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Comparative Assessment of Watermelon (*Citrullus lanatus*) Rind and Seed Powders for Turbidity and Methylene Blue Removal at Different Contact Times

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Abstract— *This study comparatively assessed the effectiveness of watermelon (*Citrullus lanatus*) rind and seed powders in removing turbidity and methylene blue from contaminated water at different contact times. The study was motivated by the need to develop affordable and environmentally friendly water-treatment materials while promoting the utilization of agricultural waste. Watermelon rinds and seeds, which are commonly discarded after consumption, were investigated as potential natural coagulants and biosorbents for water purification. The materials were prepared by washing, drying, grinding and sieving to obtain a uniform particle size of approximately 300 µm. A fixed dosage of 20 mg of each powder was used during the treatment experiments. Water samples with different initial turbidity levels (50, 100, 150, 200 and 250 NTU) and methylene blue colour levels were prepared and treated using the two materials at different contact times. Turbidity was measured using a digital turbidity meter, while methylene blue concentration was determined using a UV–Visible spectrophotometer. The percentage removal efficiency was calculated by comparing the initial and final concentrations of the contaminants. The results showed that both watermelon rind and seed powders were effective in reducing turbidity and methylene blue concentrations. Watermelon seed powder achieved the highest turbidity removal efficiency of 99.8% at 10 hours, compared with 96% for watermelon rind powder. Similarly, watermelon seed powder recorded a maximum methylene blue removal efficiency of 92.8%, while watermelon rind powder achieved 90%. Turbidity removal increased with contact time up to 10 hours but decreased at 12 hours, whereas methylene blue removal generally increased with increasing contact time. The observed differences may be associated with variations in the chemical composition and surface characteristics of the two materials. The study concludes that watermelon rind and seed powders have potential as low-cost and environmentally friendly materials for turbidity and methylene blue removal from contaminated water. Their utilization could also contribute to agricultural-waste management and environmental sustainability. Further studies are recommended to optimize treatment conditions, establish the statistical reliability of the findings and assess the quality and safety of treated water.*

Keywords— **Citrullus lanatus, *Watermelon rind powder, Watermelon seed powder, Turbidity removal, Methylene blue, Biosorption, Natural coagulant, Water treatment.***

I. INTRODUCTION

1.1 Background of the Study

Water is one of the most important natural resources required for the survival of humans, animals, plants, and aquatic ecosystems. Access to adequate quantities of safe and acceptable-quality water is essential for domestic activities, agriculture, industrial production, and environmental sustainability. However, population growth, urbanization, agricultural activities, and industrialization have contributed to increasing pressure

on water resources and deterioration of water quality. Wastewater from domestic, agricultural, and industrial activities may contain suspended solids, organic matter, dyes, heavy metals, microorganisms, and other contaminants that negatively affect water quality and its suitability for different uses (United Nations Environment Programme [UNEP], 2023; World Health Organization [WHO], 2023). Furthermore, inadequate wastewater treatment contributes to environmental pollution and poses risks to human health and aquatic ecosystems. Recent global assessments have highlighted the need to improve wastewater treatment and reduce the discharge of untreated or inadequately treated wastewater into the environment (UN-Water, 2024).

Among the important physical characteristics used to assess water quality is turbidity. Turbidity refers to the cloudiness or haziness of water caused by suspended and colloidal particles such as clay, silt, organic matter, microorganisms, and other finely divided materials (Matos et al., 2024; Zezulka et al., 2024). Although turbidity itself is not necessarily a direct measure of a specific toxic substance, high turbidity can indicate the presence of contaminants and interfere with water treatment processes (World Health Organization [WHO], 2022). The presence of suspended particles may reduce the effectiveness of disinfection by shielding microorganisms from disinfectants. High turbidity may also increase disinfectant demand and reduce the acceptability of drinking water (Wang et al., 2024). Therefore, monitoring and controlling turbidity is important for improving water treatment efficiency and protecting public health.

The presence of colour in water is another important water-quality concern. Natural colour may originate from humic substances, decomposed vegetation and minerals, whereas anthropogenic colour may originate from industrial activities, particularly textile, paper, leather and dye-producing industries. Synthetic dyes are of particular concern because many are designed to be chemically stable and resistant to degradation. Consequently, untreated dye-containing wastewater can introduce persistent colour and organic pollutants into receiving water bodies (Srivastava et al., 2022; Lin et al., 2023; Parida et al., 2025).

Methylene blue (MB) is a commonly used cationic dye and is frequently employed as a model pollutant in adsorption studies. It is used in several industrial and laboratory applications, including textile-related processes. Its presence in water can cause intense coloration and can therefore reduce the aesthetic quality of water. Because of its well-defined optical properties, methylene blue is also commonly used to evaluate the adsorption performance of different low-cost adsorbents (Oladoye et al., 2022). Recent reviews have identified adsorption using agricultural and biomass wastes as an environmentally attractive approach for removing methylene blue from aqueous solutions (Hamad & Idrus, 2022; Shelke et al., 2022).

Conventional water and wastewater treatment technologies include coagulation, flocculation, sedimentation, filtration, oxidation, membrane processes, and adsorption. Although these methods can effectively remove various contaminants from water, some require costly infrastructure, specialised equipment, high energy consumption, and chemical reagents, which may increase overall treatment costs. These challenges are particularly significant in developing countries and rural communities where financial resources, technical expertise, and access to advanced treatment facilities may be limited. Consequently, increasing attention has been directed towards the development of affordable, locally available, and biodegradable materials for water treatment. The use of agricultural waste as a potential treatment material offers a promising approach to reducing treatment costs, minimizing environmental waste, and promoting sustainable water management.

Agricultural wastes have attracted considerable attention as potential adsorbents because they are widely available and contain functional groups capable of interacting with contaminants (Kainth et al., 2024). Biomass materials commonly contain cellulose, hemicellulose, lignin and other organic components containing hydroxyl, carboxyl and other functional groups. Such functional groups can provide active sites for the adsorption of pollutants from aqueous solutions (Liu et al., 2022; Sen, 2023).

One promising agricultural material for water treatment is watermelon (*Citrullus lanatus*), which is widely cultivated and consumed in many parts of the world. During consumption and processing, substantial quantities of watermelon rind and seeds are generated as organic waste. Instead of being discarded, these residues can potentially be converted into useful biosorbents for removing contaminants from water (Awogbemi & Von Kallon, 2023).

Watermelon rind is particularly promising because it contains lignocellulosic components, including cellulose and lignin, with functional groups that may interact with pollutants. These characteristics can support the adsorption of contaminants from aqueous solutions (Wang et al., 2022). Recent studies have demonstrated the potential of watermelon-rind-based materials for methylene blue removal. Shukla et al. (2024) investigated biochar prepared from watermelon rind and reported its

effectiveness in adsorbing methylene blue from aqueous solutions. Similarly, Teng et al. (2024) developed watermelon-rind-based hydrogels that demonstrated substantial methylene blue adsorption capacity. These findings support the potential use of watermelon rind as a precursor for producing low-cost adsorbent materials.

Watermelon seeds have also demonstrated potential for water purification. Their organic composition and surface characteristics may contribute to pollutant removal through adsorption and other interactions with contaminants. Grassi et al. (2024) investigated watermelon seed powder as a biosorbent for removing cationic dyes from water. Their findings demonstrated that the material could adsorb crystal violet and basic fuchsin dyes, supporting its potential application in wastewater treatment.

In addition to adsorption, watermelon seeds may be useful as natural coagulants. Natural coagulants derived from plant materials have attracted attention because of their potential affordability, availability, and biodegradability (Panwar et al., 2022; Koul et al., 2022). Their application can promote the aggregation and subsequent settling of suspended particles, thereby improving water clarification.

Overall, previous research suggests that both watermelon rind and seed powders have potential applications in water treatment. However, their performance may differ because of variations in chemical composition, surface characteristics, and available functional groups. Therefore, a comparative investigation is necessary to determine whether watermelon rind powder or seed powder performs better in removing turbidity and methylene blue from contaminated water.

The present study therefore focuses on the comparative assessment of watermelon (*Citrullus lanatus*) rind and seed powders for the removal of turbidity and methylene blue from contaminated water at different contact times. It aims to determine how contact time influences the removal efficiency of each material and to identify the treatment duration at which the highest removal efficiency is achieved. The study also compares the performance of rind and seed powders to establish their potential as affordable and environmentally friendly materials for water treatment. Furthermore, it seeks to promote the beneficial utilisation of agricultural residues by converting discarded watermelon rinds and seeds into potentially useful materials for water purification, thereby contributing to sustainable waste management and environmental protection.

1.2 Statement of the Problem

The increasing generation of watermelon (*Citrullus lanatus*) rinds and seeds as agricultural and household waste, together with the need for affordable and environmentally friendly water-treatment materials, presents an important environmental challenge and an opportunity for resource recovery. Water contaminated with suspended particles and colored substances, such as methylene blue, requires appropriate treatment to improve its quality and suitability for different uses. However, conventional water-treatment methods may involve high costs, specialised equipment, and chemical reagents, creating a need to investigate alternative materials that are locally available and affordable.

Watermelon rinds and seeds are commonly discarded after the edible portion of the fruit has been consumed, despite containing organic components that may contribute to contaminant removal. Previous studies have demonstrated the potential of watermelon-rind-based materials for methylene blue adsorption, while watermelon seed-based materials have also shown potential for removing dyes and suspended particles from water (Jawad et al., 2019; Grassi et al., 2024). These findings suggest that watermelon residues could be converted into useful materials for water treatment instead of being discarded as waste.

However, limited comparative information is available on the performance of watermelon rind powder and seed powder in their simple, unmodified forms for removing both turbidity and methylene blue under comparable experimental conditions. Furthermore, the influence of contact time on the performance of each material requires investigation because the duration of contact may affect the interaction between the treatment materials and contaminants, thereby influencing removal efficiency. Without such a comparison, it remains difficult to determine which material performs better for each water-quality parameter and at what contact time the highest removal efficiency can be achieved.

Therefore, this study aims to comparatively assess watermelon (*Citrullus lanatus*) rind and seed powders for turbidity and methylene blue removal at different contact times. The study will evaluate the removal efficiencies of both materials, examine how contact time influences their performance, and identify the conditions under which each material achieves its highest removal efficiency. The findings are expected to contribute to knowledge of the potential use of watermelon residues as affordable and environmentally friendly materials for water treatment while promoting agricultural-waste utilization and sustainable environmental management.

1.3 Main Objective

The main objective of this study is to comparatively assess the effectiveness of watermelon (*Citrullus lanatus*) rind and seed powders in removing turbidity and methylene blue from contaminated water at different contact times.

1.4 Specific Objectives

The study was guided by the following specific objectives:

1. To prepare watermelon (*Citrullus lanatus*) rind and seed powders for use as water-treatment materials.
2. To determine the effectiveness of watermelon rind powder in removing turbidity and methylene blue at different contact times.
3. To determine the effectiveness of watermelon seed powder in removing turbidity and methylene blue at different contact times.
4. To compare the turbidity and methylene blue removal efficiencies of watermelon rind and seed powders at different contact times under similar experimental conditions.

1.5 Significance of the Study

This study was significant in several ways. Firstly, it contributed to environmental protection by promoting the utilization of watermelon (*Citrullus lanatus*) rind and seeds, which are commonly discarded as waste after consumption. The use of these residues as materials for water treatment helped reduce the amount of agricultural waste disposed of in the environment while promoting the beneficial reuse of locally available resources. Secondly, the study contributed to water treatment by providing information on the ability of watermelon rind powder and seed powder to remove turbidity and methylene blue colour from contaminated water. The findings provided insights into the potential of these materials as simple and environmentally friendly treatment materials, particularly in areas where conventional treatment materials are not easily accessible. Thirdly, the study had economic significance because watermelon rind and seeds were obtained from waste materials at relatively low cost. Their use in water treatment demonstrated the potential to reduce dependence on expensive commercial treatment materials. The preparation of the powders involved simple processes such as cleaning, drying and grinding, which made them potentially suitable for small-scale applications. Fourthly, the study had scientific significance because it provided comparative information on the performance of watermelon rind powder and seed powder under similar experimental conditions. The findings established whether the two materials differed in their ability to remove turbidity and methylene blue colour from contaminated water.

Finally, the study had academic significance because it provided useful information for students, researchers and other institutions interested in environmental chemistry, water treatment and waste utilization. The findings also provided a foundation for future studies on the improvement and application of watermelon-derived materials for the treatment of contaminated water.

1.6 Scope of the Study

The study focused on the comparative performance of powdered watermelon rind and powdered watermelon seeds for the treatment of contaminated water.

The investigation specifically considered two major water-quality parameters:

- **Turbidity**, which was measured as an indicator of suspended and colloidal particles in water.
- **Methylene blue colour**, which was used as a model colour pollutant to evaluate the ability of the materials to remove a cationic dye.

The study involved the preparation of *Citrullus lanatus* rind and seed materials through cleaning, drying and grinding them into powder. The prepared powders were then introduced into contaminated water under controlled laboratory conditions.

Selected experimental variables, including adsorbent dosage and contact time, were varied to determine their effects on treatment performance. Other parameters, such as pH, initial methylene blue concentration and temperature, were also considered depending on the available laboratory facilities.

II. LITERATURE REVIEW

2.1 Introduction

Water pollution caused by suspended particles, organic matter, color-producing substances and synthetic dyes remains an important environmental and public-health concern. Turbidity and color are among the major parameters used to assess water quality because high turbidity indicates the presence of suspended and colloidal materials, while color may indicate the presence of dissolved organic compounds, industrial dyes or other contaminants. Methylene blue (MB), a cationic dye, is commonly used as a model contaminant in adsorption studies because it is highly soluble in water and can be readily monitored through color measurements. The

removal of such contaminants using low-cost agricultural materials has received increasing attention because conventional treatment technologies may require relatively expensive chemicals, specialized equipment and skilled operation.

Agricultural wastes and fruit residues are increasingly being investigated as alternative biosorbents and bio-coagulants for water treatment because of their availability, low cost, biodegradability, and potential for waste valorization. Among these materials, *Citrullus lanatus* (watermelon) is of particular interest because its rind and seeds are generated in considerable quantities as household and food-processing wastes. Instead of being discarded, these residues can be converted into useful materials for environmental applications. Watermelon rind contains important lignocellulosic and pectic components, together with proteins and other oxygen-containing compounds that provide functional groups capable of interacting with contaminants in water (Méndez et al., 2021).

The presence of cellulose, pectin, and other structural components makes the rind a promising biomass for adsorption and related water-treatment applications. Watermelon seeds also contain lignocellulosic materials, particularly cellulose and lignin, and possess a heterogeneous surface with cavities and other surface features that can provide active sites for the adsorption of dissolved pollutants (Grassi et al., 2024). Recent research has demonstrated that watermelon seed powder can remove cationic dyes from aqueous solutions, further supporting its potential as a low-cost biosorbent (Elboughdiri et al., 2024). Therefore, both watermelon rind and seed residues have potential for conversion into environmentally friendly treatment materials for contaminated water.

Recent studies have demonstrated the ability of watermelon rind to remove dyes and turbidity from water, while research on watermelon seed powder has demonstrated its ability to remove several cationic dyes. However, relatively limited information is available on the direct comparison of untreated watermelon rind and seed powders for the simultaneous or comparative removal of turbidity and methylene blue under similar experimental conditions. This review therefore discusses the chemical composition, adsorption and coagulation mechanisms, and treatment potential of *C. lanatus* rind and seed powders, with particular emphasis on turbidity and colour removal.

2.2 Watermelon (*Citrullus lanatus*) as a Source of Biosorbent Materials

Citrullus lanatus, commonly known as watermelon, belongs to the family Cucurbitaceae. The fruit consists mainly of edible pulp, rind, and seeds. During household consumption and food processing, the rind and seeds are commonly discarded as by-products or waste. However, recent research has emphasized the potential of converting these residues into value-added products because they contain important nutritional, phytochemical, and functional compounds. Watermelon rind and seeds have therefore attracted increasing interest for applications in food, pharmaceutical, industrial, and environmental fields, including their potential use as biosorbents and other treatment materials (Vinhas et al., 2021; Zia et al., 2021). The valorization of these residues can also contribute to waste reduction and promote a more sustainable circular-economy approach by converting discarded biomass into useful products.

Watermelon rind is particularly attractive because it represents a substantial fraction of the fruit and is rich in carbohydrates and structural polymers. A study on watermelon rind composition reported carbohydrates as the major component, with pectin, cellulose and free sugars representing important fractions. The same study reported approximately 31.61% pectin and 14.28% cellulose on a dry basis, although composition varies according to cultivar, maturity and processing conditions (Méndez et al., 2021).

Watermelon rind is a lignocellulosic biomass composed mainly of cellulose, hemicellulose, and lignin. These structural components are important in water-treatment applications because they contain oxygen-containing functional groups that can interact with contaminants through adsorption and other surface interactions. A compositional analysis of untreated watermelon rind reported approximately **39.67% cellulose, 23.21% hemicellulose, and 10.63% lignin**. The presence of these lignocellulosic components provides functional groups, particularly hydroxyl groups, which can contribute to the interaction and retention of pollutants on the biomass surface (Ibrahim et al., 2020).

2.3 Watermelon Seeds and Their Potential as a Biosorbent.

Watermelon (*Citrullus lanatus*) seeds have a chemical composition that differs considerably from that of the fruit rind. Unlike the rind, which is mainly characterized by lignocellulosic and pectic materials, watermelon seeds contain appreciable amounts of proteins, lipids, dietary fibre, carbohydrates, ash and mineral elements. This composition makes the seeds a nutritionally valuable by-

product and also provides several chemical constituents that may contribute to their potential application as a biosorbent for water treatment (Falade et al., 2020; Eke et al., 2021). Studies on watermelon seeds have reported considerable amounts of crude protein, fat, fibre and mineral components, although their concentrations may vary depending on cultivar, geographical location, soil conditions, maturity and processing method (Falade et al., 2020; Eke et al., 2021).

Protein is one of the important components of watermelon seeds. Proteins are composed of amino acids containing functional groups such as amino ($-NH_2$), carboxyl (-COOH), hydroxyl and other polar groups. These functional groups can potentially interact with dissolved contaminants through electrostatic attraction, hydrogen bonding and other surface interactions. Therefore, the relatively high protein content of watermelon seeds may contribute to the availability of active sites on the seed-powder surface when the material is used for water treatment. In addition, the amino-acid composition of watermelon seeds includes relatively high proportions of arginine, glutamic acid and aspartic acid, which further demonstrates the presence of chemically active groups within the seed material (Falade et al., 2020). Such groups may participate in interactions with charged pollutants in aqueous systems.

The lipid fraction is another major characteristic of watermelon seeds. Watermelon seed oil contains predominantly unsaturated fatty acids, with linoleic acid being one of the major components, followed by palmitic and oleic acids. Eke et al. (2021) reported that the major fatty acids in watermelon seed oil were 9,12-octadecadienoic acid (linoleic acid) at approximately 52.32%, n-hexadecenoic acid (palmitic acid) at 21.23%, and oleic acid at 10.11%. These findings confirm that watermelon seeds are an important source of plant oil and contain a considerable proportion of biologically active fatty acids (Eke et al., 2021). Earlier work on *C. lanatus* seed also demonstrated substantial crude fat and protein contents and identified linoleic acid as an important component of the seed oil (Coşkuner & Tekin, 2002).

Although lipids are not necessarily the principal functional components responsible for adsorption, they can influence the surface characteristics of the untreated seed material. During preparation of seed powder, drying and grinding expose different components of the seed matrix, including proteins, carbohydrates and lipid-associated compounds. Consequently, the overall chemical composition of the seed may affect surface polarity, accessibility of active sites and interaction with contaminants.

Watermelon seeds also contain fibre and structural carbohydrates. These components contribute to the physical structure of the seed and can provide oxygen-containing functional groups capable of interacting with pollutants. The presence of structural carbohydrates is particularly relevant when the seeds are converted into powder because grinding increases the exposed surface area and can make previously inaccessible functional groups available for interaction with contaminants. Studies of watermelon seed composition have confirmed the presence of fibre together with protein, fat and mineral components (Falade et al., 2020; Eke et al., 2021).

Mineral components are also present in watermelon seeds. Falade et al. (2020) reported appreciable levels of minerals such as iron, copper, zinc, calcium and magnesium in *C. lanatus* seeds. These mineral constituents are important from a nutritional perspective, but they may also influence the physicochemical properties of the biomass. Depending on the water chemistry and treatment conditions, mineral-containing sites may contribute to interactions between the seed powder and dissolved substances.

From a water-treatment perspective, the combination of proteins, structural carbohydrates and other functional constituents is important because it creates a chemically heterogeneous biosorbent surface. Different functional groups can provide different types of interaction sites. For example, carboxyl and amino groups may participate in electrostatic interactions with charged contaminants, while hydroxyl-containing structures can contribute to hydrogen bonding. These interactions can occur simultaneously and may contribute to the retention of dissolved pollutants on the seed-powder surface.

The physical structure of the seed is equally important. When watermelon seeds are dried and ground into powder, the resulting particles provide a larger contact area between the biomass and contaminated water than an intact seed. Smaller and relatively uniform particles can expose more surface sites and improve contact between the biosorbent and the contaminant. However, excessively fine particles may remain suspended in water and can make separation after treatment more difficult. Therefore, controlling particle size is important when evaluating watermelon seed powder for water treatment.

The potential of watermelon seeds as a biosorbent is further supported by recent research demonstrating their ability to interact with dissolved dyes. Grassi et al. (2024) reported that *C. lanatus* seed powder was capable of removing cationic dyes from aqueous solutions. The authors characterized the seed powder as a heterogeneous

material containing lignin and cellulose, with surface cavities and bulges that could provide sites for pollutant attachment. Although this study was published after 2021, it provides experimental evidence that the chemical and physical characteristics described in earlier compositional studies can translate into practical adsorption performance.

Overall, the chemical composition of *C. lanatus* seeds provides a reasonable basis for considering them as a potential biosorbent. Their protein content provides amino and carboxyl-related functional groups, structural carbohydrates contribute hydroxyl-containing sites, and the heterogeneous physical structure of the powdered material provides a surface for contaminant interaction. The presence of minerals and other phytochemical constituents may further influence the physicochemical behavior of the biomass. Therefore, watermelon seed powder represents a potentially inexpensive and renewable material for water-treatment applications, particularly for the removal of dissolved color and other pollutants from contaminated water (Coşkuner & Tekin, 2002; Falade et al., 2020; Eke et al., 2021).

The difference in chemical composition between rind and seeds is important when comparing their water-treatment performance. Rind is relatively rich in pectin and lignocellulosic polymers, while seeds contain a larger proportion of protein and lipid-related constituents in addition to structural components. Consequently, the two materials may interact with contaminants through somewhat different mechanisms.

2.4 Chemical Characteristics Responsible for Water Treatment Ability

The treatment capacity of plant-derived biosorbents is strongly related to their chemical composition and surface characteristics. In general, adsorption occurs when pollutant molecules interact with active sites located on the surface of the biomass. These interactions may include electrostatic attraction, hydrogen bonding, ion exchange, van der Waals forces, π–π interactions and, depending on the contaminant and surface chemistry, chemical complexation.

2.4.1 Chemical characteristics of watermelon rind

Watermelon rind contains cellulose, hemicellulose, lignin and pectin. These polymers contain functional groups such as hydroxyl (-OH) and carboxyl (-COOH), which are particularly important for adsorption. A review by Bhattacharjee et al. (2020) concluded that carboxyl and hydroxyl groups are among the main functional groups responsible for the sorption of dyes and metals onto watermelon rind. The same review indicated that pH, initial contaminant concentration, biosorbent dose and co-solutes can significantly influence the adsorption process.

Pectin is particularly important because it contains galacturonic-acid-derived carboxyl groups. Research on watermelon rind pectin has demonstrated that the rind can provide considerable amounts of pectin and that its structural properties depend on extraction conditions. Méndez et al. (2021) reported that pectin represented a major carbohydrate fraction of watermelon rind, demonstrating the importance of this polymer in the chemical structure of the material.

The lignocellulosic structure also contributes to the physical characteristics of the rind. Grinding the rind into powder increases its available surface area, making more functional groups accessible to contaminants. Particle size therefore becomes an important experimental variable because smaller particles may provide a larger effective surface area and shorter diffusion paths.

2.4.2 Chemical characteristics of watermelon seeds

Watermelon seeds contain proteins, lipids, fibre and other biochemical components. The protein fraction is particularly relevant because proteins contain functional groups such as amino, carboxyl and hydroxyl groups that can interact with dissolved contaminants. The seed also contains structural materials such as lignin and cellulose.

Grassi et al. (2023) characterized *C. lanatus* seed powder as a heterogeneous biosorbent containing lignin and cellulose. Microscopic analysis showed a heterogeneous surface with cavities and irregular structures. Such physical characteristics can increase the number of potential sites available for interaction with dissolved dye molecules.

The presence of functional groups and heterogeneous surface structures means that watermelon seed powder can act as a biosorbent rather than simply being an inert solid. The effectiveness of the seed powder can therefore depend on pH, dose, contact time, initial contaminant concentration and particle size.

2.5 Removal of Methylene Blue Using *Citrullus lanatus* Rind and Seed Powders

Methylene blue (MB) is a cationic dye that is widely used as a model contaminant in adsorption studies because its concentration can be readily determined using spectrophotometric methods. Its positively charged nature allows it to interact with negatively charged functional groups present on the surfaces of many agricultural biosorbents. These interactions may occur through electrostatic attraction, hydrogen bonding, π–π interactions, and other surface forces. Therefore, the

chemical composition, surface characteristics and functional groups of a biosorbent are important factors determining its ability to remove MB from aqueous solutions (Bhattacharjee et al., 2020; Rafatullah et al., 2010).

Both watermelon (*Citrullus lanatus*) rind and seed have attracted attention as potential low-cost biosorbents because they are readily available agricultural and food-processing residues. Although they originate from the same fruit, their chemical compositions are different and this may result in differences in their adsorption behavior. Watermelon rind contains mainly lignocellulosic and pectic materials, including cellulose, hemicellulose, lignin and pectin, together with hydroxyl, carboxyl and other oxygen-containing functional groups. These groups provide potential active sites for the interaction and retention of dissolved pollutants. Bhattacharjee et al. (2020) reviewed the use of watermelon rind as a biosorbent and reported its potential for removing dyes and heavy metals from aqueous solutions.

Watermelon seed has a different chemical profile from the rind. The seeds contain appreciable amounts of protein, oil, fibre, carbohydrates and minerals. Proteins can provide amino and carboxyl groups, while structural carbohydrates such as cellulose and lignin provide hydroxyl and other oxygen-containing functional groups. These chemical constituents can create a heterogeneous surface with several potential sites for interaction with dissolved pollutants. Eke et al. (2021) reported that watermelon seeds contain substantial nutritional components and that their oil is characterized mainly by linoleic, palmitic and oleic acids. These chemical characteristics suggest that seed powder may also be useful as a biosorbent material.

The potential of watermelon rind for MB removal has been demonstrated in several studies. Garba et al. (2021) investigated activated carbon produced from watermelon rind for the removal of methylene blue. FTIR characterization indicated the presence of hydroxyl and carbonyl-related functional groups associated with the lignocellulosic structure of the material. Under the experimental conditions investigated, the activated watermelon-rind carbon achieved a maximum adsorption capacity of approximately **197.5 mg/g**. This result demonstrates the strong potential of watermelon rind as a precursor for the production of adsorbent materials for dye-contaminated water.

Similarly, Lee and Choi (2021) investigated sulfuric-acid-modified watermelon rind for methylene blue adsorption. Chemical modification increased the availability of surface functional groups, including sulfonic, carboxyl and hydroxyl groups. The modified material achieved a reported Langmuir maximum adsorption capacity of approximately **334.45 mg/g at pH 7** under the experimental conditions. The authors associated MB removal with several mechanisms, including electrostatic interactions, hydrogen bonding, electron donor–acceptor interactions and π–π interactions. These findings demonstrate that modification of watermelon rind can enhance its adsorption performance by changing the surface chemistry and increasing the accessibility of active sites.

Watermelon seed powder has also demonstrated potential for removing cationic dyes from water. Grassi et al. (2024) investigated *C. lanatus* seed powder for the removal of crystal violet and basic fuchsin and demonstrated that the material could remove these dyes from aqueous solutions. The seed powder was characterized as a heterogeneous material containing lignin and cellulose, with surface cavities and bulges that could provide sites for contaminant attachment. The study reported adsorption capacities of approximately **48.13 mg/g for crystal violet** and **44.26 mg/g for basic fuchsin**. Although these dyes are different from methylene blue, their cationic nature provides useful evidence that watermelon seed powder can interact with positively charged dye molecules.

The ability of both rind and seed powders to interact with cationic dyes can be explained by their surface chemistry. For watermelon rind, pectin and lignocellulosic components provide carboxyl and hydroxyl groups that can become negatively charged depending on the solution pH. These sites can attract positively charged MB molecules through electrostatic interactions. Similarly, the protein and lignocellulosic components of watermelon seed provide amino, carboxyl and hydroxyl groups that may participate in electrostatic attraction and hydrogen bonding. The heterogeneous surface of the seed powder may further provide physical sites for adsorption (Grassi et al., 2024).

P^H is therefore an important parameter controlling the adsorption of MB by both materials. Changes in pH can alter the protonation or deprotonation of functional groups on the biosorbent surface. At suitable pH conditions, negatively charged sites can become more available for interaction with the positively charged MB molecules. Bhattacharjee et al. (2020) emphasized the importance of pH in the biosorption behavior of watermelon rind, while similar pH-dependent behaviors has been reported for other agricultural-waste biosorbents (Rafatullah et al., 2010).

Adsorbent dosage also affects the removal of MB. Increasing the amount of rind or seed powder generally increases the number of available adsorption sites and may therefore increase the percentage removal of the dye. However, the increase in removal does not necessarily continue indefinitely because adsorption sites can become excessive relative to the amount of dye present. An optimum dosage is therefore necessary to obtain effective treatment while avoiding unnecessary use of the biosorbent.

Contact time is another important parameter. During the initial stage of treatment, a large number of active sites are available and adsorption can occur relatively rapidly. As these sites become occupied, the rate of adsorption decreases until equilibrium is reached. Grassi et al. (2024) reported that watermelon seed powder approached adsorption equilibrium after approximately 120 minutes when removing cationic dyes. Similar time-dependent behaviors has been reported for watermelon-rind-based adsorbents.

Particle size is particularly important when raw rind and seed powders are compared. Grinding the biomass into smaller particles increases the exposed surface area and can make more functional groups accessible to the contaminated water. However, extremely fine particles may remain suspended after treatment and make separation difficult. Consequently, using a standardized particle size is important when comparing the adsorption performance of rind and seed powders.

It is also important to distinguish between **raw powders and activated or chemically modified materials**. The high adsorption capacities reported by Garba et al. (2021) and Lee and Choi (2021) were obtained using activated or chemically modified watermelon rind rather than untreated rind powder. Activation and chemical modification can increase surface area, alter pore structure and introduce or expose additional functional groups. Therefore, these adsorption capacities should not automatically be considered representative of untreated *C. lanatus* rind powder.

In contrast, the study by Grassi et al. (2024) provides evidence for the adsorption ability of watermelon seed powder without requiring the same type of activation used in some rind studies. This makes seed powder particularly relevant when evaluating simple, low-cost treatment materials that can be prepared through basic processes such as washing, drying, grinding and sieving.

The comparison between watermelon rind and seed powder is therefore important because the two materials possess different chemical characteristics. Rind is relatively rich in pectin and lignocellulosic components and has demonstrated strong potential for dye adsorption, particularly after activation or chemical modification. Seed powder contains protein, oil, fibre and structural carbohydrates and has also demonstrated an ability to remove cationic dyes. Their different compositions may result in different affinities for MB and may influence their adsorption capacities under identical treatment conditions.

Overall, existing literature indicates that both *C. lanatus* rind and seed powders have potential for the removal of color from contaminated water. The rind has stronger documented evidence for MB adsorption, including studies using activated and chemically modified materials, while recent evidence demonstrates that seed powder can remove other cationic dyes from water. However, direct comparative studies using **untreated watermelon rind and seed powders under the same experimental conditions for methylene blue removal remain limited**. This creates an important research gap and provides justification for comparatively evaluating *C. lanatus* rind and seed powders for the removal of methylene blue from contaminated water.

2.6 Watermelon Rind and Seed Powders for Turbidity Removal

Turbidity in water is mainly caused by suspended and colloidal particles such as clay, silt, organic matter and microorganisms. The removal of these particles commonly involves coagulation, flocculation, adsorption, sedimentation and physical entrapment. In recent years, agricultural wastes have received increasing attention as alternative natural coagulants because they are readily available, inexpensive, biodegradable and environmentally friendly. Among these materials, watermelon (*Citrullus lanatus*) rind and seed powders have potential for water-treatment applications because they contain proteins, polysaccharides, cellulose, hemicellulose, lignin, pectin and other functional compounds that may interact with suspended particles (Eke et al., 2021; Zia et al., 2021).

Watermelon rind is particularly promising for turbidity removal because of its lignocellulosic and pectic composition. The presence of hydroxyl, carboxyl and other functional groups can promote interactions with colloidal particles and contribute to particle destabilization and aggregation. During coagulation–flocculation, these components may reduce the repulsive forces between suspended particles, allowing them to form larger flocs that can subsequently settle from the water. Recent experimental research demonstrated the effectiveness of watermelon-rind powder as a natural coagulant, with optimized treatment conditions achieving

approximately **99.21% turbidity removal**. The study also showed that factors such as pH, coagulant dosage and particle size significantly influenced treatment efficiency (Ben Biyi et al., 2024).

Particle size is an important factor in the application of watermelon rind powder for turbidity removal. Grinding and sieving the rind produces particles with a more uniform size and increases the surface area available for interaction with suspended particles. However, particles that are excessively fine may remain suspended in the treated water and may themselves contribute to turbidity. Therefore, selecting an appropriate and uniform particle size is necessary to achieve effective coagulation while allowing the formed flocs to separate easily during sedimentation.

Watermelon seed powder may also contribute to turbidity removal because its proteins and polysaccharides contain functional groups capable of interacting with suspended and colloidal particles. Proteins can provide amino and carboxyl groups that may participate in charge neutralization and particle aggregation, while structural carbohydrates provide hydroxyl-containing sites that can contribute to surface interactions. The chemical composition of watermelon seeds, which includes considerable amounts of protein, fibre and other structural components, therefore provides a basis for investigating the seeds as a natural treatment material (Eke et al., 2021).

Compared with watermelon rind, however, **less research has directly investigated watermelon seed powder specifically for turbidity removal**. Most recent studies involving watermelon seeds have focused on adsorption of dissolved dyes rather than coagulation of suspended particles. Consequently, the turbidity-removal performance of seed powder cannot be assumed to be equivalent to that of rind powder. Direct experimental comparison is necessary to establish the relative effectiveness of the two materials.

Overall, watermelon rind appears to have stronger documented potential for turbidity removal because its pectic and lignocellulosic components can contribute to coagulation, flocculation and adsorption of suspended particles. Watermelon seed powder also has potential because of its protein and polysaccharide content, but its effectiveness for turbidity removal requires further investigation. Therefore, comparing *C. lanatus* rind and seed powders under the same initial turbidity, dosage, particle size, pH, mixing conditions and settling time can provide useful evidence on their suitability as natural coagulants for contaminated water treatment.

2.7 Possible Mechanisms of Methylene Blue Removal

The removal of MB by watermelon-derived powders can be explained through several possible mechanisms. The first is electrostatic attraction. Methylene blue is a positively charged dye, while some functional groups on biomass surfaces can become negatively charged depending on solution pH. Attraction between the positively charged dye and negatively charged surface sites can therefore promote adsorption.

The second mechanism is hydrogen bonding. Hydroxyl and carboxyl groups present in cellulose, pectin and other biomass components can participate in hydrogen-bond interactions with dye molecules. The presence of these groups on watermelon rind has been demonstrated through spectroscopic characterization.

The third mechanism is physical adsorption and surface interaction. Powdering the biomass increases the available surface area and exposes internal and external active sites. Heterogeneous surface structures, such as the cavities reported for watermelon seed powder, may provide additional locations for dye molecules to attach.

Ion exchange and other interactions may also contribute depending on the chemical composition of the water. In general, adsorption is not necessarily controlled by a single mechanism; several mechanisms can occur simultaneously. For watermelon-rind-based adsorbents, recent studies have reported combinations of electrostatic interaction, hydrogen bonding, electron donor–acceptor interaction and π–π interaction.

The adsorption process is also affected by pH. Changes in pH alter the surface charge of the biosorbent and the chemical form of functional groups. Bhattacharjee et al. (2020) identified pH as one of the most important parameters controlling biosorption using watermelon rind.

2.8 Possible Mechanisms of Turbidity Removal

Turbidity removal by plant-derived powders is different from the removal of dissolved MB because turbidity mainly involves suspended and colloidal particles. A natural coagulant may contain polymeric compounds that destabilize colloids and promote their aggregation into larger flocs.

The coagulation-flocculation mechanism may involve adsorption and charge neutralization. When the natural material is introduced into turbid water, active molecules on the biomass surface can interact with suspended particles. Once particles lose their stability, they can collide and form larger aggregates. These aggregates can subsequently settle, resulting in lower turbidity.

Polymeric components such as pectin and other macromolecules may contribute to bridging between suspended particles. Watermelon rind contains substantial pectin and structural carbohydrates, making it chemically suitable for interactions with particles in water. The high pectin content reported in watermelon rind supports the possibility that these polymers contribute to its coagulation properties. The experimental evidence from Ben Biyi et al. (2024) provides strong support for this mechanism because watermelon rind powder achieved approximately 99.21% turbidity removal under optimized coagulation-flocculation conditions. The same research demonstrated that dose, pH and particle size were important factors controlling the treatment process.

Therefore, the reduction of turbidity observed when using *C. lanatus* rind powder should not necessarily be interpreted as simple adsorption alone. Coagulation, flocculation, adsorption and physical entrapment may all contribute to the observed reduction.

2.9 Comparison between Rind and Seed Powders

The chemical differences between watermelon rind and seed powder suggest that the two materials may perform differently during water treatment.

Watermelon rind has a strong lignocellulosic and pectin-rich structure. Its cellulose, hemicellulose, lignin and pectin provide hydroxyl and carboxyl-containing sites that can interact with dyes and suspended contaminants. Recent research has demonstrated both dye-removal and turbidity-removal capabilities. Therefore, the rind has evidence supporting its application for both major contaminants considered in the present research.

Watermelon seed powder also has treatment potential. Its lignin and cellulose content and heterogeneous surface structure support adsorption of cationic dyes. The study by Grassi et al. (2023) showed that seed powder removed crystal violet and basic fuchsin and could operate in both discontinuous and continuous systems.

However, there is an important difference in the available evidence. For watermelon rind, recent research directly demonstrates turbidity removal and MB adsorption. For watermelon seed powder, recent research demonstrates removal of other cationic dyes, but direct evidence for MB and turbidity removal is comparatively limited. Consequently, it cannot yet be concluded from literature alone that seed powder is superior or inferior to rind powder for MB or turbidity removal.

A comparative experiment using identical conditions is therefore necessary. If both powders are prepared to the same particle size and applied at the same dosage to water with the same initial turbidity and colour level, their treatment performances can be compared more reliably. Such an approach can determine whether the chemical and structural differences between the rind and seed produce measurable differences in removal efficiency.

2.10 Factors Affecting the Performance of *Citrullus lanatus* Powders

Several factors influence the ability of watermelon rind and seed powders to remove contaminants.

2.10.1 Particle size

Particle size affects the available surface area and the accessibility of active sites. Reducing particle size generally increases surface area and may improve contact between the biosorbent and contaminants. However, excessively fine particles can create difficulties in separation after treatment and may themselves contribute to turbidity. Therefore, maintaining a uniform particle size is important when comparing treatment performance.

2.10.2 Adsorbent or coagulant dose

Increasing the amount of biomass generally increases the number of available active sites. However, beyond an optimum dose, removal efficiency may not increase proportionally because the contaminant concentration becomes insufficient to occupy all available sites. The 2024 watermelon-rind turbidity study identified coagulant dose as one of the important factors affecting removal.

2.10.3 pH

pH affects surface charge and the ionization of functional groups. For cationic dyes such as MB, the charge of the biomass surface can strongly influence adsorption. The review by Bhattacharjee et al. (2020) identified pH as one of the most important parameters affecting watermelon-rind biosorption.

2.10.4 Contact time

The interaction between contaminants and biosorbent normally increases with contact time until equilibrium is approached. Grassi et al. (2023) reported equilibrium within approximately 120 minutes for the removal of cationic dyes using watermelon seed powder.

2.10.5 Initial contaminant concentration

The initial concentration provides the driving force for mass transfer between water and the adsorbent surface. At low concentrations, a large proportion of contaminants may be removed because sufficient active sites are available. At higher concentrations, the active sites can

become saturated, resulting in lower percentage removal unless the adsorbent dose is increased.

2.10.6 Water matrix and competing substances

The presence of salts, dissolved organic matter and other contaminants can influence adsorption by competing for active sites. This is important for real contaminated water because its chemical composition is more complex than a synthetic solution. Grassi et al. (2023) demonstrated that seed powder could still operate in a synthetic mixture containing dyes and inorganic salts, although the performance was lower than in simpler systems.

2.10.7 Environmental and Practical Advantages

The use of *C. lanatus* rind and seed powders for water treatment has several potential advantages. First, the materials are derived from agricultural and food waste, meaning that their use can contribute to waste valorization and circular-economy principles. Instead of treating rind and seeds as unwanted wastes, they can be converted into useful water-treatment materials.

Second, these materials are renewable and biodegradable. Their availability may also make them particularly attractive in areas where commercial activated carbon or specialized treatment chemicals are expensive or difficult to obtain.

Third, preparation of untreated powders can be relatively simple. Washing, drying, grinding and sieving can produce a material suitable for laboratory-scale treatment without necessarily requiring chemical activation. This is important because chemical activation may increase adsorption performance but also increases preparation cost and may introduce additional chemicals into the process.

Fourth, watermelon rind has demonstrated potential for both coagulation-flocculation and adsorption. The ability to address turbidity and dissolved colour using the same agricultural waste material could be useful in developing low-cost treatment approaches. Recent evidence of approximately 99.21% turbidity removal under optimized conditions demonstrates the potential of rind powder as a natural coagulant.

2.10.8 Research Gap

Although considerable research has been conducted on agricultural waste as biosorbents, important gaps remain regarding the direct comparison of watermelon rind and seed powders. Much of the recent literature has investigated watermelon rind for individual pollutants, particularly heavy metals and dyes, while seed powder research has focused mainly on selected cationic dyes.

For watermelon rind, evidence is available for MB adsorption and, more recently, for turbidity removal through coagulation-flocculation. For watermelon seeds, evidence demonstrates removal of crystal violet and basic fuchsin, but there is less direct evidence concerning MB and turbidity under the same experimental conditions.

Another important gap concerns the comparison of untreated rind and seed powders. Many studies use activated or chemically modified watermelon rind. Although such modifications can substantially improve adsorption capacity, they do not necessarily represent the performance of simple, untreated powders that would be easier and cheaper to apply in low-resource settings.

There is also limited research comparing the two parts of the same fruit while controlling important experimental parameters such as particle size, adsorbent dose, initial turbidity, initial color, contact time and sample volume. Without such controlled comparisons, it is difficult to determine whether the rind or seed provides better overall treatment performance.

The present study therefore addresses this gap by comparatively evaluating *C. lanatus* rind and seed powders for the removal of turbidity and methylene blue from contaminated water. By preparing the powders at a controlled and uniform particle size and exposing them to water samples with defined initial turbidity and colour levels, the study can provide a more direct comparison of their treatment abilities.

III. METHODOLOGY

3.1 Preparation of Methylene Blue Color Standards and Contaminated Water Samples

Methylene blue was used to prepare water samples with different color levels for the treatment experiment. A stock solution was prepared by accurately weighing methylene blue powder and dissolving it in distilled water. The solution was transferred into a volumetric flask and diluted to the required volume to obtain a homogeneous stock solution. It was then stored in a clean, covered container and protected from direct light.

Different color levels were prepared from the stock solution by dilution using distilled water. The selected color levels were **15, 20, 30, 40 and 50 TCU**. The required volumes were calculated using the dilution equation:

$$C_1V_1 = C_2V_2$$

where C_1 and V_1 are the concentration and volume of the stock solution, while C_2 and V_2 represent the required

concentration and final volume, respectively. Each prepared solution was thoroughly mixed before measurement.

3.2 Determination of TCU

The color of the prepared samples was measured using a calibrated spectrophotometer instrument. Distilled water was used as the blank before measuring the samples. The standards were measured starting from the lowest color level to the highest: **15, 20, 30, 40 and 50 TCU**. The instrument readings obtained from these standards were used to establish a calibration curve relating the instrument response to TCU.

After preparing the methylene blue solutions at the required color levels, distilled water was used as the base water for preparing the test samples. The color of the distilled water was first measured using a spectrophotometer, and the result showed **0 TCU**, confirming that it was suitable as the blank or initial water sample.

Afterwards, the distilled water was mixed with the prepared methylene blue solution in appropriate proportions to obtain **100 mL of water** at each required color level, namely **15, 20, 30, 40 and 50 TCU**. Each sample was thoroughly mixed to ensure uniform distribution of the methylene blue and then measured using the spectrophotometer to confirm the required TCU level before being used for the treatment experiment.

3.3 Storage of Contaminated Water Samples

After preparation and measurement, the contaminated water samples were transferred into clean, labelled containers according to their color levels (**15, 20, 30, 40 and 50 TCU**). The containers were tightly closed to prevent contamination and evaporation and were protected from direct sunlight. The samples were stored under appropriate laboratory conditions until treatment.

Before treatment, each sample was gently mixed and its initial TCU was measured again to confirm the starting color level. These initial values were used as baseline values for comparison with the TCU values obtained after treatment.

3.4 Preparation and Storage of Water Samples with Different Turbidity Levels

Water samples with turbidity levels of **50, 100, 150, 200 and 250 NTU** were prepared for the treatment experiment. For each turbidity level, **100 mL of water sample** was prepared. The required amount of turbidity-producing material was added gradually to the water and thoroughly mixed until the desired turbidity level was obtained.

The turbidity of each **100 mL sample** was measured using a turbidity meter and adjusted until the required values of **50, 100, 150, 200 and 250 NTU** were achieved. Each sample was then transferred into a clean, labelled container, tightly covered, and stored under suitable laboratory conditions until it was required for the treatment experiment. Before treatment, each sample was mixed gently and its turbidity was measured again to confirm the initial value.

3.5 Preparation of *Citrullus lanatus* Rind Powder for Water Treatment

The rind of *Citrullus lanatus* was prepared for use as a natural material for water treatment. Fresh watermelon rinds were collected and washed thoroughly with clean tap water to remove soil, dirt and other visible impurities. The rinds were then rinsed several times with distilled water to minimize the presence of substances that could interfere with the treatment process. The green outer skin was retained as part of the rind material, while unwanted portions were removed.

The cleaned rinds were cut into small pieces to increase the surface area and facilitate uniform drying. The pieces were spread in a clean tray and dried under controlled conditions until they became completely dry. Proper drying was important to reduce the moisture content and prevent microbial growth during storage. After drying, the rind pieces were crushed using a clean grinder to produce a fine powder.

The powdered *Citrullus lanatus* rind was then passed through a sieve to obtain particles of a uniform size. A particle size of approximately **300µm** was selected for the treatment experiment. The ground material was continuously sieved, and particles retained on the sieve were re-ground and sieved again until most of the material passed through the selected sieve. This process ensured that the final powder had a relatively uniform particle size.

The use of a uniform particle size was important because particle size can influence the efficiency of water treatment. Smaller and relatively uniform particles provide a more consistent surface area for interaction with contaminants in the water. If particles of different sizes were used, the surface area available for adsorption would vary considerably, which could result in inconsistent treatment performance and make comparison between experiments difficult. Therefore, sieving was carried out to ensure that the *Citrullus lanatus* rind powder used in all treatment experiments had approximately the same particle size.

After sieving, the prepared powder was collected and stored in a clean, dry, airtight container until it was

required for the water treatment experiments. The container was properly labelled and kept in a dry place to prevent moisture absorption and contamination. The same particle size was maintained throughout the experiments to ensure that differences in treatment performance were mainly associated with the experimental treatment conditions rather than variations in the physical size of the rind powder.



Fig 1: Prepared Watermelon rind Powder with the Required Particle Size for the Study.

3.5 Preparation of *Citrullus lanatus* Seed Powder

The seeds of *Citrullus lanatus* (watermelon) were prepared for use as a natural material in the water treatment experiment. Mature watermelon fruits were obtained and the seeds were separated from the fruit pulp manually. The collected seeds were thoroughly washed with clean water to remove adhering pulp and other visible impurities. They were then rinsed with distilled water to minimize contamination from external materials.

After washing, the seeds were spread evenly on a clean tray and dried under suitable conditions until they were completely dry. Drying was necessary to reduce the moisture content of the seeds, prevent microbial growth, and make them easier to grind into powder. The dried seeds were then ground using a clean laboratory grinder until a fine powder was obtained.

The resulting powder was sieved using a **300 µm sieve** to obtain particles of relatively uniform size. The material that did not pass through the sieve was collected, ground again, and passed through the same sieve until the required particle size was obtained. The sieving process was repeated to minimize the presence of larger particles and ensure that the final seed powder used in the experiment had approximately the same particle size.

Maintaining a uniform particle size was important because particle size affects the surface area available for interaction with contaminants in water. Smaller particles generally provide a greater surface area, while larger particles provide a smaller surface area per unit mass. If different particle sizes were used in the treatment experiments, the amount of surface area available for adsorption or other treatment interactions would vary, potentially affecting the treatment efficiency and making comparison between samples less reliable. Therefore, using a relatively uniform particle size helped to maintain consistent experimental conditions.

After sieving, the *Citrullus lanatus* seed powder was collected in a clean, dry and airtight container. The container was properly labelled and stored in a dry place until it was used for the water treatment experiments. The same sieved particle size was maintained throughout the experiment so that variations in treatment performance would be attributed mainly to the treatment conditions rather than differences in the physical size of the seed particles.



Fig.2: Prepared Watermelon Seed Powder with the Required Particle Size for the Study.

IV. RESULTS AND DISCUSSION

4.0 Physical Characteristics of the Prepared Powders

The prepared watermelon rind powder and seed powder were examined based on their physical appearance and suitability for laboratory treatment.

Table 1: Physical characteristics of Citrullus lanatus rind and seed powders

Characteristic	Rind powder	Seed powder
Initial material	Watermelon rind	Watermelon seeds
Preparation method	Washing, drying, grinding and sieving	Washing, drying, grinding and sieving

Selected particle size	300 µm	300 µm
Physical appearance	Dry, fine, and slightly granular powder	Dry, powdered material with visible small particle.
Color of powder	Light green, pale green, or yellowish-green	Light brown
Storage condition	Dry, airtight container	Dry, airtight container

The preparation procedure produced two powdered materials intended for use in water-treatment experiments. The use of a similar particle size was important for maintaining consistency between the experimental treatments.

Any observed differences in powder color, texture or physical structure may reflect differences in the chemical composition and physical characteristics of the rind and seeds.

Watermelon rind is primarily characterized by structural carbohydrates and pectic materials, whereas watermelon seeds contain proteins, lipids and structural carbohydrates. These compositional differences may influence the interaction of the two materials with suspended particles and dissolved dye molecules.

However, physical appearance alone cannot establish the adsorption capacity or coagulation efficiency of either material. Their actual performance must be determined from the experimental measurements of turbidity and methylene blue removal.

4.1 Turbidity Removal by Watermelon Rind Powder

The effectiveness of watermelon rind powder in removing turbidity was evaluated by measuring the turbidity of each water sample after treatment and comparing it with the corresponding initial turbidity.

The percentage turbidity removal was calculated using the following equation:

$$\text{Turbidity Removal (\%)} = \frac{T_i - T_f}{T_i} \times 100\%$$

Where:

- Ti = initial turbidity before treatment (NTU).
- Tf = final turbidity after treatment (NTU).

Table 2: Below shows the results of the first experiment conducted using watermelon rind powder for turbidity removal.

Initial turbidity (NTU)	**Final turbidity (NTU)**	**Turbidity removed (NTU)**	**Removal efficiency (%)**	**Time (hours)**
50	37.50	12.50	25	2
100	57.50	42.50	42.5	4
150	15.03	134.97	89.98	8
200	8.00	192.00	96	10
250	26.58	223.75	89.37	12

A decrease in turbidity after treatment would indicate that suspended or colloidal particles had been removed from the measurable water phase. This reduction may occur through coagulation, flocculation, sedimentation, adsorption or physical entrapment of particles.

Watermelon rind contains pectic and lignocellulosic components that may contribute to interactions with suspended particles. These components contain functional groups, including hydroxyl and carboxyl groups, which may participate in interactions between the treatment material and particles in water.

During treatment, interactions between suspended particles and components released from the rind may promote the formation of larger aggregates. These aggregates may settle under gravity, resulting in a reduction in the turbidity of the water.

However, the extent of turbidity removal depends on several factors, including powder dosage, initial turbidity, pH, mixing conditions, contact time, and settling time. The performance of the rind powder should therefore be interpreted in relation to the actual experimental conditions. The most effective initial turbidity level and treatment conditions should be identified from the measured results rather than assumed in advance.

Furthermore, the experimental findings indicate that the turbidity removal efficiency of the rind powder is strongly influenced by contact time. When the dosage remains constant, the removal efficiency may initially increase as the contact time increases, allowing more time for the active components of the powder to interact with suspended particles and promote coagulation and flocculation. However, after approximately 10 hours, the

removal efficiency may decrease. This reduction could be attributed to the possible destabilization or breakdown of previously formed flocs, the re-suspension of settled particles, or changes in the interactions between the natural coagulant components and suspended particles over time. Other possible explanations include the saturation of available binding sites and the release of soluble organic compounds from the rind powder into the water, which may contribute to an increase in measured turbidity. Therefore, prolonged contact time does not necessarily result in higher turbidity removal efficiency.

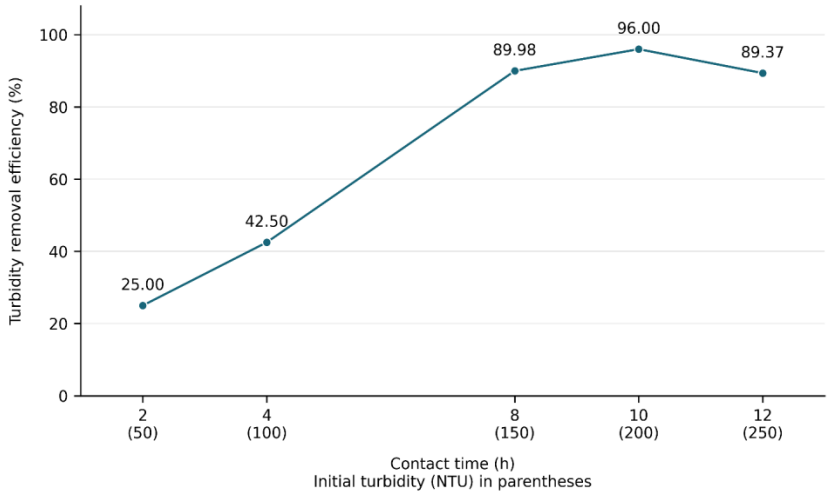

Fig.1: Graph 1 Showing the Effectiveness of Watermelon Rind Powder in Turbidity Removal at Different Contact Times Using a Constant Adsorbent Dosage.

4.2 Turbidity Removal by Watermelon Seed Powder

Watermelon seed powder was evaluated using the same initial turbidity levels and, where applicable, the same treatment conditions used for the rind powder. The percentage turbidity removal was calculated using the same equation applied to the rind powder.

Table 3: Below shows the results of the second experiment conducted using watermelon seed powder for turbidity removal.

Initial turbidity (NTU)	Final turbidity (NTU)	Turbidity removed (NTU)	Removal efficiency (%)	Time (hours)
50	32.50	17.50	35	2
100	47.50	52.50	52.5	4
150	12.03	137.97	91.98	8
200	0.40	199.60	99.8	10
250	56.25	193.75	77.5	12

Watermelon seeds contain proteins and structural carbohydrates that may contribute to interactions with suspended particles. Depending on the chemical characteristics of the water and the surface properties of the seed powder, these components may contribute to particle aggregation and subsequent sedimentation.

The experimental results showed that watermelon seeds achieved a higher turbidity removal efficiency of 99.8.%, compared with 96% for watermelon rind powder. This difference may be attributed to variations in the chemical composition and coagulation properties of the two materials. Watermelon seeds may contain proteins and other organic compounds capable of promoting coagulation and flocculation by neutralizing the electrical charges of suspended particles, thereby encouraging them to aggregate into larger flocs that can settle more easily. In contrast, watermelon rind powder contains structural

components such as cellulose, hemicellulose, and pectin, which may contribute to particle adsorption and bridging.

Furthermore, the results indicated that turbidity removal efficiency decreased after approximately 10 hours of treatment. This decline may be explained by several possible mechanisms. First, previously formed flocs may become unstable and break apart over prolonged contact periods, releasing smaller suspended particles back into the water. Second, soluble organic compounds released from the seeds or rind powder may increase the amount of fine suspended or colloidal material in the treated water, potentially contributing to increased turbidity. Third, prolonged contact may alter interactions between the coagulant components and suspended particles, reducing the stability of the aggregates formed during treatment. If the treated water is disturbed, settled particles may also become resuspended.

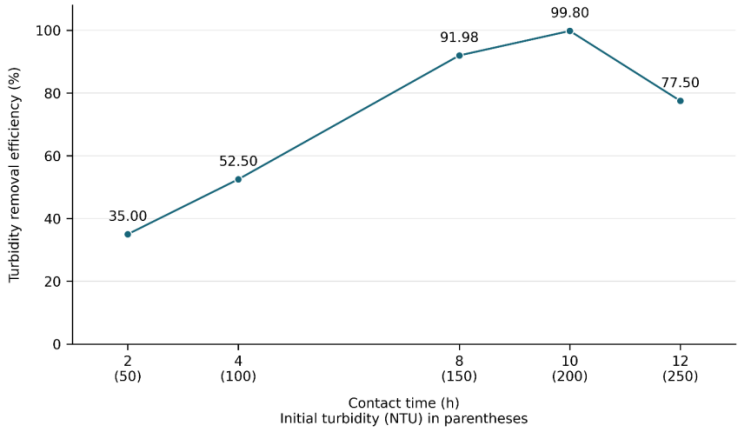

Fig. 2: Graph 2 Showing the Effectiveness of Watermelon Rind Powder in Turbidity Removal at Different Contact Times Using a Constant Adsorbent Dosage.

4.3 **Methylene Blue Removal by Watermelon Seed Powder**

Table 4 : Showing the Effectiveness of Watermelon Rind Powder in Colour Removal from Water at Different Contact Times Using a Constant Adsorbent Dosage.

Initial dye concentration (TCU)	**Final dye concentration (TCU)**	**Dye removed (TCU)**	**Removal efficiency (%)**	**Time(hours)**
10	7	3.00	30	2
20	12.82	7.18	35.9	4
30	17.16	12.84	42.8	8
40	12.44	27.56	68.9	10
50	5.00	45.00	90	12

Watermelon rind powder may achieve higher dye removal efficiency at contact times exceeding 10 hours because dye removal mainly occurs through adsorption, a process that may require more time for dye molecules to attach to active sites on the rind powder. The rind contains cellulose, hemicellulose, pectin, and lignin, which provide functional groups such as hydroxyl (-OH) and carboxyl (-COOH) groups that can interact with dye molecules through electrostatic attraction, hydrogen bonding, and other adsorption mechanisms. Longer contact time allows more dye molecules to interact with these sites, potentially increasing dye removal.

In contrast, turbidity removal mainly involves coagulation, flocculation, and sedimentation of suspended particles. As contact time increases to approximately 12 hours, the removal efficiency may decrease because previously formed flocs can break apart, settled particles may become resuspended, or soluble organic compounds released from the rind powder may increase the measured turbidity. Therefore, longer contact time may enhance dye

adsorption while reducing turbidity removal efficiency, as the two processes involve different mechanisms.

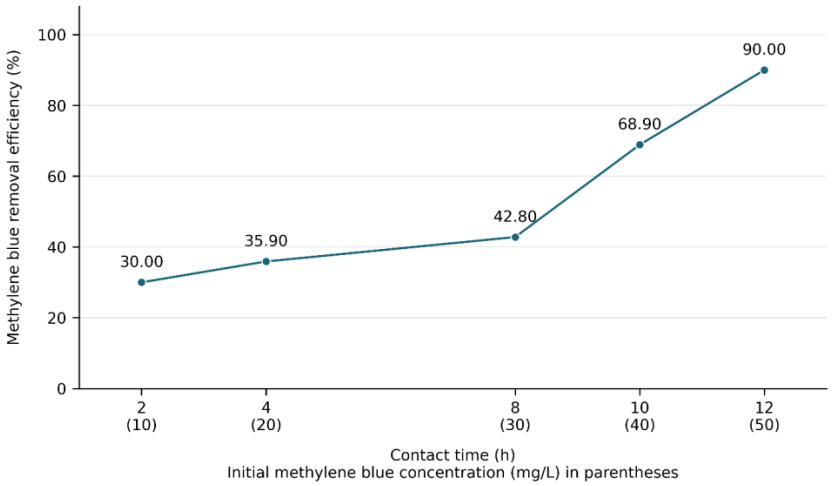

Fig.3: Graph 3 Methylene blue removal efficiency of watermelon rind powder under the tested treatment conditions. Corresponding initial dye concentrations are shown in parentheses.

4.4 Methylene Blue Removal by Watermelon Seed Powder

Watermelon seed powder was evaluated for methylene blue removal using the same analytical method and comparable experimental conditions applied to the rind powder.

The initial and final dye concentrations were used to calculate percentage removal efficiency.

Table 5: Methylene blue removal efficiency of watermelon seed powder

Initial dye concentration (TCU)	Final dye concentration (TCU)	Dye removed (TCU)	Removal efficiency (%)
10	6.00	4	40
20	10.84	9.156	45.78
30	12.327	17.673	58.91
40	5.27	34.76	86.9
50	3.60	46.40	92.8

Watermelon seeds achieved a higher dye removal efficiency of 92.8%, compared with 90% for watermelon rind powder. This difference may be attributed to variations in their chemical composition. Watermelon seeds contain proteins and lipids that may facilitate dye adsorption through hydrophobic interactions and interactions between functional groups and dye molecules. They may also contain amino, carboxyl, and hydroxyl groups that contribute to dye binding. In contrast, watermelon rind contains cellulose, hemicellulose, pectin, and lignin, which provide hydroxyl and carboxyl groups for dye adsorption. However, differences in the availability and accessibility of these active sites may explain the slightly lower removal efficiency of the rind powder.

Furthermore, increasing contact time did not reduce dye removal efficiency as observed in turbidity removal. This may be because dye removal primarily involves adsorption, whereby dye molecules attach to active sites on the seed or rind powder over time. Once adsorbed, the dye molecules may remain bound to the material under the experimental conditions. In contrast, turbidity removal involves coagulation, flocculation, and sedimentation, which may be affected by floc destabilization, particle resuspension, or the release of soluble organic compounds during prolonged treatment. Therefore, dye removal may remain stable or improve with longer contact time, whereas turbidity removal may decrease after prolonged treatment.

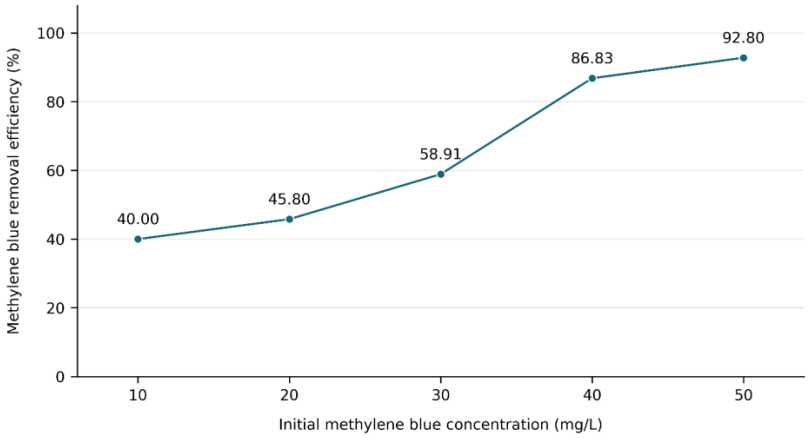

Fig.4: Graph 4 Methylene blue removal efficiency of watermelon seed powder under the tested treatment conditions. Corresponding initial dye concentrations are shown in parentheses.

Note: In each experiment, either watermelon (*Citrullus lanatus*) rind powder or seed powder was added at a fixed dosage of 20 mg per treatment.

Effect of Treatment Time on Turbidity and Methylene Blue Removal

The experimental results showed that watermelon rind and seed powders were effective in removing turbidity and methylene blue from water. Watermelon seed powder achieved a higher turbidity removal efficiency of 98.7%, compared with 96% for rind powder. Similarly, seed powder achieved a higher methylene blue removal efficiency of 92.8%, compared with 90% for rind powder. These differences may be attributed to variations in their chemical composition. Watermelon seeds contain proteins that may promote coagulation by neutralizing particle charges, while their functional groups may facilitate dye adsorption. In contrast, watermelon rind contains cellulose, hemicellulose, pectin, and lignin, whose hydroxyl and carboxyl groups may contribute to the adsorption of dye molecules and interactions with suspended particles.

Treatment time influenced turbidity removal differently from methylene blue removal. Turbidity removal efficiency increased up to 10 hours, reaching 96% for rind powder and 98.7% for seed powder, before decreasing to 89.5% and 77.5%, respectively, after 12 hours. This decline may result from floc destabilization, particle resuspension, or the release of soluble organic compounds from the powders into the water.

In contrast, methylene blue removal remained effective at longer treatment times, potentially because adsorption allows dye molecules to bind to active sites on the powders. The functional groups present in both materials may facilitate these interactions, allowing dye removal to continue until adsorption sites approach saturation. Unlike turbidity removal, which depends largely on coagulation, flocculation, and sedimentation, dye removal primarily involves adsorption. Therefore, prolonged treatment may maintain or improve dye removal without necessarily improving turbidity removal.

4.5 Comparative Discussion of Turbidity and Methylene Blue Removal

The performance of watermelon rind powder and seed powder was compared in terms of turbidity and methylene blue removal. Turbidity removal mainly involves coagulation, flocculation, and sedimentation, while methylene blue removal primarily depends on adsorption and interactions between dye molecules and the powder surfaces.

Watermelon rind contains pectin and lignocellulosic materials, whereas watermelon seeds contain proteins, lipids, and carbohydrates. These compositional differences may influence their pollutant removal capacities.

The better-performing material for each parameter was determined from the experimental results. One powder may be more effective in turbidity removal, while the other may perform better in methylene blue removal. The two parameters were evaluated separately using their respective removal efficiencies.

4.6 Statistical Analysis of the Results

Statistical analysis was used to evaluate and compare the performance of watermelon rind powder and watermelon seed powder in removing turbidity and methylene blue

from water. The analysis focused on removal efficiency, changes in contaminant concentration, and the influence of treatment time on the performance of the two materials.

The removal efficiency of each powder was calculated using the initial and final turbidity or dye concentration. The percentage removal was determined using the following equation:

$$\text{Removal Efficiency (\%)} = \frac{C_i - C_f}{C_i} \times 100\%$$

Where:

- Ci = initial turbidity or dye concentration.
- Cf = final turbidity or dye concentration.

For turbidity measurements, the concentrations were expressed in nephelometric turbidity units (NTU), whereas methylene blue concentrations were expressed in mg/L.

4.7 Statistical Comparison of Turbidity Removal

The experimental results indicated that both watermelon rind powder and watermelon seed powder reduced turbidity under the investigated treatment conditions. The highest recorded turbidity removal efficiencies were 96% for watermelon rind powder and 99.8% for watermelon seed powder at 10 hours.

These results suggest that watermelon seed powder performed better than rind powder in turbidity removal under the conditions represented by the reported measurements. The difference may be associated with variations in the chemical composition and surface properties of the two materials. Proteins and other organic components in watermelon seeds may promote coagulation and flocculation, while pectic and lignocellulosic components in watermelon rind may contribute to particle adsorption and bridging.

At 12 hours, turbidity removal efficiency decreased to 89.5% for rind powder and 77.5% for seed powder. This reduction suggests that extending treatment time did not necessarily improve turbidity removal. Possible explanations include floc destabilization, particle resuspension, and the release of fine particles or soluble organic matter from the powders.

However, these explanations remain possible mechanisms rather than experimentally confirmed causes. Additional measurements would be required to establish the factors responsible for the observed decline.

4.8 Statistical Comparison of Methylene Blue Removal

The methylene blue removal results also demonstrated that both powders could reduce dye concentrations in water. The highest reported removal efficiencies were 90% for watermelon rind powder and 92.8% for watermelon seed powder at an initial dye concentration of 50 mg/L.

Watermelon seed powder therefore showed a slightly higher reported maximum dye removal efficiency than watermelon rind powder. This difference may be related to variations in the availability of surface functional groups and the accessibility of adsorption sites.

Watermelon rind contains cellulose, hemicellulose, pectin, and lignin, which provide functional groups that may interact with dye molecules. Watermelon seeds contain proteins and other organic components that may also contribute to interactions with methylene blue.

Unlike turbidity removal, which mainly involves particle aggregation and sedimentation, methylene blue removal primarily involves adsorption onto available binding sites. These differences may explain why the removal patterns for turbidity and dye were not identical.

Nevertheless, the reported maximum efficiencies alone are insufficient to establish that one powder is statistically superior to the other. A reliable statistical comparison requires replicate measurements under comparable experimental conditions.

4.9 Instruments Used for Measurement and Verification

Several laboratory instruments were used to measure water quality parameters and evaluate the performance of watermelon rind powder and watermelon seed powder in removing turbidity and methylene blue from water. The instruments supported the collection of quantitative data and improved the reliability of the experimental results.

(i) A **digital turbidity meter (nephelometer)** was used to measure the turbidity of water samples before and after treatment. The instrument measured light scattered by suspended particles in the samples and expressed the results in nephelometric turbidity units (NTU). The initial and final turbidity readings were compared to determine the amount of turbidity removed and calculate the percentage removal efficiency. The measurements provided the basis for comparing the performance of watermelon rind powder and seed powder in reducing suspended particles.

(ii) A **UV–Visible spectrophotometer** was used to determine the concentration of methylene blue in water samples before and after treatment. The instrument measured the absorbance of the dye at an appropriate wavelength, and the concentrations were

determined using a calibration curve prepared from standard methylene blue solutions. The difference between the initial and final dye concentrations was used to calculate the amount of dye removed and the percentage removal efficiency. These measurements provided quantitative evidence of the ability of the two powders to remove dissolved methylene blue from water.

(iii) An **analytical balance** was used to measure the mass of watermelon rind powder and seed powder to ensure accurate and consistent quantities were used during the experiments. A **digital pH meter** was used to measure the pH of the water samples because pH could influence the surface charge of the powder materials and their interactions with suspended particles and dye molecules. Monitoring these parameters helped maintain consistency during the experimental procedures.

(iv) A **laboratory shaker or mechanical stirrer** was used to mix the powder materials with the water samples under controlled conditions, where applicable. A **stopwatch or digital timer** was used to record the treatment contact time. Maintaining consistent mixing conditions and accurately recording contact time helped ensure that differences in removal efficiency were evaluated under comparable experimental conditions.

Overall, the measurements obtained using these instruments were used to calculate and compare turbidity and methylene blue removal efficiencies for watermelon rind powder and seed powder. Proper calibration, appropriate operating procedures, and consistent measurement conditions were important for obtaining reliable results. The recorded measurements provided the quantitative basis for assessing the treatment performance of the two materials.

4.9.1 Implications of the Findings for Water Treatment

This study contributes to the investigation of watermelon rind and seed powders as potential low-cost materials for water treatment. By evaluating their effectiveness in removing turbidity and methylene blue, the study provides information on the potential use of agricultural waste as an alternative or supplementary material in water purification.

The use of watermelon residues offers an opportunity to convert agricultural waste into valuable environmental resources. Instead of disposing of watermelon rinds and seeds, these materials can be collected, dried, ground, and investigated for their ability to remove contaminants from water. This approach may help reduce agricultural waste, promote recycling, and support sustainable waste management practices.

Furthermore, agricultural waste may provide a locally available and potentially affordable source of water-treatment materials, particularly in communities where conventional treatment materials are expensive or difficult to obtain. The use of these residues could also encourage the development of environmentally friendly treatment technologies while reducing dependence on commercially produced materials.

The findings may help identify whether watermelon rind powder or seed powder has greater potential for turbidity removal or methylene blue adsorption under the investigated conditions. This information could support further research into natural coagulants and biosorbents derived from agricultural residues.

However, the practical application of these materials depends on their treatment efficiency, dosage, preparation costs, contact time, and ease of separation from treated water. Additional investigations are also necessary to determine whether the powders introduce organic matter, microorganisms, or fine particles into the water.

Importantly, the removal of turbidity and methylene blue alone does not establish that the treated water is safe for drinking. Further filtration, appropriate treatment, and microbiological and chemical testing would be required before considering any drinking-water application.

Overall, this study highlights the potential environmental and economic value of transforming watermelon agricultural waste into useful water-treatment materials. It supports the principles of waste valorization, resource recovery, and sustainable water management while providing a basis for further research into affordable and environmentally responsible water-treatment technologies.

V. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study comparatively assessed the effectiveness of watermelon (*Citrullus lanatus*) rind and seed powders in removing turbidity and methylene blue from contaminated water at different contact times. The findings demonstrated that both materials had the potential to reduce turbidity and methylene blue concentrations under the experimental conditions. Watermelon seed powder achieved a maximum turbidity removal efficiency of 99.8%, compared with 96% for rind powder. Similarly, seed powder achieved a

maximum methylene blue removal efficiency of 92.8%, compared with 90% for rind powder.

The results indicated that contact time influenced the removal efficiency of both materials. Turbidity removal increased up to 10 hours before decreasing at 12 hours, whereas methylene blue removal generally increased with contact time. These differences may be attributed to the different mechanisms involved in removing suspended particles and dissolved dye molecules. The findings suggest that watermelon rind and seed powders are promising, low-cost materials for further investigation in water treatment. Their utilisation could also contribute to agricultural-waste reduction and environmental sustainability. However, further studies are required to establish the reproducibility of the results and assess the quality and safety of treated water.

5.2 Recommendations

Based on the findings, the following recommendations are made:

1. **Optimization of treatment conditions:** Further studies should investigate different powder dosages, pH values, particle sizes and contact times to determine the optimum conditions for turbidity and methylene blue removal.
2. **Further comparative studies:** Experiments should be repeated to establish the consistency and statistical significance of the differences between watermelon rind and seed powders.
3. **Water quality assessment:** Additional analyses, including microbial testing, pH measurement and assessment of residual organic matter, should be conducted to determine the quality of treated water. The powders should not be considered sufficient for producing safe drinking water without appropriate additional treatment and verification.
4. **Practical application:** Further research should evaluate the performance of both materials using real wastewater and assess the feasibility of scaling up the treatment process.
5. **Agricultural-waste utilization:** Communities and researchers should explore the potential of converting discarded watermelon rinds and seeds into useful water-treatment materials as a means of promoting waste valorization and sustainable environmental management.

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