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Adaptability and stability of nine onion (*Allium cepa* L.) varieties for bulb yield in off-season cultivation at the Guinean high savannah zone of Cameroon

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***Abstract*— *The sensitivity of onions (Allium cepa L.) genotypes to environmental changes significantly influences yield and quality, necessitating adaptability studies across diverse locations. In Cameroon, onions are produced mainly in the sudano-sahelian regions. They are grown worldwide at different latitudes between 10°S and 65°N and are a very important source of food and income for rural populations. The current study investigates how the genotype by environment interaction (GEI) affects the bulb yield of nine onions varieties grown in diverse conditions at the Guinean high savannah zone of Cameroon, in order to contribute to food security and local development.The analysis of variance through Statgraphics Plus 5.0 program was used to study the variability of yield of the nine onions varieties grown on four environmental conditions in two locations, Marza and Bini, during dry season 2024 and 2025. Employing a split-split plot design with three replications, with genotypes as the main factor and environments as sub-factor, we assessed GEI effects on onion yield using GEST 98 software and identified adaptable and stable varieties. The results showed that bulb yield varied significantly with genotypes and environments and ranged from 23.82 to 87.23 t.ha. Three varieties namely Safari, El Kara and Violet de Galmi exhibited the highest bulb yield while lowest yields were noted on Ares and Red Creole.The combination of organic chiken manure and mineral NPK fertilize (CM+NPK) appeared as the best environement. The site of Marza and the growing season 2024 offered best conditions for onions cultivation comparing to the site of Bini and growing season 2025. Stability indices and AMMI analyses showed that varieties Ares, Red Creole and Prema were the most stable but with poor yield performance, while the other genotypes were with specific adaptability. The sudy concluded that varieties Safari, El kara and Violet Galmi could be selected as potential candidates for developing onion cultivation in the Guinean high savanna zone of Cameroon.*

***Keywords*— Allium cepa L., adaptability, stability, Guinean high savannas, off-season, Cameroon.**

I. INTRODUCTION

Onion (*Allium cepa* L.) is among the oldest cultivated crops and one of the most economically important vegetables worldwide. The onion is a bulbous crop consumed on daily basis in fresh as well as dried form, throughout the world. It belongs to the family Alliaceae and genus *Allium*. It shows more variation in eastern Mediterranean countries like Tajikistan, Turkmenistan to Pakistan and India. Central Asia is considered its center of origin (Jokanovic *et al.*, 2016). In India, it is an integral part of daily cuisine and is often referred to as the 'Queen of the Kitchen' (Biswas *et al.*,2020). Onions are one of the most widely traded raw vegetables in the world due to their relatively long shelf life (Cattivelli *et al.*, 2021). They have dietary, nutritional, and therapeutic benefits (Bianchini and Vainio, 2001). On average, a person consumes roughly 10 kilograms of onions per year and can be eaten raw, cooked, pickled, or powdered (Cattivelli *et al*., 2021). The growing demand for onion is driven due to its nutritional value and health-promoting constituents, including essential minerals and vitamins (Gupta *et al.,*2025a). Historically, onions have also played an important role in traditional medicine, being recognized for their therapeutic properties in treating fever, bronchitis, and cardiovascular ailments, as well as for their diuretic, digestive, and lipid-lowering effects (Gupta *et al.,*2025a). Therapeutically, various studies have shown that regular consumption of raw onions plays a role in blood clotting and the prevention of various diseases as certain cardiovascular diseases, and cancers (Bianchini and Vainio, 20012; Graf *et al*., 2005).

Onion marketable yield can be greatly impacted by climate and environmental conditions (Gupta *et al.,* 2024). Varieties that thrive in one environment may not necessarily flourish in other environments or in a range of climates (Brdar-Jakanovic *et al*., 2012). The genotype-by-environment interaction (GEI) is an important phenomenon in plant breeding which defines the differential response of genotypes to various environments as multiple environment trials (Brancourt-Hulmel *et al*., 1997; Annichiarico, 2002; Gupta *et al*., 2024). The cultivation of onions is widespread throughout Africa, with farmers producing the crop across diverse agroecological zones and climatic conditions (Atnafu, 2023). The total onion production in Africa was 14.9 million tons (FAOSTAT, 2023). The main onion-producing countries in Africa are Egypt, Algeria, Sudan, Nigeria, Niger, and Morocco (FAOSTAT, 2023). In the Central African sub-region in particular, annual onion production was about 90000 tons with an average yield of 10 t.ha (FAOSTAT, 2023). In Cameroon, onions are produced mainly in the sudano-sahelian regions, and unfortunately their expansion at the national level is statistically low (Cathala *et al*., 2023). Production in the North and Far North regions of Cameroon accounts for 85% of national production. The diversity of agroecological zones in Cameroon poses an adaptability problem for certain crops, notably onions in the Guinean high savannah zone. In Cameroon, the onion sector is an agricultural sector that brings together the various actors and accounts for most of the national production, with a production of 390.000 tons (Cathala *et al*., 2023). The onion sector is an economic powerhouse that brings together various stakeholders and accounts for most of the national production (Cathala *et al*., 2003). The predominance of market gardening in Adamawa, is focused on tomatoes, potatoes, sweet potatoes, peppers, and eggplants. The abundance of rainfall and low temperatures make this environment a complex area for onion cultivation (Yonkeu, 1993; Kamga *et al*., 2016). The low productivity of this important vegetable crop is often attributable to the poor application of appropriate farming techniques and poor access to agricultural inputs (Ayalew *et al*., 2015). Furthermore, important genetic diversity has been reported in onions (Tignegre *et al*., 2022 ; Gupta *et al*., 2025b). Onion crop is known to require substantial amounts of nutrients to be applied before planting (Kazimierczak *et al*., 2021). Given these conditions, studying the adaptability and stability of nine onion varieties based on their genetic performance would be beneficial for food security and local development. Crop trait stability is known to be influenced by factors including the environment, genotype and the genotype-environment interaction. The objective of the present study was to identify adapted onion genotypes for sustainable production in the Guinean high savannah zone of Cameroon. The aim of the study was to evaluate bulb yield performance and stability in nine onion cultivars grown in two locations of the high Guinean savannah zone under conventional (mineral fertilization) and organic (chiken manure, unfertilized control) production systems during two-year trials (2024 and 2025).

II. MATERIALS AND METHODS

Testing environments

The field experiment was carried out in two consecutive dry seasons (october to march 2024 and 2025) at Bini (7°13' N; 13°34' E) and Marza (7°27' N; 13°61' E) in the Adamawa region of Cameroon. The Adamawa region belongs to the Guinean high savannah zone, characterized by a tropical Sudano-Guinean climate with a long rainy season from April to October and a dry season from November to March (Yonkeu, 1993). The annual rainfall is approximately 1440 mm and the temperatures are cool, averaging 22°C with a maximum of 34.6°C in May and a minimum of 9.9°C in January. Relative humidity is around 70% and the soils are predominantly red ferralitic soils developed on granite or old basalt, and hydromorphic (gleysoils) soils found near rivers (Yonkeu, 1993).

Genotypes

The experimental material (Table 1) comprised nine onion varieties including four cultivars (Goudami, Kada Goudami, El kara and Chagari) produced locally by onion farmers in the Far North region, and five improved varieties (Ares, Prema, Red Créole, Safari and Violet de Galmi) obtained from SEMAGRI compagny. Onion seedlings were produced for forty days in nurseries before transplantation into the experimental plots.

Table 1: Onion seed varieties and their characteristics

Genotype	Origin	Cycle (Days)	Suitable season
Ares	SEMAGRI	90-110	Rainy season
Chagari	Local, Mayo-Tsanaga	100-135	Rainy season
El-Kara	Local, Far North	100-130	Dry/rainy season
Goudami	Local, Far North & North	105-110	Dry season
Kada Goudami	Local, Far North	120-130	Dry season
Prema	Agricultural Seed Shop	110-120	Dry/rainy season
Red Creole	SEMAGRI	135 - 145	Dry season
Safari	SEMAGRI	110-120	Dry season
Violet de Galmi	SEMAGRI	120-143	Dry season

Field experimental trials

The study took place from October to March in 2024 and 2025, from nursery planting to harvest. In each location, the experimental design used is a split plot with three replications, the main factor being the genotypes and the sub-factor is the environments (negative control, chicken manure, NPK fertilizer, and combination of chicken manure and NPK 20-10-10 fertilizer). The experimental unit consists of a 1m² plot and a 30cm irrigation channel, as well as a 20cm earth embankment between the plots or experimental units on the same line. The experimental plot is 12 m long and 10.8 m wide, giving a total area of 129.6 m². On the experimental units, the plants are transplanted at equidistant intervals of 10 cm and 15 cm between rows.

The nursery was established on October 1 on a 1m² plot with 30g of seeds for each variety. The maximum time for plants in the nursery is 45 days. Transplanting consists of removing the plants from the nursery and returning them to the field. The plants are transplanted superficially. Transplanting is carried out on previously watered beds. On a 1m² experimental unit, the plants are transplanted at 10cm intervals and 15cm spacing, giving a density of 60 plants per 1m² unit.

The organic fertilizer was applied before transplanting at a rate of 1 kg per tray, then lightly watered for two weeks. The mineral NPK fertilizer was spreaded two weeks after transplanting and six weeks after transplanting. Weeding was carried out regularly at different stages of the plant's development.

The only variable measured concerned the bulb yield at maturity. The weight of ten selected bulbs was measured using an SF-400 digital scale with a capacity of 1000g×1g/353oz×0.1oz. The yield was extrapolated to t.ha as Tignegre *et al*. (2022)

$$\text{Bulb yield} = (\text{PmB} \times (\text{NP/m}^2) \times 600000) / 10000$$

Where PmB is the average bulb weight and NP/m² is the number of plants per square meter.

Characterization of soils

Soil sampling was carried out according to the method described by Pauwels *et al*. (1992) at a depth of 30 cm. Once collected, the soils samples were mixed several times to ensure homogeneity, and analyzed at the laboratory of soil analysis and environmental chemistry of the the University of Dschang. The pH of the soil was determined in a 1:2.5 (w/v) soil: water suspension, according to the method described by Pauwels *et al*. (1992). The soil total nitrogen was determined after mineralization of substrate samples using the AFNOR method (1984) and the calorimetric technique described by Devani *et al*. (1984). The phosphorus content was determined by absorption spectrophotometry (Rodier, 1978). The organic matter was measured as described by Pauwels *et al*. (1992).

The determination of exchangeable bases in the soil was carried out using the Metson method for soils (Pauwels *et al*., 1992) with a pH below 7, and extraction was carried out with ammonium acetate at pH 7. The potassium in the extract was measured by flame spectrophotometry (Pauwels *et al*., 1992).

III. DATA ANALYSIS

Separate analysis of variance was performed for each location, environments and season to acess the variabiliy of the onions yield using STAGRAPHICS PLUS 5.0 software. The means were separated using the Least Significant Difference (LSD) at the 5% level of probability. The combined analysis of variance was done using Hardwick and Wood (1972) model with the nine genotypes being considered as fixed effects and replications within the 16 environments being random mode. GEI was quantified used pooled analysis of variance, which partitioned the total variance into its component parts (genotype, environment, interaction and error).

Different stability models were performed to support decision-making for varietal selection: Finlay and Wilkinson's (1963) joint regression analysis (bi), Wricke's (1962) ecovalence (Wi), Shukla's (1972) procedure of stability (σ^2i) and the AMMI analysis described by Yan and Tinker (2006).

The joint regression model of Finlay and Wilkinson (1963) assesses the stability and adaptability based on the regression coefficient (bi) of the mean of each variety in all environments on the environmental index.

The concept of ecovalence (Wi), introduced by Wricke (1962), quantifies genotypic contributions to the sum of squares of the GEI. The Wi value for the ith genotype is determined by squaring and summing its interactions across different environments. Genotypes characterized by lower Wi values exhibit minor deviations from the mean across environments, indicating heightened stability. The ecovalence stability coefficient, W_i, is a measure of genotype stability over locations and is computed as:

$$Wi=\sum(Y_{ij}-Yi-Yj+\mu)^2$$

where Y_{ij} is the mean performance of genotype i in the j^{th} environment; Y_i is means of i^{th} genotype across environments, Y_j is means of j^{th} environment across all genotypes and μ is the grand mean (Wricke, 1962)

Shukla (1972) stability variance σ_i^2, is a stability index given by the following formula:

$$\sigma^2 i= (p/ (p-2) (q-1)) \Sigma i (Y_{ij} - Y_i - Y_j + \mu)^2 - \Sigma i \Sigma j (Y_{ij} - Y_i - Y_j + \mu)^2/p/ (p-2)(q-1),$$

where Y_{ij} is the mean performance of genotype i in the j^{th} environment; Y_i is means of i^{th} genotype across environments, Y_j is means of j^{th} environment across all genotypes and μ is the grand mean, p is the number of genotypes and q is the number of environments (Shukla, 1972).

The stability analyses, the AMMI and biplot models were evaluated using the program GEST 98 (Ukai, 2000).

IV. RESULTS AND DISCUSSION

Physico-chemical characterization of the soil

The characterization of the experimental soil at the two locations, Marza and Bini (Table 2), revealed a sandy-clay texture at Marza with sand (57%) and clay (23.5%) and at Bini with sand (48.5%) and clay (36.5%). The water pH was slightly basic at Marza (7.5) and Bini (7.7). Similarly, the KCl pH was acidic (6.8) at Marza and neutral (7) at Bini. These results showed that the pH levels at Marza and Bini were within the favorable range (6 and 7) for onion cultivation (Gelahun and Getaneh, 2019). The locality of Bini had more macroelements (nitrogen nitrate, phosphorus, and potassium) available in the soil than Marza. The composition of organic matter, the sum of exchangeable bases, and the cation exchange capacity offered the locality of Marza the possibility of great water retention and accessible microelements for gardening crops. With a view to improving the exchangeable base capacity and cation exchange capacity in order to enhance the availability of macro- and microelements in different soils, it was necessary to apply undecomposed chicken manure as a base fertilizer, with or without the addition of synthetic NPK compound fertilizer (20-10-10).

Table 2: Physicochemical characteristics of the study soils

Characteristic	Marza	Bini
Clay (%)	23.5	36.5
Silt (%)	19.5	15
Sand (%)	57	48.5
pH water	7.5	7,7
pH KCl	6.8	7
Organic matter (%)	7.7	6.5
Nitrogen nitrate, N-NO3	2078.95	3518.53
Phosphorus (mg/Kg)	25.31	26.05
Potassium (méq/100g)	0.173	0.298
Exchange bases (méq/100)	11.11	3.25
Cation Exchange Capacity	21.45	11.74

Variability of bulb yield of nine onion varieties over environments

The yield values of the nine selected varieties at the locations of Marza and Bini during dry seasons 2024 and 2025, undrer four fertilizations regimes: control, chicken manure, NPK fertilizer and combination of NPK and chicken manure were presented on Tables 3, 4, 5 and 6. In the first year of the experiment in Marza in 2024 (Table 3), the most favorable environment for onion cultivation was the combination of chicken manure and mineral fertilizer CM+NPK (87.23 t. ha^{-1}) and the least favorable was control (23.82 t. ha^{-1}). The genotypes best suited to all environments were variety Safari (77.56 t. ha^{-1}), Violet Galmi (70.07 t. ha^{-1}), Prema (69.42 t. ha^{-1}), Kada Goudami (64.24 t. ha^{-1}) and El Kara (63.11 t. ha^{-1}). The lowest yield values were noted on Ares (35.25 t. ha^{-1}) and Red Creole (48.58 t. ha^{-1}).

At Bini during 2024 growing period (Table 4), the most suitable growing environment is CM+NPK (57.33 t. ha^{-1}) and the least suitable is control (21.64 t. ha^{-1}). The most suitable genotypes were Chagari (51.09 t. ha), El Kara (46.12 t. ha^{-1}), Safari (45.66 t. ha^{-1}) and Prema (44.66 t. ha^{-1}). The lowest yield values were recorded on Ares (18.67 t. ha^{-1}) and Red Creole (30.23 t. ha^{-1}). Globally, during the 2024, growing season, the tested genotypes significantly had poor performance at Bini (mean yield = 39.0 t. ha^{-1}), comparing to Marza (mean yield = 60.85 t. ha^{-1}).

During the second experimental campaign (2025), the study revealed that at Marza site highly significant difference were noted among genotype ($p<0.01$) (Table 5). Five varieties showed good yield performance: El Kara (89.34 t. ha^{-1}), Goudami (76.32 t. ha^{-1}), Galmi Violet (72.19 t. ha^{-1}), Safari (68.05± t. ha^{-1}), and Prema (63.03 t. ha^{-1}). Genotype Ares, Chagari and Kada Goudami were the least suitable with yield values of 27.8 t. ha^{-1}, 33.4 t. $ha^{-1}$and 42.9 t. ha^{-1}respectively. The most suitable environment for cultivation was CM+NPK (76.75 t. ha^{-1}) and the poorest environment was the control (19.9 t. ha^{-1}). At Marza, the growing season 2024 (mean yield = 60.85 t. ha^{-1}) offered best conditions for onions cultivation comparing to growing season 2025 (mean yield = 57.89 t. ha^{-1}).

At the Bini site during 2025 campaign, the analysis of variance showed highly significant difference ($p<0.01$) for genotypes (Table 6). The most suitable varieties in the different environments are: El Kara (51.26 t. ha^{-1}), Safari (48.33 t. ha^{-1}), Prema (44.05 t. ha^{-1}) and Violet Galmi (42.71 t. ha) while the poorest varieties were Ares (21.20 t. ha^{-1}) and Chagari ((23.33 t. ha^{-1}). The best environment was the combination CM+NPK (50.8 t. ha^{-1}). The growing season 2024 at Bini (mean yield = 39.00 t. ha^{-1}) offered best conditions for onions cultivation comparing to growing season 2025 (mean yield = 37.98 t. ha^{-1}).

Overall, for both the 2024 and 2025 campaigns, the study showed significant variability within varieties, environments, and locations. The variations observed between the different varieties are due to genotypic factors and environmental factors. Horn et al. (2018), Tignegre et al. (2022), Gupta et al. (2024), Gupta et al. (2025b) mentioned that, the highly significant differences in locations, years, and genotypes for onions bulb yields may be due to variable climatic and edaphic conditions between locations and the diversity of the genetic makeup of genotypes that may respond differently to locations. Ayalew *et al*. (2015); Gethaun and Getaneh (2019), also observed significant variations in the performance of garlic cultivars from different locations in Gonder, northern Ethiopia. As expected, the highest yields have been measured for onion grown on plots treated with mineral fertilizer and chicken manure. In Serbia, Brdar-Jakanovic *et al.* (2012) noted that highest yields were obtained from NPK fertilized plots and out of three organic production systems, onion grown under bacterial fertilization had the highest yield, whereas no significant yield differences have been observed between unfertilized and farmyard manure fertilized plots. Kazimierczak *et al.* (2021) clearly demonstrated that organic fertilizer products can deliver the same and possibly slightly higher yields when compared to the recommended mineral fertilization regimes in onions. The performance of the varieties fluctuated sightly during the two years of trials. In sudano-sahelian zone of Northern Cameroon, Moutsavara *et al.* (2025) noted high repeatability values (0.61 to 0.77) for bulb yield of seven varieties grown in three locations during two-year trials.

Table 3: Bulb yield (t/ha) of nine onion varieties in four environments at the Marza in 2024

Varieties	Control	CM	CM+NPK	NPK	Gen. Mean
Ares	14.9±3.63^{d}	40.52±2.59^{f}	56.62±5.52^{d}	28.94±5.87^{e}	35.25±4.40 (9)
Chagari	27.36±7.61^{a}	72.66±5.59^{d}	94.96±5.53^{b}	54.34±4.74^{c}	62.33±5.86 (6)
El Kara	18.24±3.5^{c}	93.4±3.64^{a}	101.4±8.42^{a}	38.4±6.21^{d}	62.86±5.44 (5)
Goudami	27.82±4.75^{a}	80.4±3.03^{c}	56.76±7.31^{d}	56.76±7.31^{c}	55.44±5.6 (7)
Kada Goudami	23.74±4.12^{b}	83.68±6.22^{bc}	87.66±6.45^{b}	61.88±5.76^{b}	64.24±5.63 (4)
Prema	27.9±6.32^{a}	87.74±5.14^{b}	101.9±18.79^{a}	60.14±8.79^{b}	69.42±9.76 (3)
Red Creole	13.74±3.85^{d}	62.16±5.22^{e}	76.91±7.76^{c}	41.5±7.29^{b}	48.58±6.03 (8)
Safari	29.76±1.63^{a}	95.58±4.09^{a}	108.24±5.64^{a}	76.66±6.66^{a}	77.56±4.51 (1)
Violet Galmi	20.9±3.25^{bc}	94.58±5.04^{a}	102.98±7.09d^{a}	61.8±9.03^{b}	70.07±6.10 (2)
Env. Mean	**23.82±4.4^{D}**	**78.97±7.08^{B}**	**87.23±9.54^{A}**	**53.38±8.15^{C}**	**60.85±9.16**
Probability	0.0001	0.0001	0.0001	0.0001	

CM: Chicken manure, CM+NPK: Chicken manure and synthetic NPK fertilizer (20-10-10) environment, Gen.: Genotypic, Env.: Environmental. In a column, numbers followed by the same small letter do not differ significantly at the 5% level. Number between parenthesis denote ranking order of genotypes. Environmental means followed by the same subscript in capital letter dot not differ significantly at 5% level.

Table 4: Bulb yield (t/ha) of nine onion varieties in four environments at the Bini site in 2024

Varieties	Control	CM	CM+NPK	NPK	Gen. Mean
Ares	10.56±0.78^{f}	25.68±3.30^{f}	28.78±5.80^{g}	9.66±1.59^{f}	18.67±2.86 (9)
Chagari	33.26±3.76^{a}	82.12±5.72^{a}	62.12±8.36^{c}	26.84±2.98^{bc}	51.09±5.20 (1)
El Kara	26.74±3.79^{b}	56.44±3.80^{cd}	74.48±14.89^{a}	26.8±9.42^{bc}	46.12±7.97 (2)
Goudami	25.94±3.89^{bc}	54.44±2.80^{d}	58.04±9.24^{de}	19.34±4.05^{de}	39.44±4.99 (6)
Kada Goudami	22.96±2.19^{cd}	61.52±4.59^{c}	56.92±6.90^{e}	17.2±8.48^{e}	39.65±5.54 (5)
Prema	24.02±2.91^{cd}	53.5±3.50^{d}	60.54±9.76^{cd}	38.54±3.81^{a}	44.15±4.99 (4)
Red Creole	13.1±1.49^{ef}	41.32±2.19^{e}	49.66±8.82^{f}	16.84±5.53^{e}	30.23±4.50 (8)
Safari	16.62±4.14^{e}	70.02±5.49^{b}	68±8.44^{b}	28.01±6.99^{b}	45.66±6.26 (3)
Violet Galmi	21.56±2.60^{d}	43.52±2.17^{e}	57.44±2.82^{de}	23.06±4.35^{cd}	36.4±2.98 (7)
Env. Mean	**21.64±5.31^{B}**	**54.28±9.20^{A}**	**57.33±11.37^{A}**	**22.74±5.27^{B}**	**39.00±11.78**
Probability	0.0001	0.0001	0.0006	0.0007	

CM: Chicken manure, CM+NPK: Chicken manure and synthetic NPK fertilizer (20-10-10) environment, Gen.: Genotypic, Env.: Environmental. In a column, numbers followed by the same small letter do not differ significantly at the 5% level. Number between parenthesis denote ranking order of genotypes. Environmental means followed by the same subscript in capital letter dot not differ significantly at 5% level.

Table 5: Bulb yield (t/ha) of nine onion varieties in four environments at the Marza site in 2025

Varieties	Control	CM	CM+NPK	NPK	Gen. Mean
Ares	11.88±2.02[e]	38.78±7.79[g]	36.10±4.92[f]	24.42±4.73[f]	27.8±4.86 (9)
Chagari	14.60±4.16[d]	50.98±3.03[ef]	39.84±6.22[f]	28.22±7.37[f]	33.41±5.19 (8)
El Kara	32.26±6.78[a]	104.74±12.87[a]	124.44±12.90[a]	95.92±27.06[a]	89.34±14.90 (1)
Goudami	21.36±3.86[c]	87.10±7.86[b]	101.76±7.05[b]	95.04±4.94[a]	76.32±5.92 (3)
Kada Goudami	15.60±4.78[ab]	46.78±3.24[f]	48.62±7.98[e]	60.6±11.12[d]	42.9±6.78 (7)
Prema	31.16±6.18[a]	66.76±5.11[d]	78.66±13.64[cd]	75.52±2.81[c]	63.03±6.93 (5)
Red Creole	11.06±2.95[e]	52.68±5.30[e]	73.58±7.83[d]	54.44±13.55[e]	47.94±7.40 (6)
Safari	25.64±4.59[b]	73.00±3.37[c]	86.2±15.10[c]	87.34±4.31[b]	68.05±6.84 (4)
Violet Galmi	15.50±4.64[d]	86.94±5.02[b]	101.52±9.0[b]	84.8±12.53[b]	72.19±6.79 (2)
Env. Mean	**19.89±8.67[C]**	**67.53±12.04[B]**	**76.75±20.15[A]**	**67.37±12.72[B]**	**57.89±11.89**
Probability	0.0001	0.0001	0.0001	0.0001	

CM: Chicken manure, CM+NPK: Chicken manure and synthetic NPK fertilizer (20-10-10) environment, Gen.: Genotypic, Env.: Environmental. In a column, numbers followed by the same small letter do not differ significantly at the 5% level. Number between parenthesis denote ranking order of genotypes. Environmental means followed by the same subscript in capital letter dot not differ significantly at 5% level.

Table 6: Bulb yield (t/ha) of nine onion varieties in four environments at the Bini site in 2025

Varieties	Control	CM	CM+NPK	NPK	Gen. Mean
Ares	14.73±3.37[d]	26.94±4.62[e]	26.84±5.64[e]	16.30±2.39[g]	21.20±4.00 (9)
Chagari	24.56±2.31[b]	23.16±7.30[f]	27.00±4.26[e]	18.60±3.99[g]	23.33±4.46 (8)
El Kara	24.23±2.58[b]	49.34±6.49[a]	68.50±8.58[a]	57.98±7.38[a]	50.01±6.25 (1)
Goudami	21.26±3.10[c]	49.73±6.17[a]	54.24±7.68[c]	37.14±4.86[e]	40.59±5.45 (5)
Kada Goudami	21.68±2.27[c]	42.44±6.75[b]	48.58±6.28[d]	43.07±4.67[d]	38.94±4.99 (6)
Prema	28.12±2.08[a]	33.82±7.99[d]	63.52±8.68[b]	52.82±6.36[b]	44.57±6.27 (3)
Red Creole	11.55±1.55[e]	36.74±7.28[cd]	48.58±6.90[d]	30.26±9.68[f]	31.73±6.35 (7)
Safari	30.80±2.60[a]	42.58±9.63[b]	66.54±3.75[ab]	53.38±8.17[b]	48.32±6.03 (2)
Violet Galmi	24.20±2.68[b]	38.64±3.30[c]	53.42±6.47[c]	48.16±9.45[c]	41.10±5.47 (4)
Env. Mean	**22.34±6.19[C]**	**38.52±10.46[B]**	**50.95±5.82[A]**	**40.11±10.07[B]**	**37.98±9.13**
Probability	0.0001	0.007	0.001	0.009	

CM: Chicken manure, CM+NPK: Chicken manure and synthetic NPK fertilizer (20-10-10) environment, Gen.: Genotypic, Env.: Environmental. In a column, numbers followed by the same small letter do not differ significantly at the 5% level. Number between parenthesis denote ranking order of genotypes. Environmental means followed by the same subscript in capital letter dot not differ significantly at 5% level.

Combined analysis of variance for bulb yield of nine genotypes over 16 environments

Hardwick and Wood (1972) analysis of variance for onion bulb yield (Table 7) showed that the mean square of environmental factors (66.51%) significantly affects yield compared to genotype-environment interaction (16.88%) and genotype (16.61%). These results showed a non-linear and insignificant interaction with genotype rank reversal (E>GEI>G). Yield variations are due mainly to environmental effects and genotype x environment effects. Although variety performance varied significantly depending on the environment, the GEI had great impacts on bulb yield. Tignegre *et al*. (2022) noted a similar result with environmental and GEI effects explaining most of the variation however, the magnitude of GEI was lower in the present study. Our result is consistent with many previous studies that reported significant GEI effects not only in onions. Environmental diversification could be a source of variability in onion bulb yield. Similarly, Bezu *et al*. (2014) noted an impact of environmental factors on the performance of garlic genotypes. This larger proportion of environmental variation can be attributed to significant disparities in soil types, annual precipitation, average temperatures, and other weather conditions (Gupta *et al*., 2024).

Table 7: Combined analysis of variance for bulb yield

Source of variation	Df	SS	MS	% SS	F-value
Genotype (G)	8	17425.44	2178.18	16.61	182.18*
Environment (E)	15	69765.80	4651.05	66.51	390.51**
Interaction (GEI)	120	17709.94	147.58	16.88	12.39*
Residual	112	13342.18	11.91		
Total	143	10490118			

dl: Degree of freedom, GEI: Genotype x environment interaction, SS: Sum of squares, MS: Mean square, % SS: percentage of the sum of squares; **: significant at the 1% probability ; *: significant at the 5% probability.

Stability and adaptability of genotypes

The values of different stability procedures and adaptability measure for bulb yield of each onion variety are presented in Table 8. The values of regression coefficient bi of Finlay and Wilkinson (1963) ranged from 0.526 (Ares) to 1.300 (Violet Galmi) (Figure 1). It can be seen that varieties 3 (El Kara), 8 (Safari), 9 (Violet de Galmi), and 4 (Goudami) had bi values larger than one (bi >1), and was therefore unstable. These varieties are specifically adapted to the favorable environments. Varieties that showed instability in different environments display a better performance for the breeder, but with a high risk of selecting varieties with weak genetic makeup. Varieties 1 (Ares), 2 (Chagari), 5 (Kada Goudami), 7 (Red Créole), and 6 (Prema) had regression coefficient smaller than one (bi < 1), which indicated highest stability. These varieties are considered to be generally adapted in the study area. Brancourt-Hulmel *et al*. (1997) indicated that the stability of a genotype depends on its resistance to fluctuations caused by variations in environmental conditions. According to Brdar-Jokanović *et al*. (2016), stability referred to the maintenance of a genotype's yield performance in various environments, and an assessment of a genotype's average performance and stability is necessary before selection. Gupta *et al.* (2022, 2024) stipulated that the identification of genotypes with both high mean performance and stability is therefore crucial for the development of cultivars suited to variable agro-climatic regions. An ideal genotype should not only demonstrate superior performance but also maintain stability within and across diverse environments.

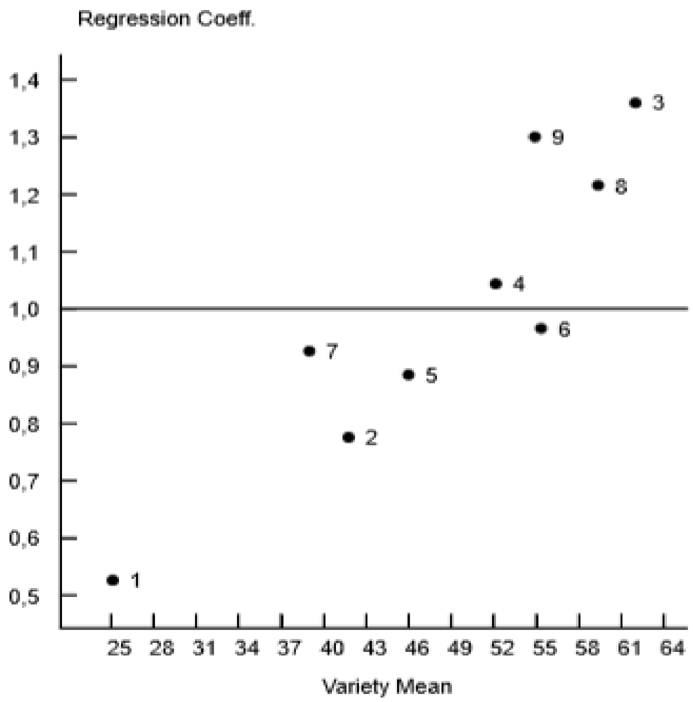

Fig.1: Adaptability and stability of nine onion varieties at the Marza and Bini sites in 2024 and 2025 according to the Finlay-Wilkinson (1963) regression

1 : Ares ; 2 : Chagari ; 3 : El Kara ; 4 : Goudami ; 5 : Kada Goudami ; 6 : Prema ; 7 : Red Creole ; 8 : Safari ; 9 : Violet de Galmi.

The Wricke (1962) ecovalence (Wi) values ranged from 211.34 (Ares) to 4770.94 (Chagari). The most stable genotypes with the lowest Wi values were Ares, Red Creole and Prema while those with highest values (Chagari, El Kara and Goudami) were the most unstable. The Wi values indicated the level of stability of the genotypes in multi-environments trials (Brancourt-Hulmel *et al.*, 1994; Annichiarico, 2002). When Wi = 0, stability is at its maximum, and when Wi is high, the genotypes are unstable.

Shukla (1972) stability variance σi^2 showed an index of stability varying from 167.57 (Ares) to 6020.96 (Chagari). Ares, Red Creole (461.40), Kada Goudami (491.58) and Prema (520.99) were the most stable, and genotypes Chagari and El Kara (1125.21) with the highest values were unstable.

In general, data obtained on stability showed that none of the tested varieties could be considered as completely stable. Similar observation has been previously reported in onion by Tignegre *et al.* (2022) in Ghana and Mali, Atnafu (2023) in Nigeria, Gupta *et al.* (2025a) in India, Moutsavara *et al.* (2015) in Northern Cameroon. The ideal genotype should have good yield performance and be absolutely stable with zero GEI. Among top yielding genotypes, Safari, El Kara and Violet Galmi could be exploited as specifically germplasm in favorable environment.

Table 8: Stability and adaptability of genotypes for bulb yield

Genotype	Code	*bi*	W_i	σ_i^2
Ares	1	0.526 (1)	211.34 (1)	167.57 (1)
Chagari	2	0.776 (2)	4770.94 (9)	6020.96 (9)
El Kara	3	1.360 (9)	3544.19 (8)	1125.21 (8)
Goudami	4	1.044 (6)	2646.97 (7)	738.93 (5)
Kada Goudami	5	0.885 (3)	1404.49 (5)	491.58 (3)
Prema	6	0.966 (5)	589.46 (3)	520.99 (4)
Red Creole	7	0.926 (4)	309.38 (2)	461.40 (2)
Safari	8	1.216 (7)	855.23 (4)	797.21 (6)
Violet Galmi	9	1.300 (8)	1477.95 (6)	925.88 (7)

bi: Finlay and Wilkinson regression coefficient; Wi: Wricke's ecovalence; σi2: Shukla's stability variance; A: Ares variety; C: Chagari variety; EK: El Kara variety; G: Goudami variety; KG: Kada Goudami; P: Prema variety; RC: Red Creole variety; S: Safari variety; and VG: Violet de Galmi.

AMMI biplot analysis

The AMMI (additive main effects and multiplicative interaction) analysis also showed the genotype x environment interaction for better selection of suitable genotypes and environments (Figure 2). This figure helps guide choices based on the distance of genotypes and environments from the center of the IPCA1 and IPCA2 axes (Yan and Tinker, 2006. The best environments were the combination of chiken manure and NPK fertilizer in 2024 and 2025 (BFP+NPK25, BFP+NPK24). These environments with shorter vectors and closer proximity to the origin are considered more reliable for selecting widely adaptable genotypes (Gauch, 2006).The top genotypes namely Safari, El Kara and Violet Galmi were in corner with a maximum distance from the origin of the biplot and were sensitive.

V. CONCLUSION

This study on adaptability and stability of the yield parameters of nine onion varieties showed that three genotypes, namely El Kara, Safari and Violet de Galmi exhibited good performance. The most suitable environments were CM+NPK at both study sites. This study showed the significant influence of genotype, environment, and their interaction on yield of onion cultivated in the high Guinean zone of Cameroon. The combined variance analysis revealed that environmental factors are more important than genotype and genotype x environment interaction. The stability analysis showed that not a single onion cultivar included in the trial exhibited both high yield and stability across conventional and organic environments. Therefore, breeding onion cultivars highly adapted to the organic production systems is required in order to obtain satisfactory high and stable yields. Top yielding varieties namely El Kara, Safari, Violet de Galmi and Goudami had specific adaptability. These lines are therefore potential candidates for release to contribute, in this way, to sustainably intensifying onion production in the region. One of the aspects that could be investigated is the assessment of genotype response to biotic constraints, which are often key to the long-term success of newly released varieties. Additionally, it would be very informative to have other quality parameters to support these results.

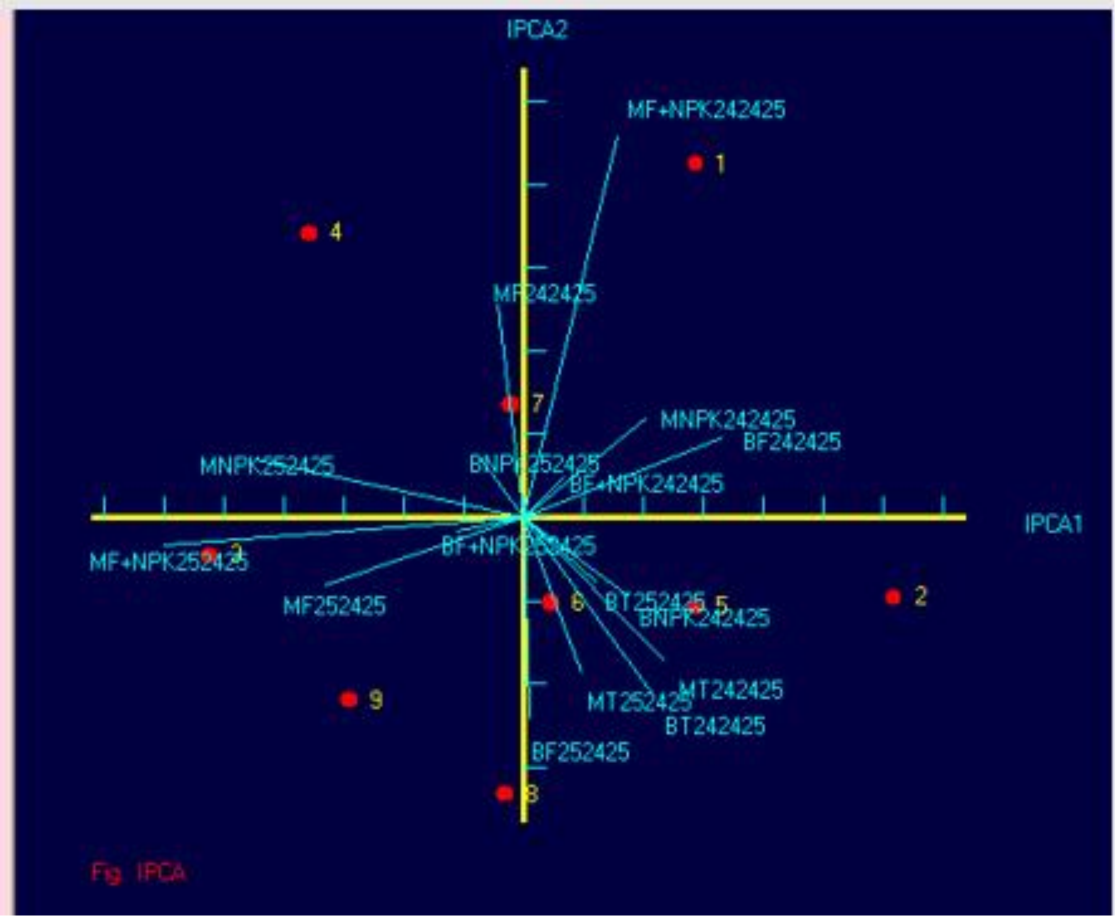

Fig.2: additive analysis of the main and multiplicative effects of interactions (AMMI) in a biplot

MT24: Marza Control 2024; MFP24: Marza Chicken Manure 2024; MFP+NPK24: Marza Chicken Manure + NPK Fertilizer 2024; MNPK24: Marza NPK Fertilizer 2024; BT24: Bini Control 2024. BFP24: Bini Chicken Manure 2024; BFP+NPK24: Bini Chicken Manure + NPK Fertilizer 2024; BNPK24: Bini NPK Fertilizer 2024; MT25: Marza Control 2025; MFP25: Marza Chicken Manure 2025; MFP+NPK25: Marza Chicken Manure + NPK Fertilizer 2025; MNPK25: Marza NPK Fertilizer 2025; BT25: Bini Control 2025. BFP25: Bini chicken manure 2025; BFP+NPK25: Bini chicken manure + NPK fertilizer 2025; BNPK25: Bini NPK 2025 fertilizer; 1: ARES variety; 2: Chagari variety; 3: El Kara variety; 4: Goudami; 5: Kada Goudami; 6: Prema; 7: Red Creole; 8: Safari; 9: Violet de Galmi

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