Contrairement aux ordures putrescibles, le sable ne se décompose pas (fraction inerte).

Les putrescibles représentaient la deuxième catégorie la plus générée par les ménages à Bamako. En effet, plusieurs chercheurs soutiennent aussi que les déchets solides ménagers des PED sont constitués essentiellement de matières fermentescibles (67%) (Aajjane et Bendahhou. 2010).

Cette catégorie joue un rôle important dans la réduction des ordures stockées dans les poubelles ou mises en décharge. En effet, les putrescibles sont dégradables avec l'appui de certains microorganismes. En effet, certains paramètres physiques comme l'humidité et la température du milieu, facilitent l'hydrolyse des déchets par microorganismes.

À Bamako, on a retrouvé une grande proportion de cette catégorie d'ordures dans les poubelles des ménages de haut standing par rapport à celles des autres ménages. Toutefois, au Benin, Kple (2015) a trouvé que la matière fermentescible est la plus importante quels que soient le standing et la saison.

Les investigations au cours de cette étude ont permis de constater que dans les ménages à faibles revenus, les catégories d'ordures comme les putrescibles (reste d'aliments, reste de pain, légumes) étaient fréquemment récupérées et séchées. Les putrescibles sont soit consommés par les habitants ou sont utilisés comme aliments du bétail. Les restes de pain et de riz étaient les plus récupérés.

Le plastique était l'objet le plus visible dans les poubelles de toute la ville. Cependant, à cause de ses caractéristiques, il reste le matériau le moins lourd. Malgré sa faible densité par rapport aux autres catégories il est la troisième catégorie la plus générée en masse. Pendant le tri granulométrique, on a constaté la prédominance des plastiques dans la fraction d'ordures ménagères supérieures à 100 mm, ce qui confirme les résultats de plusieurs études dont celles de Dahmane, (2012) et Koledzi, (2011), qui ont également trouvé entre 20 à 32% de plastiques dans les fractions >100 mm.

La plupart des déchets plastiques générés par les activités des ménages sont des plastiques non dégradables.

Les habitants de la ville de Bamako utilisent les emballages en–plastiques non dégradables de façon excessive malgré la promulgation de la Loi N° 2014-024/ du 03 juillet 2014 portant interdiction de la production et de la commercialisation des sachets plastiques non biodégradables en République du Mali. Les autorités peinent à mettre en œuvre cette Loi qui, sur un point de vue environnemental pourrait constituer un outil juridique efficace dans la lutte contre les pollutions diverses et la dégradation des écosystèmes.

Les déchets ménagers spéciaux (DMS) sont une catégorie peu fréquente dans les poubelles d'où sa faible production (0,7 g/hbt/jour) de cette catégorie.

Dans les poubelles à Bamako, les emballages de produits cosmétiques et de produits d'entretien sont les plus visibles parmi les DMS. Cependant, on constate également la présence des piles.

Avec la croissance de la population chaque année, une quantité supplémentaire d'ordures composée de toutes les catégories est générée. Tant qu'un système durable de gestion des ordures ménagères n'est pas mis en place, les populations seront impactées directement ou indirectement par les conséquences de la mauvaise gestion des ordures dans la vielle de Bamako.

IV. CONCLUSION

Cette étude consacrée à la caractérisation des ordures générées par les ménages à Bamako a révélé les grands enjeux autour de la gestion des déchets à Bamako.

Elle a permis de découvrir que les ménages produisent une grande quantité d'ordures. Les différentes catégories et fractions d'ordures produites par les ménages sont estimées. Leur accroissement a été simulé.

Les ordures de la catégorie des fines représentent la catégorie la plus importante. Les sables constituent la principale composante de cette catégorie. Ils augmentent significativement la masse et le volume des ordures. Dans certains ménages pour des raisons culturelles, religieuses et à cause de la pauvreté les restes d'aliments qui sont les principaux constituants de la catégorie des putrescibles ne sont pas jetés à la poubelle par les habitants.

La caractérisation physique des ordures reste l'étape la plus importante à réaliser dans une démarche systémique de gestion des ordures ménagères. Elle fournit les données quantitatives et qualitatives nécessaires pour le choix de technologies de traitement.

V. REMERCIEMENTS

Je remercie le personnel du programme de formation des formateurs et le Professeur Mohamed S. MAIGA pour ses enseignements.

RÉFÉRENCES BIBLIOGRAPHIQUES

[1] Aajjane A. et Zourarah B. (2010). Gestion des déchets dans les pays en voie de développement : spécificités, enjeux et perspectives *Colloque Eau, Déchets et Développement Durable*, 28 – 31 mars 2010, Alexandrie, Égypte, p : 23-31

[2] ADEME. (2009). Campagne nationale de caractérisation des ordures ménagères [Internet]. Angers, France, 39 P. URL : « www.ademe.fr » [Consulté le 15/03/2016].

[3] Alouemine S. O. (2006). Méthodologie de caractérisation des déchets ménagers de Nouactchoctt (Mauritanie) : contribution à la gestion des déchets et outils d'aide à la décision. Thèse de doctorat de l'Université de Limoges-France, discipline Chimie et Microbiologie de l'eau. 195 P.

[4] Banque Mondiale - Mali. (2011). Analyse environnementale du milieu urbain, volume 2 : profil environnemental des villes de Bamako, Gao, Mopti et Sikasso. Rapport final numéro : 60788-ML région Afrique, département du développement durable, 69 p.

[5] Cissé O. (2012). « Déchets, activités, effectifs et revenus à Mbeubeuss », dans « Les décharges d'ordures en Afrique :

Mbeubeuss à IAGU », 133 – 134 pp. IBN : 978-2-8111-0633-1

[6] Charnay F. (2005). Compostage des déchets urbains dans les pays en développement : élaboration d'une démarche méthodologique pour une production pérenne de compost. Thèse de doctorat de l'Université de LimogesFrance, discipline Chimie et Microbiologie de l'eau. 227 P.

[7] Dahmane S. (2012). Évaluation de la gestion des déchets ménagers et assimilés de la ville d'Oran. Mémoire de Magister en Gestion et contrôle de l'environnement, spécialité chimie industrielle. Université des Sciences et de la Technologie d'Oran Mohamed BOUDIAF (USTO-MB), Faculté des Sciences Département de Chimie. Oran – Algérie. 76 p.

[8] Ngnikam E. ; Naquin P., Oumbe R., K. bruno Djietcheu. (2017). Évolution de caractéristiques des déchets solides ménagers dans la ville de Yaoundé au Cameroun 1995-2015). *Déchets Sciences et Techniques* **N°74** Septembre 2017, 16p.

[9] Institut Nationale de la Statistique. (2021). Collecte des déchets municipaux (DSM) dans les dépôts de transit. Rapport d'analyse. 32 p. URL : https://www.instat-mali.org/storage/

[10] Koledzi K. Edem. (2011). Valorisation des déchets solides urbains dans les quartiers de Lomé (Togo) : Approche méthodologique pour une production durable de compost. Thèse doctorale, discipline chimie et microbiologie de l'eau. École Doctorale Science et Techniques. 224 p.

[11] Melhyas Kple. (2015). Étude des voies de valorisation des déchets ménagers au Bénin : cas de la ville d'Abomey-Calvi, thèse de l'Université d'Abomey-Calvi et de l'Université de Laurraine. Formation Doctorale Sciences et Techniques pour Ingénieurs (FDSTI) et Université de Laurraine École Doctorale Sciences et Ingénierie Ressources, Procédés, Produits et Environnement 26p.

[12] Wicker A. (2000). "Gestion des déchets." dans " Statistiques pour la politique de l'environnement". 27-28 novembre. *Munich.*

[13] Zurbrugg C. & Ahmed R. (1999). "Enhancing Communauty Motivation and Participation in Solid Waste Management." *SANDEC News 4*. URL : https://www.eawag.ch/fileadmin/

International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-2; Mar-Apr, 2023

Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Impact of Eggshells on Growth and Production of Soybean (Glycine max(L) Merril) in Ultisol

Desi Pramida Sari, Warnita, Muhsanati*

Study Program of Agrotechnology, Faculty of Agriculture, Andalas University, Indonesia
*Corresponding author

Received: 14 Mar 2023; Received in revised form: 14 Apr 2023; Accepted: 22 Apr 2023; Available online: 30 Apr 2023

Abstract— *Soybean (Glycine max (L) Merril) is one of the agricultural commodities to help the food crop of the Indonesian people. Soybeans are one of the commodities that support the implementation of food crop diversification programs and support national food crop security. Increasing soybean productivity in ultisols can be done through liming using eggshell powder. This experiment has been implemented at Jalan Muhammad Hatta, RT 02, RW 08, Pauh, Padang, West Sumatera from October 2020 to March 2021. The purpose is to get the best eggshell powder dose to increase the growth and yield of the soybean on ultisol. The experiment method uses a complete random design (RAL) with 5 levels of eggshell powder treatment 0; 25; 50; 75; 100 g / plant. Data on the observation are analyzed statistically with the F test at a 5% level. If the F count of treatment is greater than the F table, proceed by the test DNMRT at α level of 5% level. The results showed the use of eggshell powder affected the growth and yield of soybean in ultisol to a dose is 25 g /plant.*

Keywords— ***soybean, eggshells powder, ultisol, growth and yield, productivity***

I. INTRODUCTION

Soybean (Glycine max (L.) Merril) is one of the agricultural commodities needed to meet the food needs of the Indonesian people. The main consumption is in the form of tempeh and tofu which are side dishes for Indonesian people. Other forms of soy products can be soy sauce, tauco, and soy milk. Demand for soybeans continues to increase which must be balanced with increased production.

The productivity of soybean in West Sumatra in 2020 is 15.48 ku/ha and in 2021 is 13.93 ku/ha, with soybean harvested areas of 30.10 ha and 4.50 ha respectively. Within these 2 years, the productivity of soybean plants decreased by 5.61% (BPS, 2023). Decreased productivity in soybean cultivation according to Abdurachman, et al. (2013) could be caused by the dry land in West Sumatra Province being dominated by the Inceptisol and Ultisol orders with the main limiting factors for nutrient retention namely acid soil pH, CEC, base saturation, and low soil organic matter.

Soybean plants will grow well in soil that is fertile, loose, and rich in organic matter, namely at a pH of 5.8 – 7.0 (Purwaningsih and Kusumastuti (2019). According to Falagh et al (2018), the optimal pH is 6.0-6.5. In the range The pH is the macro and micro nutrients available to soybean plants. In soils that have an acid reaction (pH less than 5.5), phosphate (P), calcium (Ca), magnesium (Mg), potassium (K), and sulfur (S) are not readily available to soybean plants.

Ultisols are soils that have problems with soil acidity, low organic matter, and low macronutrients and have very low P availability (Fitriatin et al. 2014). In ultisol with a pH of < 5.5, it is necessary to add lime. Economically, the use of chemical-based lime requires a sizable amount of money which is expensive.

One of the livestock wastes is eggshell which is very easy to find in everyday life (Sihotang et al, 2016) which can

pollute the environment and health (Ajala et al, 2018) and can be used as an alternative material to increase soil pH. Eggshell waste containing high calcium can be used to increase soil fertility and plant growth, including soybeans.

The high calcium content of eggshells, which is about 36% of the total weight of eggshells, can be used as a material to improve soil fertility. The composition of the eggshell consists of 97% calcium carbonate, 3% magnesium and 3% phosphorus, sodium, potassium, zinc, manganese, iron, and copper (Saragih, et al. 2016). The eggshell membrane consists of 69.2% protein, 2.7% fat, 1.5% water, and 27.2% ash (Bimasri and Murniati, 2017).

Giving eggshell flour can be used as a substitute for lime because it can increase the pH of alluvial soil. In addition, the element calcium is the nutrient that most determines the level of pod health in soybean plants (Nurjayanti, 2012). According to Bimasri and Murniati (2017), eggshell flour can be used as lime because it contains calcium carbonate compounds (CaCO3), which are useful for reducing soil acidity. Calcium in soybean plants is useful for filling cells, growing root hairs, resistance to disease and increasing the nutritional value of soybeans. Furthermore, Nurjanah et al., (2017) stated that calcium in fertilizers is a macro element besides nitrogen, phosphorus, and potassium, which functions to encourage earlier root formation and growth, improve plant toughness, and increase soil pH.

Based on research conducted by Saragih, et al. (2016), giving eggshell flour at a dose of 0; 25; 50; 75 g/polybag on soybean plants showed a significant effect on the number of productive branches, number of pods, effective root nodule weight, and seed weight per plant at a rate of 75 g/plant polybags. The increase in the weight of nodules was effective because the soil that had been added with eggshell powder increased the pH in the ultisol soil so that the soybean plants could grow better. The increase in seed weight per soybean plant was caused by the element Ca contained in the egg shells helping soybean plants in the growth phase of filling the pods. Lack of calcium nutrients in soybean plants causes many empty pods, while high seed weight production per plant occurs due to the fulfillment of the Ca element needed by plants, especially in the pod formation phase.

The purpose of this study was to obtain the best eggshell flour dosage for the growth and yield of soybean plants on ultisols.

II. RESEARCH METHODS

This research was conducted from October 2020 to March 2021 at Jalan Muhammad Hatta, RT 02, RW 08, Limau Manis Village, Pauh District, Padang City, West Sumatra. The altitude of the research site is ± 1,300 m above sea level.

This study was conducted using a completely randomized design (CRD) with 5 treatments repeated 4 times, so there were 20 experimental units. The treatment in the form of a dose of eggshell flour used is 0, 25, 50, 75 and 100 g/plant. Observational data were analyzed by means of variance. If the F count is greater than F table 5% then continue with Duncan's New Multiple Range Test (DNMRT) at the 5% level.

The research was started by clearing the land used from weeds and garbage, then making experimental plots measuring 200 cm x 200 cm, the distance between plots was 20 cm and the distance between blocks was 40 cm. The soil used is ultisol. The soil is put together with manure with a ratio of 1: 2 into a polybag measuring 35 x 40 cm with a weight of 10 kg of soil.

The eggshells were washed with water, then the shells were separated from the inner membrane and then dried in the sun to dry for 3 days. Furthermore, the shells were crushed with a blender to become eggshell powder (SCT) and sieved through an 80-mesh sieve.

The seeds of the soybean plants used are soaked first in water for selection. The planting medium is soil mixed with manure and stirred evenly. After that, the calcification of CaCO3 is carried out using eggshell flour in each polybag. The manure given was 100 g/plant and for SP36 fertilizer 100 kg/ha (0.5 g/plant), urea fertilizer 75 kg/ha (0.375 g/plant), and KCl 100 kg/ha (0.5 g /plant).. After all the planting media is mixed evenly, put the soil into each polybag as much as 10 kg Then the polybags were labeled and neatly arranged in the field according to the layout of the experimental unit. The prepared planting medium was then incubated for 14 days.

Soybean seed planting is done by making planting holes on the surface of the polybag using a small shovel with a depth of 2.5-5 cm. Furthermore, the seeds are inserted into the planting hole as many as 2 seeds. Soybean seeds begin to grow at the age of 5-6 DAP. Then after 7 days of planting, the soybean plants were thinned by cutting the soybean plants so that only one soybean plant was left

Plant maintenance in the form of watering, weeding, fertilizing, and controlling pests and diseases. Soybean plants are watered every day with fanfare. twice, namely in the morning and in the evening, if the rain is not watered. Weeding is done twice and is done mechanically when the soybean plants are 15-20 DAP, and the second wedding is when the soybean plants have finished flowering, which is 40-45 DAP.

The fertilizers used in the cultivation of soybean plants are manure, SP36 fertilizer, urea, and KCl. Manure is given once at the time of processing the planting media. As for the application of SP36, urea, and KCl fertilizers, it was carried out 2 times, namely when the soybean plants were 7 DAP and 20-30 DAP. Manure fertilization is done by stirring the manure together with the ultsiol soil that has been loosened, and for SP36, urea, and KCl fertilization it is done by placing the fertilizer around the planting hole with a distance of 7-10 cm.

Pest and disease control is carried out mechanically, namely by removing or cutting parts of soybean plants that are attacked by pests and diseases by using hands or tools such as knives, sickles, and machetes. or use insecticides, and fungicides if there is a severe attack. For pest and disease control using insecticides and fungicides, the active ingredient formulas used are Deltamethrin 25g/l with a concentration of 2 ml/liter of water and Mancozeb 80% with a concentration of 1-2 g/liter of water. Insecticide spraying was carried out at 30 HST and fungicide was carried out at 50 DAP

Harvesting was carried out after the soybeans showed the harvest criteria, namely the plants were ripe where 90% of the pods were ripe, brown in color, the leaves had fallen off, the pod skin was easy to peel and the stems were dry. How to harvest is by picking the pods from the plant. Harvesting was done at 11 WIT. Effective root nodule weighing was carried out at 6 WAP. The characteristic of an effective root nodule is that the root nodule is still fresh and filled with a reddish liquid.

Soybean plants are harvested in two ways. First, for observing root nodules, soybean plants are harvested by dismantling polybags, and then the roots are separated from the soil. Soybean plants whose samples were taken for observation of root nodules were 40 samples of soybean plants per polybag. Second, for plants outside the destructive sample, it is harvested by cutting the main stem of the soybean plant just above the soil surface. The stover and the pods that were still attached were removed to be dried for 3 days. Harvesting soybean plant pods was carried out by cutting the planting pods and separating them based on predetermined treatments and repetitions. Meanwhile, the harvesting of soybean plant seeds is done after the stover is dry enough or the pods are opened a lot or the water content is 14-16%, the dry seeds are separated from the pods and the seeds are put in separately.

The observed variables were plant height, number of productive branches, number of fruitful pods, number of empty pods, the total number of pods, weight of fruitful pods, and weight of seeds planted. weight of 100 seeds planted, effective root nodule weight, power of hydrogen (pH).

III. RESULT AND DISCUSSION

Planting Media Analysis

Analysis of the planting media was carried out at the beginning of the study with the aim of knowing the nutrient content of the media. In Table 1 it can be seen that the soil pH, Available-P, K-dd, Ca-dd, and CEC values are below normal, and soil Al-dd is classified as high. In Table 1, soil pH analysis shows that the planting medium has a pH of 5.61 with slightly acidic criteria. According to Falagh et al (2018), soybean plants grow well on slightly acidic to nearly neutral soils with an optimal pH of 6.0 - 6.5. Soil acidity can be caused by several factors, including soil parent material, organic matter, aluminum hydrolysis, oxidation reactions to certain minerals, and alkaline leaching. This is in accordance with what was stated by Damanik, et al (2011), that increased soil acidity is caused by the leaching of cations which are replaced by H+ and Al3+.

In the analysis of the planting media, the soil Al-dd is 5.68 me/100 g with high criteria. Based on the soil analysis results, it can be seen that the Al-dd value has a relationship with aluminum saturation. The high Al-dd value of the soil causes the aluminum saturation to increase, thus causing low exchangeable bases. With the low exchangeable bases, the saturation value of Al shows that the cation exchange complex is dominated by Al.

According to Syahputra, et al. (2015), the lack of phosphate in ultisol can be caused by the phosphate content of the soil parent material which is definitely low, or the phosphate content is actually high but not available to plants because it is absorbed by other elements such as Al and Fe. The low CEC value of the soil is due to the low organic matter of the soil. As stated by Mukhlis, et al (2011) that the amount of CEC in the soil is determined by the following factors, namely the soil texture, soil with a clay texture will have a greater CEC value than soil with a sandy texture. This is because clay is a soil colloid; second, the amount of organic matter, because some of the organic matter is humus that acts as a soil colloid, the more organic matter, the greater the CEC of the soil; and the third type of clay mineral contained in the soil, the type of clay mineral greatly determines the size of the CEC of the soil.

Power Of Hydrogen (pH)

The pH analysis of the P3IN Laboratory of the Faculty of Agriculture of Andalas University shows the influence of several treatments of eggshell flour on the pH of ultisol as

a medium for soybean plants. The results can be seen in Table 2.

Table 2 shows that the administration of several doses of eggshell flour can increase the pH of ultisol. The increase in the ultisol pH of the soybean plant media is caused by the eggshell containing calcium carbonate (CaCo3) or lime which functions to reduce soil Al-dd levels so that soil pH increases. Alibasyah, R. M. (2016) stated that the general reaction of lime carbonate produces hydroxyl ions that bind to acidic cations (H and Al) so as to increase soil pH.

An increase in soil pH indicates that eggshell fertilizer has the opportunity to reduce the limiting factor of soils that have high acidity. Taufiq and Sundari (2012) explained that soybean plants can grow well at a soil pH of 5.8-7.0. In this pH range, macro and micronutrients are available to soybean plants. In soils with an acid reaction (pH less than 5.5), phosphate (P), calcium (Ca), magnesium (Mg), potassium (K), and sulfur (S) nutrients are not easily available to soybean plants. In acid soils, the minerals Mn, Al, and Fe are available in excess, so they can be toxic to soybean plants.

Acidic soils containing high Al, levels of more than 20% cause poisoning of the roots of soybean plants, so that the roots do not develop, the plants grow stunted, the leaves are brownish yellow, and are unable to form pods. The development of Rhizobium bacteria is also hampered in acidic soil, caused by a lack of photosynthesis from the leaves (Sumarno and Manshuri, 2013). The increased pH value causes the availability of macro-nutrients to increase and are needed by soybean plants for growth. Optimal pH and the availability of soil nutrients improve soil fertility status, so that plants can respond to the application of nutrients in the form of fertilizer. The higher the increase in the pH value which is close to the pH value needed by plants, the better the growth rate and amount of production produced by plants.

Plan Heigh, Number of Productive Branches, Number of Fill Pods, and the Total Number of Pods

Plant height, number of productive branches, number of fruity pods, and total number of pods of soybean plants were affected by the dose of eggshell flour (Table 3). In Table 3 it can be seen that the application of eggshells at a rate of 25 g/plant gave the best results for plant height, number of productive branches, number of fruitful pods, and the total number of pods. The results of the study by Bachtiar et al. (2013) showed that the Anjasmoro variety had a positive response to the administration of eggshell flour during the early stages of growth. This is because Rhizobium bacteria are already capable of forming root nodules, which are around 4-5 days after planting and root nodules can bind nitrogen (N) from the air at the age of 10-12 days after planting so they can support plant growth.

Eggshells contain essential nutrients in the form of macronutrients, namely calcium, magnesium, phosphorus, and carbonate-free macronutrients, while for micronutrients, namely manganese, sodium, potassium, zinc, and copper (Noviansyah and Chalimah, 2015). According to Saragih, et al. (2016), egg shells consist of 97% calcium carbonate (CaCO3). In addition, according to him, the average eggshell contains 3% magnesium, phosphorus and manganese, sodium, potassium, zinc, manganese and copper. These nutrients have an impact on the growth of plant height and the number of productive branches, the number of fruitful pods and the number of soybean plant pods.

The element phosphorus (P) plays a role in accelerating the growth and development of the root tips and growing points of soybean plants. The role of phosphorus (P) for soybean plants according to Taufiq (2014), among others, is as a component of the compound ATP (Adenosine Triphosphate) which serves as a source of energy for the growth of soybean plants, a constituent of DNA (Deosiribonucleic Acid), RNA (Ribonucleic Acid) which are important in the fission of soybeans. cells and reproduction, and as a constituent of cell membranes. According to Anwar. (2019), excessive calcification can cause the availability of phosphate elements to decrease again due to the formation of insoluble calcium phosphate, absorption or uptake of phosphorus by plants is very difficult, causing plant metabolism to be disrupted

According to Fitri, et al (2014), stated that magnesium (Mg) is an activator of photosynthetic enzymes needed to produce photosynthate for plant development and plants also need the nutrient potassium (K) to accelerate the growth of soybean plants. In the vegetative growth phase of plants, photosynthetic results are translocated to the roots, stems and leaves. The distribution of photosynthetic results during the vegetative phase of the plant determines the branching development of soybean plants. It is necessary to apply the fertilizer that contains all three macronutrients like N, P and K (Warnita *et al*, 2017)

The element calcium (Ca) is one of the most important elements in determining the health of the pods. Eggshell flour contains calcium (Ca) which is needed by legumes during the pod filling phase. Soybean plants that lack Ca result in an increase in empty pods. The increase in the number of rice pods occurred due to the fulfillment of the element Ca needed by soybean plants, especially in the formation of pods. This is in accordance with the opinion of Nurjayanti (2012), which states that egg shells contain a high element of Ca up to 98%. The element Ca is the

nutrient that most determines the level of fruitiness of the pods.

Plants that receive phosphorus (P) nutrients grow taller so that the number of pods formed is greater. Fitri et al. (2014), suggested that phosphorus (P) in soybean plants functions in cell division, albumin formation, fruit formation and maturation, root development, disease resistance. The nutrient element potassium (K) can increase the efficiency of photosynthesis. In addition, potassium also plays a role in strengthening the plant body so that it does not collapse easily and flowers and fruit do not fall easily. The higher the nutrient calcium (K) absorbed by soybean plants, the pod filling process runs smoothly and the number of pithy pods increases.

Soybean plants that lack calcium result in an increase in empty pods. Nurjayanti (2012). In addition, the nutrient that affects the number of soybean plant pods is the nutrient phosphorus (P). Deficiency of phosphorus in soybean plants can inhibit the formation of root nodules, root development, pod and seed formation so that the pods are few and the seeds are smaller. Phosphorus deficiency generally occurs in acid soils and acid soils generally contain high iron (Fe) and aluminum (Al) (Taufiq, 2014). Therefore, the addition of eggshell flour to the planting medium can reduce the acidity of the soil and the availability of nutrients needed by soybean plants.

In soybean plants, the pods formed will enlarge and increase with age and the number of flowers. The number of pods formed varies from leaf axil, while the number of pods that can be harvested depends on the soybean variety planted and the growing environmental conditions. The Anjasmoro variety has soybean plant pods that are resistant to pod bursting

The formation of soybean pods depends on the condition of the plants in the flowering phase. In the flowering phase, plants need a lot of photosynthetic which is necessary for the development of flowers and preparation for the formation of pods. According to Wiyono (2017), the availability of sufficient water determines the efficiency of photosynthesis. Water stress can cause a decrease in photosynthetic efficiency which can be seen from the reduced net assimilation rate, this decreased photosynthetic rate causes a reduction in plant yield components both in quantity (seed dry weight) and quality (number of pods and seeds).

In addition, the formation of plant pods is influenced by the conditions and content of the planting medium used, the element phosphorus (P) contained in the egg shells is needed by soybean plants because element P can activate pod formation and fill empty pods, and accelerate fruit ripening. The greatest period of P use begins during pod formation until approximately 10 days before the seeds are fully developed (Irwan and Nurmala, 2018). The role of phosphorus absorbed by plants is important for cell growth, formation of fine roots and root hairs, strengthening plants so they don't fall over easily, improving plant quality, forming flowers, fruits and seeds as well as strengthening resistance to disease attacks, so that the number of filled pods is getting stronger. (Kurniawan, et al. 2014).

The weight of filled pods and the weight of seeds per plant, the weight of 100 seeds, and the weight of effective root nodules

The weight of filled pods and the weight of seeds per plant, the weight of 100 seeds, and the weight of root nodules of soybean plants were affected by the dose of egg shells given (Table 4). Nurjayanti (2012) stated that calcium is the nutrient that most determines the level of pod health. Eggshell flour contains calcium which is needed by legumes during the pod-filling phase. According to Saragih, et al. (2016), egg shells contain a very high element of calcium, up to 98%. Soybean plants that lack calcium result in an increase in empty pods.

The increase in rice pod weight occurred due to the fulfillment of the elements needed by soybean plants, especially in the formation of pods. In addition, phosphorus also has a role in the process of increasing fruit and seed formation, as well as accelerating plant maturation. The nutrient element phosphorus also plays an important role in increasing the weight of seeds per plant. Fitri, et al. (2014), stated that phosphorus can increase root development which can then increase the element of phosphorus in plants so that photosynthesis also increases, resulting in greater seed weight produced.

Kurniawan, et al. (2014) stated that the elements contained in the eggshell are components that are absorbed rapidly during vegetative growth and are translocated from vegetative tissues to seeds after flowering. The increased yield of soybean varieties is due to an increase in the rate of transport of dry matter to the seeds due to the nutrients contained in it. Availability of sufficient assimilate in plants increases seed weight. The large seed size gives a high total dry seed yield.

According to Irwan and Nurmala (2018), seed filling comes from photosynthates produced after flowering and translocation of stored photosynthates. Therefore, during filling of newly formed or stored photosynthate seeds can be used to increase seed weight. In soybean plants that are given additional eggshell flour will give 100 more seed weight per plant

Treatment of egg shell flour in accordance with the needs of plants can increase the weight of effective root nodules

in soybean plants. The increase in effective root nodule weight is because the soil that has been added eggshell flour can increase the soil pH, so that soybean plants grow better in soil that has a suitable pH for growth between 5.8 – 7.0.

Nurjayanti (2012) also stated that, adding eggshell flour can be used as a substitute for lime, by adding eggshell flour the pH of acidic soil can be neutralized. With the presence of calcification on acid soils, elements such as P, K, and Mg needed by soybean plants are simultaneously available in the soil. With increasing soil pH, soybean plants can properly fix nitrogen (N), so that root nodules develop properly. The element nitrogen (N) in the soil is used by legume plants to form root nodules. The presence of nitrogen (N) in the soil determines the number of nodules formed on legume plants.

The formation of root nodules in soybean plants is influenced by nitrogen (N) fixation. Root nodules are formed starting from the entry of Rhizobium bacteria into the young and tender root hairs, once inside the roots the bacteria then infect plant roots and form root nodules. Zhang et al (2020) Up to 81.5%–87.1% of the N absorbed by the soybean roots and fixed by the root nodules was supplied for shoot growth, leaving 12.9%–18.5% for root and nodule growth. Soybeans preferentially used fertilizer N in the presence of the NO− 3 or NH+ 4 supply. After the absorbed fertilizer N and nodule-fixed N was transported to the shoot, a portion of it was redistributed to the roots and nodules

The role of calcium (Ca) in soybean plants is very important at the root growing point. Because it has a direct effect on the growing point, a deficiency of this element causes stunted flower production.

IV. FIGURES AND TABLES

Table 1. Planting media analysis

Soil Chemical properties	Value	Criteria
pH H_2O	5,61	slightly sour
N-Total	0,31%	medium
P-Available	1,37 ppm	very low
K-dd	0,30 me/100 g	low
Ca-dd	1,13 me/100 g	very low
Al-dd	5,68 me/100 g	height
CEC	12,40 me/100 g	low

Note: Means with different letters, in the same column differ significantly (p≤0.05, according to Duncan's New Multiple Range test

Table 2. pH of planting media when giving several amounts of eggshell powder

Dosage eggshell Powder	pH H_2O			
	Early	Criteria	After	Criteria
0 g/plant	5,61	SC	5,61	SC
25 g/ plant	5,61	SC	6,63	N
50 g/ plant	5,61	SC	6,78	N
75 g/ plant	5,61	SC	6,93	N
100 g/ plant	5,61	SC	7,15	N

Note: Means with different letters, in the same column differ significantly (p≤0.05, according to Duncan's New Multiple Range test

SC: slightly sour, N: neutral

Table 3. Plant height, number of productive branches, number of fill pods, and total pods of soybean plants at various doses of eggshell powder

Dosage of eggshell powder	Plant height (cm)	Number of branches (piece)	Number of fill pod (fruit)	Total number of pod (fruit)
0 g/plant	56,25 a	5,00 a	54,38 a	57,75 a
25 g/ plant	67,50 b	6,00 c	101,38 b	111,63 b
50 g/ plant	61,25 ab	5,88 bc	66,00 a	69,88 a
75 g/ plant	60,00 ab	5,25 ab	59,38 a	64,63 a
100 g/ plant	52,50 a	4,75 a	45,50 a	49,00 a
CV =	9,58 %	8,52 %	26,06 %	29,12 %

Note: Means with different letters, in the same column differ significantly (p≤0.05, according to Duncan's New Multiple Range test

Table 4. The weight of filled pods, the weight of seeds per plant, the weight of 100 seeds, and the weight of effective root nodule

Dosage of eggshell	The weight of filled pods (g)	The weight of seeds per plant (g)	The weight of 100 seeds (g)	The weight of effective root nodule (g)
0 g/plant	25,57 a	17,69 a	13,15 a	3,31 ab
25 g/plant	42,16 b	26,34 b	16,11 b	6,60 c
50 g/plant	29,82 a	19,32 a	15,16 ab	5,05 bc
75 g/plant	27,14 a	18,04 a	14,23 ab	4,48 abc
100 g/plant	19,50 a	12,98 a	12,53 a	2,23 a
CV=	25,09 %	23,67%	11,39%	15,22%

Note: Means with different letters, in the same column differ significantly ($p \leq 0.05$, according to Duncan's New Multiple Range test.

V. CONCLUSION

Based on the results of the research that has been done, it can be concluded that the administration of various doses of eggshell flour affected the growth and yield of soybean plants in ultisols with the best yield of 25 g/plant.

ACKNOWLEDGEMENTS

Thanks to Mr. Dean of the Faculty of Agriculture, Andalas University, plant physiology laboratory technicians and all those who have helped carry out this research.

REFERENCES

[1] Abdurachman, A., Mulyani, A., Irawan. 2013. *Sumber Daya Lahan untuk Kedelai di Indonesia.* Balai Penelitian dan Pengembangan Sumber Daya Lahan Pertanian: Bogor.

[2] Ajala E., Eletta O., Ajala M., Oyeniyi S. (2018): Characterization and evaluation of chicken eggshell for use as a bioresource. Arid Zone Journal of Engineering, Technology and Environment, 14: 26–40.

[3] Alibasyah, R. M. 2016. *Perubahan Beberapa Sifat Fisika dan Kimia Ultisol Akibat Pemberian Pupuk Kompos dan Kapur Dolomit pada Lahan Berteras.* Jurnal Floratek. Vol.11. No.1. Hal: 75-87.

[4] Bachtiar, T. dan Waluyo, S.H. 2013. *Pengaruh Pupuk Hayati Terhadap Pertumbuhan dan Serapan Nitrogen Tanaman Kedelai (Glycine max. L.) Varietas Mitani dan Anjasmoro.* Jurnal Widyariset. Vol.16. No.3. Desember 2013: Hal. 411–418.

[5] [BPS] Badan Pusat Statistik Provinsi Sumatera Barat. 2023. *Luas Panen, Produksi, dan Produktivitas Kedelai 2019-2021. Sumatera Barat : Badan Pusat Statistik.* https://sumbar.bps.go.id/indicator/53/59/1/luas-panen-produktivitas-dan-produksi-kedelai-.html Diakses pada tanggal 17 Februari 2023.

[6] Bimasri, J. dan Murniati, N. 2017. *Eksplorasi Manfaat Limbah Cangkang Telur Untuk Peningkatan Produksi Tanaman Kedelai (Glycine max (L). Merril) Pada Tanah Ultisol.* Jurnal Klorofil. Vol. XII. No.1. Juni 2017: Hal. 52 – 57.

[7] Damanik, M. M. B., Hasibuan, B. E., Fauzi., Sarifuddin, dan Hanum, H. 2011. *Kesuburan Tanah dan Pemupukan*. USU Press: Medan.

[8] Falaqh, H.N., Sabrina, dan Fauzi. 2018. *Peningkatan Kesuburan Tanah Inseptisol serta Pertumbuhan dan Produksi Kedelai Akibat Pemberian Kompos diperkaya Cangkang Telur Ayam dan Mikroba Bermanfaat.* Jurnal Agroekoteknologi FP USU. Vol. 6. No.4. Oktober 2018: Hal. 862-873.

[9] Fitriatin, B. N., Yuniarti A., Turmuktini T., dan Ruswandi, F.K. 2014. *The Effect of Phosphate Solubilizing Microbe Producing Growth Regulators on Soil Phosphate, Growth and Yield of Maize and Fertilizer Efficiency on Ultisol.* Eurasian Journal of Soil Science. Vol.3. No.3. Oktober 2014: Hal. 101-107.

[10] Fitri, Y., Armaini, dan Silvina, F. 2014. *The Growth And Production Of Soybean Plant (Glycine Max (L.) Merril) With Giving The Janjang Dust Of Oil Palm.* Jurnal Online Mahasiswa Faperta UNRI. Vol.1. No.1. Februari 2014.

[11] Irwan, A.W., dan Nurmala, T. 2018. *Pengaruh Pupuk Hayati Majemuk Dan Pupuk Fosfor Terhadap Pertumbuhan Dan Hasil Kedelai Di Inceptisol Jatinangor.* Jurnal Kultivasi. Vol.17. No.3. Desember 2018: Hal. 750-759.

[12] Kurniawan, S., Rasyad, A., dan Wardati. 2014. *Pengaruh Pemberian Pupuk Posfor Terhadap Pertumbuhan Beberapa Varietas Kedelai (Glycine max (L.) Merril).* J urnal Online Mahasiswa Faperta UNRI. Vol.1. No.2. Oktober 2014.

[13] Mukhlis., Sarifuddin., dan Hanum, H. 2011. *Kimia Tanah, Teori, dan Aplikasi*. USU Press: Medan.

[14] Noviansyah, B., dan Chalimah, S. 2015. *Aplikasi Pupuk Organik Dari Campuran Limbah Cangkang Telur Dan Vetsin Dengan Penambahan Rendaman Kulit Bawang Merah Terhadap Pertumbuhan Tanaman Cabai Merah Keriting* (*Capsicum annum* L) *Var. Longum*). Jurnal Bioeksperimen. Vol.1. No.1. Maret 2015: Hal. 43-48.

[15] Nurjanah, Susanti R, & Nazip K. 2017. Pengaruh pemberian tepung cangkang telur ayam (Gallus gallus domesticus) terhadap pertumbuhan tanamancaisim (Brassica juncea L.) dan sumbangannya pada pembelajaran biologi SMA. Prosiding Seminar Nasional IPA 2017

[16] Nurjayanti, Zulfita, D., Raharjo, D. 2012. *Pemanfaatan Tepung Cangkang Telur sebagai Subtitusi Kapur dan Kompos Keladi terhadap Pertumbuhan dan Hasil Cabai*

Merah pada Tanah Aluvial. Jurnal Sains Mahasiswa Pertanian. 1(1) : 1621.

[17] Purwaningsih, O dan C. T. kusumastuti. 2019. Pemanfaatan bahan organic dalam budidaya kedelai. UPY Press. Yogyakarta

[18] Saragih, S. D., Hasanah, Y. dan Bayu E. S. 2016. *Respons Pertumbuhan dan Produksi Kedelai (Glycine max* (L.) Merril.*) terhadap Aplikasi Pupuk Hayati dan Tepung Cangkang Telur*. Jurnal Agroekoteknologi. Vol.4. No.3. Juni 2016: Hal. 2167-2172.

[19] Sitohang F, Yelmida A & Zulnitiar. 2016. Sintesis hidroksiapatit dari precipitated calcium carbonate (PPC) kulit telur ayam ras melalui metode hidrotermal. Jurnal Onlie Mahasiswa Fakultas Teknik. 3(2), 1 – 7

[20] Sumarno dan Manshuri, A.G. 2013. *Persyaratan Tumbuh dan Wilayah Produksi Kedelai di Indonesia.* Balai Penelitian Tanaman Aneka Kacang dan Umbi: Malang.

[21] Syahputra, E., Fauzi, dan Razali. 2015. *Karakteristik Sifat Kimia Sub Grup Tanah Ultisol di Beberapa Wilayah Sumatera Utara*. Jurnal Agroekoteknologi. Vol.4. No.1. Desember 2015: Hal. 1796-1803.

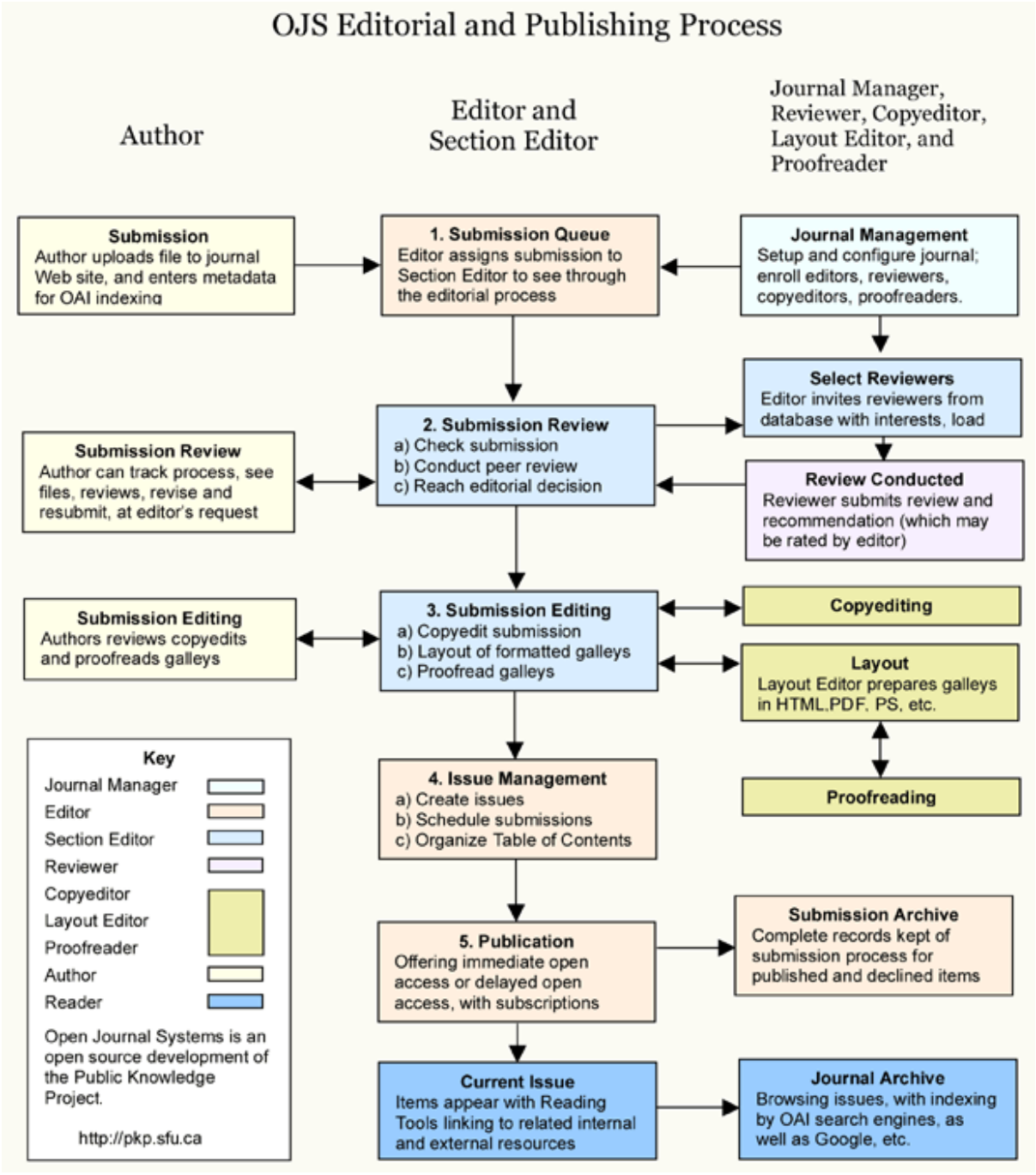
[22] Taufiq, A. 2014. *Identifikasi Masalah Keharaan Tanaman Kedelai*. Balai Penelitian Tanaman Aneka Kacang dan Umbi (Balitkabi): Malang.

[23] Taufiq, A., dan Sundari, T. 2012. *Respons Tanaman Kedelai terhadap Lingkungan Tumbuh*. Jurnal Palawija. No. 23. Februari 2012: Hal. 13–26.

[24] Warnita, Akhir N, Vina. Growth response of two varieties chrysanthemum (*Chrysanthemum* sp.) on some media composition. International Journal on Advanced Science, Engineering and Information Technology. 2017;7(3): 928-935.

[25] Wiyono. 2017. *Respon Beberapa Varietas Kedelai (Glycine max (L) Merril) Terhadap Cekaman Air*: Jurnal Agrineca. Vol.3. No.3. 13 November.

[26] Zhang, R , C. Wang, W. Teng , J.Wang, X. Lyu, S. Dong, S. Kang, Z. Gong and C. Ma. 2020. Accumulation and Distribution of Fertilizer Nitrogen and Nodule-Fixed Nitrogen in Soybeans with Dual Root Systems. Agronomy. **2020**, *10*, 397; doi:10.3390/agronomy10030397 : 1 – 17.



~OJS Workflow~

Important links:

Paper Submission Link:
OJS:
https://ijeab.com/ojs/index.php/ijeab/about/submissions
https://ijeab.com/submit-paper/
Editorial Team:
https://ijeab.com/editorial-board/

Peer Review Process:
https://ijeab.com/peer-review-process/
Publication Ethics:
https://ijeab.com/publication-policies-and-ethics/
Author Guidelines:
https://ijeab.com/author-guidelines/
Join Us a Reviewer:
https://ijeab.com/join-us/

Journal Indexed and Abstracted in:

- Qualis-CAPES -Brazil
- Normatiza (Under Review)
- Bielefeld Academic Search Engine(BASE)
- Aalborg University Library (Denmark)
- WorldCat: The World's Largest Library Catalog
- Semantic Scholar
- J-Gate
- Open J-Gate
- CORE-The world’s largest collection of open access research papers
- JURN
- Microsoft Academic Search
- Google Scholar
- Kopernio - powered by Web of Science
- Pol-Index
- PBN(Polish Scholarly Bibliography)Nauka Polaska
- Scilit, MDPI AG (Basel, Switzerland)
- Tyndale University College & Seminary
- indiana Library WorldCat
- CrossRef DOI-10.22161/ijeab
- Neliti - Indonesia's Research Repository
- Journal TOC
- Dimensions.ai: Re-imagining discovery and access to research
- Citeseerx
- Massachusetts Institute of Technology (USA)
- Simpson University (USA)
- University of Louisville (USA)
- Biola University (USA)
- IE Library (Spain)
- Mount Saint Vincent University Library (Halifax, Nova Scotia Canada)
- University Of Arizona (USA)
- INDIANA UNIVERSITY-PURDUE UNIVERSITY INDIANAPOLIS (USA)
- Roderic Bowen Library and Archives (United Kingdom)
- University Library of Skövde (Sweden)
- Indiana University East (campuslibrary (USA))
- Tilburg University (The Netherlands)
- Williams College (USA)
- University of Connecticut (USA)
- Brandeis University (USA)
- Tufts University (USA)
- Boston University (USA)
- McGill University (Canada)
- Northeastern University (USA)
- BibSonomy-The blue social bookmark and publication sharing system
- Slide Share
- Academia
- Archive
- Scribd
- SJIF-InnoSpace
- ISSUU
- Research Bib
- DRJI
- journal-repository

Platform & workflow by OJS / PKP

Infogain Publication
International Journal of English, Literature and Social Science (IJELS)