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Effect of Water Stress on Morpho-physiological Trait of Some Accessions of Bambara Groundnut [*Vigna subterranea* (L). Verdcourt]

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ABSTRACT

Background: The cultivation of Bambara groundnut in arid zones, such as the Sahelian regions of Cameroon, has received scant attention despite its nutritional and agronomic potential. The Sahelian regions of Cameroon are classified as part of the arid zones of the world, characterized by a rainy season of approximately three to four months in duration. Nevertheless, the cultivation period of Bambara groundnut is approximately four to six months, a duration that hinders its cultivation. The objective of this study is to assess the impact of water stress on the morpho-physiological traits of select Bambara groundnut accessions cultivated in the Sahelian regions of Cameroon.

Methods: The experiment was executed in accordance with the fisher bloc design, employing four replicates. The water stress was induced using distilled water in pot experiments to monitor thirteen (13) morphological traits and six (06) physiological traits.

Result: The results demonstrated significant variability among the accessions under water stress. Accession V2 exhibited the greatest resistance, characterized by diminished leaf areas and reduced stomatal number. The findings demonstrated a consistent increase in relative water content, accompanied by a decrease in water loss and transpiration. This observation suggests a reduced response to stress. The genetic material of the accession exhibited a range of morphological responses. The considerable impact of water stress was evident on the 100-pod weight produced per accession. Accession V1 exhibited a significant response to water stress, resulting in the production of the smallest pods (22 g). Accession V2 demonstrated the least susceptibility to the 100-pod weight (26 g), exhibiting the highest weight among the other accessions. The evaluation of the 100 seeds' weight revealed that accession V2 exhibited a significantly higher seed weight compared to the other accessions. The grain yield in the accession V2 was higher for both sites (65.39±1.15 and 65.72±0.50). Principal component analysis demonstrated a positive correlation between stress and the weights of 100 pods and seeds (r = 0.956). The results obtained underscore the capacity of accession V2 to adapt to the environmental conditions prevalent in the Sahelian regions of Cameroon.

Key words: Accessions, Physiological traits, Variability, *Vigna subterranea,* Water stress.

INTRODUCTION

Global population growth over the past few decades is generating enormous needs, the most notable of which in sub-Saharan Africa are energy and food demand. in fact, the report published by the FAO, shows the absolute number of people suffering from hunger and under nourishment reached almost 821 million in 2017, compared with around 804 million in 2016, (Salomon *et al.,* 2023), Indeed, in developing countries, 12.9% of the population is undernourished and malnutrition is the cause of 45% of deaths in children under 5.

[*Vigna subterranea* (L.) Verct], commonly known as Bambara groundnut, is a plant indigenous to Africa and is one of the often-neglected subsistence crops in Africa (Soumare *et al.,* 2022). It is a minor food legume adapted to a variety of stressful climatic and ecological conditions (Onwubiko *et al.,* 2011). It is a calorie-rich plant food, with an energy value of around 387 Kcal/100 g. It is also rich in vitamins, minerals, proteins (20-25%), lipids (6-8%) and carbohydrates (50-57%) (Gbaguidi *et al.,* 2015). Bambara peanut seeds are used as human food as well as for the treatment of certain pathogens (Gbaguidi *et al.,* 2015). However, many plant species grown around the world for food production are considered minor crops compared to

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other food crops considered major food crops (rice, maize, wheat, sorghum, yam, plantain, cassava, *etc.*) which make up almost the entire diet in Africa (Bricas *et al.,* 2009). However, these minor crops play a crucial role in food security, nutrition and generate income for many rural populations (Ouoba *et al.,* 2018). Despite its nutritional qualities, Bambara groundnut is on the list of neglected species in varietal breeding programs (Tadele Zerihun, 2009). However, the plant offers enormous potential for improvement, thanks to its genetic diversity found in thousands of accessions harvested throughout the world. (Djè *et al.,* 2005); (Ndiang *et al.,* 2012). In Cameroon for instance, very little information is currently available on the genetic and morpho-physiological diversity of this species.

In the arid regions of Cameroon, water scarcity and precarious access to water for agriculture are major constraints to improving living conditions (Castillo *et al.,* 2007). Water appears to be the most limiting factor for plant production. In arid and semi-arid areas, water losses through evapotranspiration are extremely high due to high temperature, sunshine and wind (Faurès *et al.,* 2008). Thus, the exploration of water-efficient accessions is important for improving plant productivity in general and that of legumes in particular. *Vigna subterranea* (L.) can play an important role because one of its main characteristics is its tolerance to poor soils and drought, as well as its ability to produce under environmental stress conditions where other plants fail. However, Bambara groundnut yields remain low due to numerous production constraints. In the Far North region (Sahelian zone) of Cameroon, Bambara groundnut is generally grown on rocky soils, yet it has ecological elasticity (Basu *et al.,* 2007). These types of soils are very porous and the plants very often face water stress. Thus, climate variability and irregular rainfall could intensify yield declines of Bambara groundnut in the Far North of Cameroon, marked by a contrasting climate. In order to overcome this shortcoming, a number of researchers have carried out extensive research on Bambara groundnut. As demonstrated by Ibrahima *et al.* (2024) in their study on the selection strategy for early maturing accessions capable of optimizing water uptake and use efficiency and Temegne *et al.* (2018) in their research on the combination of water deficit and phosphate fertilizer. It would therefore be important to explore the least water-demanding accessions. Thus, to contribute to the production of Bambara groundnut accessions that are physiologically adapting to water deficits, an assessment of the morphological and physiological characteristics of these accessions is necessary.

MATERIALS AND METHODS

Field experiments were conducted at two sites: an experimental station (Site A: 10°33′N, 14°16′E) and a selected site (Site B: 10°32′N, 14°14′E). These sites are located in the Maroua 1^(er) district in the Far North region of Cameroon. They are characterized by a Sudano-Sahelian climate, with average temperatures between 28°C and 29°C, cumulative annual rainfall of 700 mm and savannah vegetation with sandy, calcareous, poorly evolved Vertisols and tropical ferruginous soils (Orstom, 1965). Seeds of four Bambara groundnut accessions were used as the initial genetic material. Four accessions were used for the pot and field experiments. They were chosen by phenotypic selection based on tegument color (Table 1).

The trial was set up using a completely randomized block design with four replications. The seeds of the four cultivars were randomly sown by block at the experimental station and in the field at the Institute for Agricultural Research and Development (IRAD) in Maroua-Cameroon. Trials at different sites were carried out from 2022 to 2023. The pot experiment was carried out during the May- October 2022 period, while the field experiment was carried out during the June-November 2023 period. Water stress was induced for these accessions 15 days after sowing. The plants were subjected to three levels of water stress: 1 L, 0.5 L and 0.25 L of water per pot every five days for the first, second and third stress levels, respectively (in-station setup). Plants in the field setup were watered every 12 hours (morning and evening).

The experiment was conducted in to experimental sites in order to evaluate the effect of water stress on Bambara groundnut accessions and assess the physiological traits such as relative water content (TRE), water loss rate (TDE), transpiration (TP), number of stomata (NS), leaf area, water use efficiency (WUE) and stress tolerance index (Table 2). The following morphological traits ere also evaluated: Germination time, germination rate, pod weight, seed weight, leaf length, leaf width, number of leaves, plant height, dry biomass, number of pods, number of seeds and grain yield (Table 2).

A statistical analysis of the variables was performed using SPSS.20 software. The collected data were then subjected to a series of statistical analyses, including an analysis of variance (ANOVA) and a Fisher test, which were employed to compare the means of the data sets. This test has facilitated the identification of varieties that exhibit substantial differences from one another. The Pearson correlation test was performed using XLSTAT version 2025.1 software.

Table 1: Characteristics of accessions used and their origins.

Accessions	Seed shapes	Seed coat color	Seed eye pattern	Seed diamter	Collection site
Accession V1	Round	Milky white	Colorful butterfly eye	1.5 cm	Mayo kani, Mayo Tsanaga
Accession V2	Oval	Light brown	White eye without outline	1.1 cm	Diamaré, Mayo danay,
Accession V3	Round	Red	White eye without outline	1.3 cm	Diamaré
Accession V4	Round	White	White eye without outline	1.7 cm	Diamaré

RESULTS AND DISCUSSION

Variation in morphological traits of accessions

Variation in germination time

The statistical outcomes presented in Table 3 demonstrate the variation in germination time among the diverse accessions. The variation in germination time was found to be significantly different between accessions (p = 0.000) and not between blocks (p = 0.42). Furthermore, the interaction between accessions and blocks was also found to be significant. Consequently, the blocks do not exert an influence on the germination time. This outcome is consistent with the hypothesis that the four blocks were exposed to identical conditions.

However, the accession V1 exhibited accelerated germination, occurring six days after sowing. The process of germination of the accession V4 is observed to occur at a later stage than that of the white accession, with a delay of three days in the onset of this process. The remaining two are considered intermediate. In all the accessions studied, radicle emergence occurred between six and nine days after sowing. The result obtained is analogous to that previously reported by Wassouo *et al.* (2019), who documented a germination time range of 6-7 days for Bambara groundnut. The findings of this study demonstrate a congruence with those of Touré *et al.* (2012), who reported that the germination of seeds in Bambara groundnut occurs within the timeframe of 6 to 15 days following the process of sowing. Karikari (1999) observed significantly higher values (14 to 24). The observed variability can be attributed to the presence of diverse plant material, variable climatic conditions and the varying quality of the seeds.

Variation in germination rate

A subsequent analysis of the results indicates a significant difference (Fig 1) between the accessions in terms of germination rate (p = 0.006). However, accession V1 exhibited the lowest germination rate (44%), while accession V2 demonstrated the highest (88%). However, no significant differences were observed between the V1 and V4 accession, the V4 and V3, or the V3 and V2. This negligible discrepancy may be attributable to the substantial variation observed among individuals (*i.e.* high standard deviations), given the limited understanding of the origins of these seeds and their parents. However, the mean germination rate was 66%. This value is higher than

Table 2: Morphological, Physiological traits measured.

Morphological traits	Physiological traits
TL: Gemination time TL = Ts - Te.	TP: Leaf transpiration: Mesure protocol
Te= Germination date, Ts = Sowing date	1- Take a plant.
	2- Record the initial weight of the plant.
	3- Keep the plant in a bag for some time.
	4- Weigh it again to obtain the final weight.
	5- Calculate the difference in weight between the initial weight and the final weight.
	6- The difference in weight is equal to the transpiration.
Tg: Germination rate (%)	TRE: Relative humidity content (%)
$Tg = \frac{\text{Number of seed sown} * 100}{\text{Total number of seed sown}}$ %	TRE (%) = (PF- PS / PT-PS).100
	PF = Wet weight; PS = Dry weight, PT = Turgescence weight (Barcelo *et al.*, 1986)
NF: Leaf number (n)	NS: Number of stomates (S): Microscopic observation
LF: Leaf length (cm),	TDE: Water loss rate (g 10^{-3}/cm^2/mn)
lF: Leaf width (cm),	TDE = (pi-p2h) /PS). (1/SF.120mn) Pi = initial weight,
	p2h = Weight after 2 hours, PS = Dry weight, SF: Leaf area (Monneveux, 1991)
HP: Plant height (cm)	$WUE(g/l) = \frac{\text{Rdt (Total dry matter)}}{\text{Amount of water used}}$
	WUE= water use efficiency; Rdt = Yield (Codon *et al.*, 1990).
PGss: Weight of 100 pods (g)	SF: Leaf Area (cm^2) = (L × l) (Martine *et al.,* 2021)
Pgrn: Weight of 100 Seeds (g)	STI: Stress tolerance index STI = [(Yp) × (Ys)/$\overline{Y}$p2
	Yp: Yield obtained under favourable conditions
	Ys: Yield obtained under stress conditions (Fernandez (1992)
Bio R: Root biomass(g)	
Bio A: Aerial biomass(g)	
NGss: Number of pods	
Ngrn: Number of seeds	
Rmt: Grain yield (g)	

that reported by Touré *et al.* (2013), who found that in Bambara peanut accessions, the average germination rate is 58% at 30 days after sowing. Accession V2 exhibited the highest (88%). Consequently, it can be deduced from this observation that accessions exhibiting high germination rates would possess sufficient plants to ensure high yields, thereby conferring them with a certain agronomic interest in enhancing Bambara groundnut cultivation in the Sahelian regions.

Variation in length

The statistical analysis performed demonstrated that leaf length exhibited significant variation between accessions (p = 0.000) (Fig 2 and 4). However, the leaves of accession V1 are notably longer (7 cm) than those of the other three accessions. The shortest of these are the accession V3, which measure 5.5 centimetres. These results are identical to those of (Djè *et al.,* 2005) who reported in Côte d'Ivoire that morphotypes of Bambara groundnut (White, Black and

Table 3: Variation in germination time of Bambara groundnut accessions.

Source	Sum of squares	DF	Mean of squares	F	P
Key effects					
A: Accessions	211.402	3	70.4673	331.86	0.0000
B: Block	0.60989	3	0.203297	0.96	0.4166
Interaction					
AB	1.72363	9	0.191514	0.90	0.5273
Residue	18.6857	88	0.212338		
Total	235.413	103			

All Fs are based on the mean square residual error.

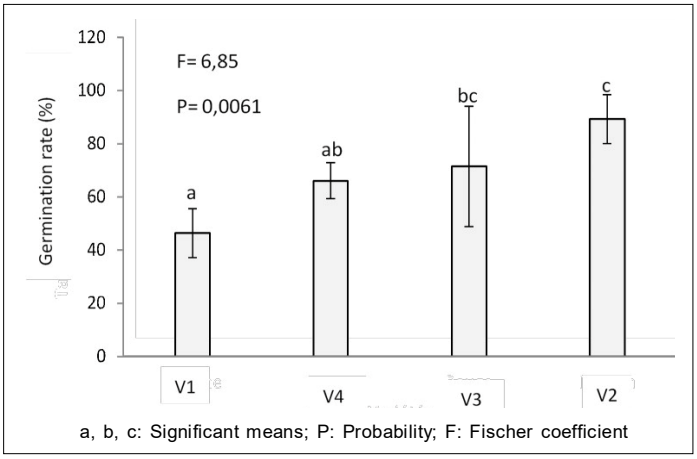


Fig 1: Variation in germination rate according to accession.

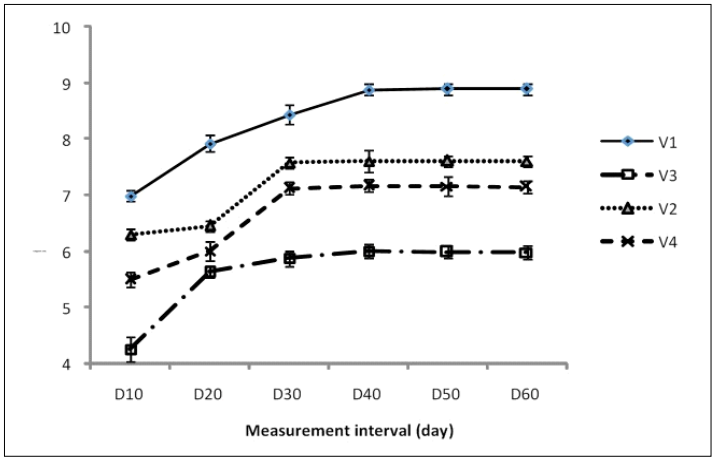


Fig 2: Variation in Length according to accessions.

Red), the white variety gave the longest leaflets than the red and black varieties. Similar to the results of Bonny *et al.* (2011) for white and brown varieties, which had the longest leaflets compared to the others.

Variation in width

The results of the analysis demonstrate the presence of variability in leaf widths (Fig 3). Indeed, a significant variation in leaf width was observed between accessions (p = 0.000), However, accession V1 exhibited the widest leaflets (2.8 cm), which was greater than the other accessions. These results differ from those reported by Yao *et al.* (2005), who found that the in Côte d'Ivoire, the Rouge variety was found to have the widest leaflets. than the white and black varieties. The leaf width observed in accession V1 indicates that these plants possess extensive photosynthetic surfaces, a trait that is likely attributable to the substantial light absorption capacity of these leaves in the Sahelian region, where temperatures are notably high. Consequently, they accumulate more organic matter.

The results from the descriptive statistical analysis (Table 4) demonstrate that, the mean number of leaves was determined to be seven at 40 days. This finding is incongruent with the observations reported by Wassouo *et al.* (2019), who documented that the mean number of leaves in Bambara groundnut is equivalent to 40 at 56 days post-sowing. The observed discrepancy can be attributed to the temporal increase in the average number of leaves. The mean plant height was found to be 15.08 centimeters, which is different to the findings of Temegne *et al.* (2018) who reported that the mean height of Bambara groundnut plants was 31,18 centimeters at 56 days post-sowing. This slight difference can be attributed to the fact that the growth of Bambara groundnut plants stabilizes after a certain number of days following the initial sowing. Consequently, the height of the plant exhibits a range from 9 centimeters to 20

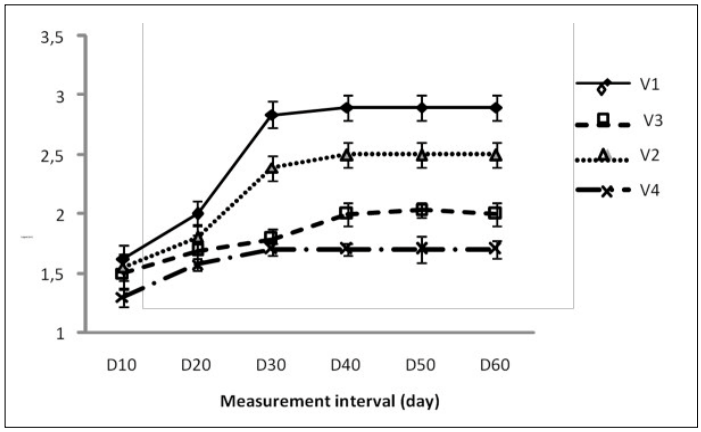


Fig 3: Variation in Width according to accessions.

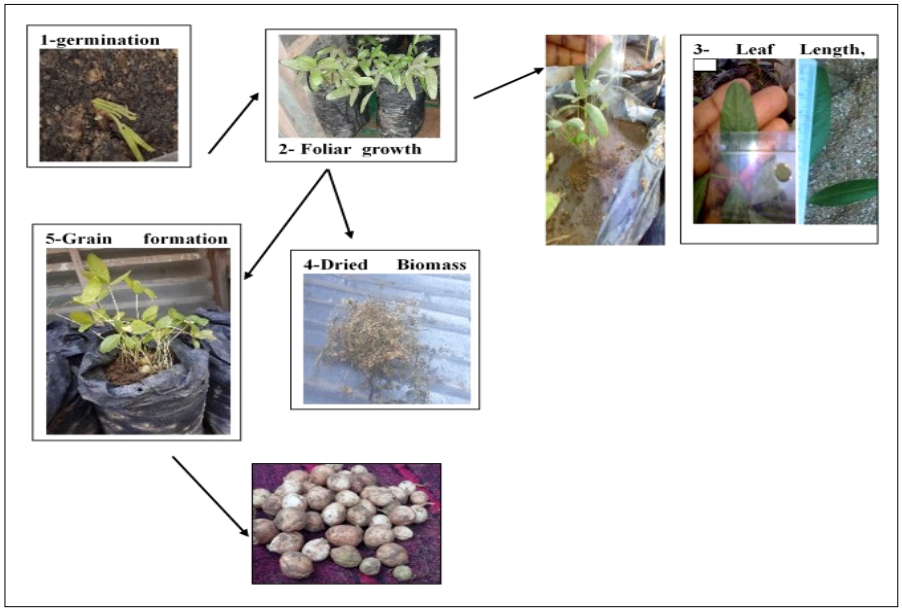


Fig 4: Pictorial presentation of the morphology of the plant at different growth stages.

centimeters. The values obtained in this study are analogous to those reported by Touré *et al.* (2013) who found values of 14 centimeters. However, these values are lower than those reported by Ndiang *et al.* (2012) in Cameroon, who found values ranging from 20 to 38 centimeters. The observed differences can be attributed to the genotype of each plant material, which is susceptible to environmental influences. A study of Bambara groundnut accessions on quantitative traits was reported by Khan *et al.* (2020), who noted a coefficient of variation (CV) ≥20% for quantitative traits studied. This finding aligns with the results of our study on variation coefficients, suggesting heterogeneity within the plant material for these variables. A similar, relevant observation of a high coefficient of variation was confirmed by Goli *et al.* (1997).

Variation in yield components and dry matter (Table 5 and 6)

A thorough examination of the data reveals a statistically significant impact of water stress on the overall weight of 100 pods and seeds produced per accession. Accession V1 exhibited a significant response to water stress, resulting in the production of the smallest pods (22 g). These results are consistent with those reported by Erskine *et al.* (1993), who found that abiotic stress significantly reduces lentil yield. In contrast, accession V4 exhibited a reduced impact, yielding an average pod weight of 24 grams. Accessions V2 and V3 exhibited the highest recorded weight of 26 g. These two accessions can be regarded as exhibiting reduced sensitivity to water stress. Consistent findings have been reported in related studies (Tambal *et al.,* 2000). On average, P100Gss exhibited a discrepancy of approximately 0.6 g in favor of the V3 accession. This phenomenon does not appear to exert a substantial influence on yield in our experimental setting, as evidenced by the observation that accession V2, characterized by a low pod weight of 26.14 g, exhibits the highest seed weight of 24.99 g. The total number of seeds is diminished; however, the reduction in the number of sheaths due to water stress is comparatively greater in accession V1, which has seeds of a lighter hue. The range of these values was from 6.16 in accession V1 to 9.47 in accession V2. Water stress has been demonstrated to result in pod abortion, which is characterized by a reduction in seed number due to the loss of young pods prior to seed formation and filling. These results are consistent with those reported by Shrestha *et al.* (2006), who observed that water stress led to a 27% reduction in the number of pods, with a significantly higher decrease in empty pods when water was retained. However, a higher root biomass weight was observed in accession V1 compared to the other accessions. However, this variability among accessions can be attributed to the observation that early accessions consistently yield high levels of dry matter. The findings of this study are consistent with those reported by Ouedraogo *et al.* (2008), who observed that late varieties yielded the least. The range of above-ground biomass values was from 5.34 grams in accession V1 to 4.19 grams

Table 4: Descriptive statistics on morphological parameters.

Variable	Observations	Minimum	Maximum	Average	Ecart-type	CV (%)
TL	12	6.500	9.000	8.354	0.727	8.70
Tg	12	44.100	88.600	66.667	0.308	18.40
NF	12	3.500	11.500	6.125	0.662	10.80
HP	12	9.000	20.000	15.083	3.655	24.20
LF	12	5.500	8.100	6.806	1.013	14.80
lF	12	1.450	2.825	2.038	0.404	19.80
SF	12	16.590	21.333	18.875	2.026	10.70
P 100 Gs	12	25.003	27.500	26.336	0.859	3.20
P 100 gr	12	24.003	26.500	26.207	0.781	2.90

CV: Coefficient of variation; TL: Germination time; Tg: Germination rate; NF: Number of leaves; HP: Height of the plant; LF: Leaves length; lF: Leaves width; SF: Leaf area; PGss: Weigth pods; Pgr: Weigth seed.

Table 5: Variation of yield components and dry matter.

Accession	P100Gss	P100grn	NGs	Ngr	Bio R	Bio A
V1	22.72±0.9b	19.10±9.1a	9.08±0.6a	6.16±0.5ab	6.04±0.5b	5.34±1.1b
V2	26.14±1.1b	24.99±0.5b	9.58±0.5d	9.47±0.3b	5.01±0.8a	4.19±1.5a
V3	26.20±0.2b	24.91±0.2b	8.16±0.8cd	8.32±0.5ab	5.67±1.2ab	4.92±0.7ab
V4	24.36±0.5a	24.10±0.4b	7.16±0.3ab	7.84±0.6a	5.72±1.1ab	4.68±1.4ab
F	7.083	4.519	12.532	2.995	1.251	1.701
P	0.000	0.003	0.000	0.026	0.301	0.163

P100Gss: Weight of 100 pods; P100grn: Weigth of 100 seed; NGs: Number of pod; Ngr: Number of seeds. Bio R: Rood biomass; Bio A: Aerial biomass; F: Coefficient of fisher; P: Probability.

in V2. Accession V1 exhibited the highest above-ground biomass value in comparison with accession V2. Despite its notably high above-ground dry weight, accession V1 exhibited the greatest sensitivity to water stress among the accessions examined, resulting in the lowest grain yield. This phenomenon could be attributed to two potential factors. Firstly, there is the possibility that vegetative organisms are being disproportionately assimilated under moderate conditions. Alternatively, the stressed V1 accession may have allocated a greater proportion of its resources to biomass growth, thereby compromising grain yield. The present findings contradict those of Bouzerzour *et al.* (1998), who posited that in variable environments, ensuring sufficient above-ground biomass production is imperative to ensure an acceptable yield. However, similar results were observed in the study by Surson *et al.* (2025), who reported that the rice M2 RD.43 variant 1 had more leaves but fewer whole seeds, as well as lower whole seed weight, seed width, seed length and seed formation percentage.

Variation of physiological traits of accessions

A statistical analysis of Table 7 reveals that the maximum error ratio (TRE) was observed at N1 (1L/5D), while the minimum was observed at N3 (0.25/5D). This finding suggests that the TRE declines with increasing water deficit. These results are consistent with those reported by Albouchi *et al.* (2000), who observed that the TRE in durum wheat declines as soil water content decreases. Lilya *et al.* (2002) observed that accessions capable of maintaining a high TRE in the presence of water stress are classified as tolerant accessions. A minimum water loss (TDE) of (-2.114± 0.067a) was observed in accession V2 at a severe stress level (N3, 0.25L 5D) compared with a high-water loss (-19.721±0.063c) recorded in accession V1. Additionally, accession V2 exhibited the smallest leaf area at (N3, 0.25L/5d). This suggests that the rate of water loss is inversely proportional to the surface area, with smaller surface areas resulting in reduced water loss. The results of this study are consistent with those reported by Kelliher *et al.* (1980). The aforementioned researchers observed that, in durum

Table 6: Effect of water stress on yield components and dry matter.

Source	DF	Mean of squares	F	P
Weight of pods				
Accession	3	4.125	23.993	0.000**
Stress levels	2	5.406	31.440	0.000**
Accession * Stress levels	6	1.686	9.804	0.000**
Error	45	0.72		
Weight of seeds				
Accession	3	76.187	629.097	0.000**
Stress levels	2	122.068	1007.946	0.000**
Accession *Stress levels	6	84713	699.490	0.000**
Error	45	0.121		
Rood biomass				
Accession	3	1.058	4.463	0.004*
Stress levels	2	15.984	67.446	0.000**
Accession* Stress levels	6	0.485	2.049	0.062^{ns}
Error	45	0.237		
Aerial biomass				
Accession	3	2.080	14.494	0.000**
Stress levels	2	27.282	190.115	0.000**
Accession * Stress levels	6	0.781	5.444	0.000**
Error	45	0.144		
Number of pods				
Accession	3	4.975	15.991	0.000**
Stress levels	2	2.517	8.089	0.001**
Accession * Stress levels	6	0.350	1.125	0.365^{ns}
Error	45	0.311		
Number of seeds				
Accession	3	0.906	3.551	0.013*
Stress levels	2	0.449	1.758	0.184^{ns}
Accession * Stress levels	6	0.532	2.086	0.057^{ns}
Error	45	0.255		

**Highly significant test at the 5% threshold; *Significant test at the 5% threshold; ns non-significant test at the 5% threshold.

wheat, the TDE increases as the leaf area expands. Accession V1 exhibited the largest surface area across all stress levels, while accession V2 demonstrated the smallest surface area in comparison to the other accessions. The smallest leaf areas were recorded at the severe stress level (N3, 0.25 L/5 d).

This finding suggests a negative correlation between leaf area and water deficit, indicating that as the water deficit increases, leaf area decreases. According to Granier *et al.* (2000), the leaves of plants subjected to water deficit exhibited smaller apparent final sizes in comparison to the control group. Lebon *et al.* (2006) confirmed that one of the earliest responses of plants to water deficit is the reduction of leaf area. Lebon *et al.* (2006) demonstrated that the reduction in leaf area under water is an adaptive mechanism for plants to limit leaf transpiration when water conditions become unfavorable. Conversely, only accessions V3 and V2 exhibited a diminished number of stomata among the accessions examined. A substantial decrease in the quantity of stomata was detected under conditions of severe stress (N3, 0.25 L/5 d) across all accessions, with the water deficit leading to a reduction of approximately 10 to 20% in stomata, there by constraining transpiration. This is explained by the fact that the onset of water stress implies a reduction in water loss, through the closure of stomata, resulting in a reduction in photosynthetic activity and transpiration. Thus, accession V2 exhibited a reduced level of transpiration in comparison to the other accessions. The findings of this study demonstrate a congruence with the results previously reported by Bourou *et al.* (2022) on the subject of Tamarindus, wherein a correlation was established between transpiration, stomatal conductance and net photosynthesis. A low water use efficiency (WUE) was observed (Fig 3) in accession V1 (0.80g/l) in contrast to accession V2, which has a higher WUE (0.89g/l). Accessions V3 and V4 demonstrate intermediate WUE values. The mean WUE values obtained from the accessions range from 0.80 g/l to 0.89 g/l. The findings of Chetto *et al.* (2020) indicated an average value of 0.712 WUE for the farms under analysis, signifying an average of 71.2% of the WUE by citrus growers. This finding aligns with the conclusions drawn from the present study. These divergent outcomes are consistent with the findings reported by Karam *et al.* (2007), who conducted a study on the water use efficiency (WUE) in corn. This phenomenon can be attributed to the higher WUE exhibited by plants with C4 photosynthetic metabolism in comparison to C3 species

Table 7: Influence of the level of water stress on the physiological parameters.

Accessions	Water stress levels			
	N0	N1	N2	N3
		Leaf area (SF)		
V1	19.59±0.43c	17.59±0.43c	13.61±2.608c	12.19±2.6 38c
V2	14.61±2.608a	13.61±2.608a	11.19±2.618a	7.73±1.97a
V3	15.15±4.896a	14.85±4.896a	11.69±2.522b	9.14±2.337ab
V4	15.93±1.95ab	16.93±1.95b	11.94±5.092b	10.25±2.745b
		Water loss rate (TDE)		
V1	-5.45±0.91c	-6.705±0.107c	-9.607±0.045c	-19.721±0.063c
V2	-8.153±0.052a	-15.153±0.052a	- 21.71±0.067a	-22.114±0.067a
V3	-7.142±0.055ab	-14.142±0.05a	-20.21±0.031ab	-21.112±0.042ab
V4	-6.251±0.045c	-9.233±0.045ab	-17.410±0.27b	-19.741±0.067c
		Relative humidity content (TRE%)		
V1	49.352±1.754c	47.441±1.754c	45.011±1.161c	37.501±0.75b
V2	47.812±1.816b	45.178±0.308	43.226±1.112a	41.881±1.213c
V3	49.441±2.881c	47.752±2.881c	43.133±1.732a	40.255±2.102c
V4	47.625±1.64ab	45.011±1.611a	43.111±1.722a	36.331±1.22a
		Stomata number		
V1	4.66±1.33bc	3.75±1.33c	2.48±0.47c	1.84±0.50c
V2	4.01±0.80a	3.04±0.80a	2.15±0.80a	1.25±0.80a
V3	4.06±0.95a	3.01±0.95a	2.11±0.80a	1.26±0.78a
V4	4.28±0.57b	3.68±0.57c	2.18±0.57ab	1.68±0.57b
		Leaf transpiration (%)		
V1	3.66±0.81c	3. 36±0.81c	2.98±0.97c	1.35±0.57c
V2	2.35±0.30a	2.151±0.50a	1.08±0.35a	1.05±0.25a
V3	2.45±0.60a	2.745±0.50b	1.09±0.42a	1.02±0.48a
V4	2.705±0.40ab	2.305±0.70ab	1.41±0.65ab	1.23±0.15b

SF: Leaf area (cm^2); TDE: Water loss rate (g $10^{-3}/cm^2/mn$); TP: Leaf transpiration (%); NS: Number of stomates; TRE: Relative humidity content (%).

(Rubino *et al.,* 1999). The V2 model demonstrated a high level of water use efficiency, as illustrated in Fig 5. This phenomenon can be attributed to the established relationship between yield and WUE, wherein elevated levels of yield are accompanied by heightened WUE. Therefore, it can be concluded from this observation that increases in yield are associated with accessions that demonstrate effective water use efficiency.

Table 8 presents the characteristics of accessions on yield in real conditions and under stress In the second season, an experiment was conducted at two distinct locations with the objective of estimating the mean yield per accession. The accessions were evaluated under two distinct conditions: Water-limited and natural. An evaluation of the test results indicates that accession V2 exhibits a significantly higher grain yield (65.72±0.50b) under conditions of water limitation in comparison to the other accessions. These results are similar to those of Karthiga *et al*. (2025), who observed an increase in cucumber productivity when genotypes were evaluated under water-deficient conditions. These results are also in line with observations of Dolinassou *et al*. (2016) on Arrachis hypogea, who reported that in the same location, the Gobo-55-437 line exhibited the highest average yield, while the NW-Red Esimbi genotype demonstrated a low yield. Water deficits have been shown to reduce yield by up to 10% in the V1 accession. Nevertheless, accession V3 demonstrated the highest yield (65.50±0.47 g) when the accessions were assessed in the field. These results are consistent with those reported by Shrestha *et al.* (2006), who found that seed yield in Lens culinaris was significantly higher than in other genotypes under conditions of adequate irrigation. Among the accessions examined, only two (accession V3 and V2) exhibited the optimal yield under stress conditions, with values of 64.96 g and 65.72 g, respectively. The observed outcomes can be attributed to the combined effects of water shock and end-of-season drought in this agroecological zone. However, it is noteworthy that only the V1 accession exhibited a reduction in grain yield. The decline in grain yield under water stress is predominantly attributed to the reduction in the number of seeds. These results are consistent with the observations of Shrestha *et al.* (2006), who noted that in Lens culinaris medikus, the 70% reduction in seed yield induced by water deficit was primarily due to a decrease in the number of pods and seeds. The utilization of the agronomic trait (number of pods and seeds) can facilitate the identification of accessions with superior traits (Gahoonia *et al.,* 2006) that can be integrated into the

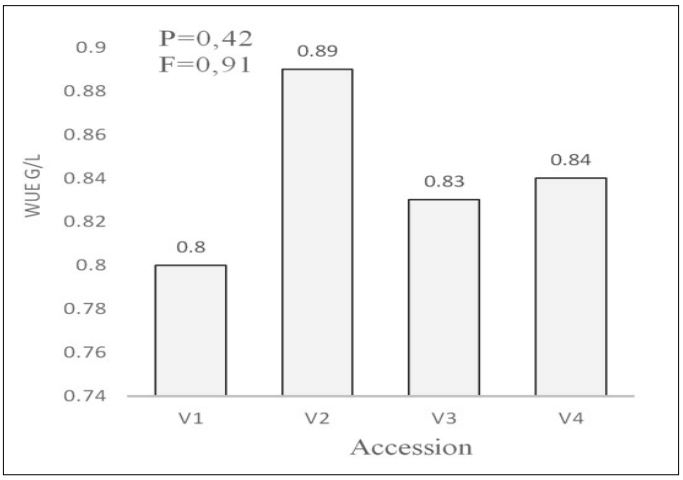


Fig 5: Variation of WUE with respect to accessions.

Table 8: Yield variability in real conditions and under stress.

Accession	Field	Station	Varietal average	STI
V1	56.80±0.63a	47.75±9.19a	52.27±9.82	0.696
V2	65.39±1.15b	65.72±0.50b	65.55±0.82	1.092
V3	65.50±0.47b	64.96±0.20b	65.23±0.67	1.013
V4	60.90±0.56a	60.25±0.47ab	60.57±1.03	0.942
Average	62.41±0.77	60.17±2.17	61.29	
σi2	0.98	1.01		
σI2	0.59	4.70		
σi2/ σI2	1.66	0.21		

σi2: Intra-varietal variance; σI2: Inter-varietal variance; σi2/σI2: Ratio of intra- and inter-varietal variance. Same letters for two lines: no significant difference; different letters: significant difference.

Table 9: Correlation matrix between the parameters studied.

Variables	T L	T g	NF	HP	LF	IF	SF	P100Gss	P 100grn	TRE (%)	TDE	NS	TP
T L	1												
T g	-0.110	1											
NF	0.501	0.166	1										
HP	0.638	0.155	0.847**	1									
LF	0.736**	-0.366	0.663	0.872**	1								
Lf	0.487	-0.142	0.677	0.845**	0.849**	1							
SF	0.483	-0.358	-0.082	0.102	0.476	0.385	1						
P100Gss	-0.140	0.198	0.210	-0.220	-0.100	-0.153	-0.153	1					
P 100grn	-0.225	0.175	0.022	-0.350	-0.173	-0.257	-0.147	0.956**	1				
TRE (%)	0.483	-0.358	-0.082	0.102	0.476	0.385	0.997**	-0.153	-0.147	1			
TDE	-0.481	0.152	0.168	-0.004	-0.217	-0.241	-0.806**	0.308	0.365	-0.806*	1		
NS	-0.208	0.000	-0.503	-0.509	-0.548	-0.673	-0.230	-0.122	0.021	-0.230	0.075	1	
TP	-0.025	-0.388	-0.312	-0.276	-0.215	-0.216	0.161	0.000	0.041	0.161	-0.135	0.437	1

**: Corrélation forte et significative (1%).

breeding program for the production of drought-tolerant varieties.

The highest stress tolerance indices were observed in accessions V2 and V3, while accession V1 was the most sensitive (Table 7). Similar results reported by Mohammadi *et al.* (2011) indicated that the index (STI) is well suited for selecting the most productive RILs (Recombinant Inbred Lines) under both stressful and favorable conditions. It is therefore clear that the stress tolerance index (STI) is a strong discriminator between genotypes with high yields and potential tolerance to water stress and other genotypes. According to Fernandez (1992), the STI can be used to identify genotypes that produce high yields under both favorable and stressful conditions.

Correlation matrix between the parameters studied

Table 9 presents the Pearson correlation matrix between the traits studied. In the genetic variability study of accessions by Khan *et al.,* 2020, it was concluded that a strong positive correlation (0.75 <r <1) was found for the seed weight and pod weight traits. A similar variation in these traits was reported by Goli *et al.* (1995), which confirms our results on the observation of strong and significant correlations between the weight of 100 seeds and the weight of 100 pods (r=0.956; p<0.01). This measurement of the weight of 100 seeds was considered an essential tool for evaluating morpho-physiological traits related to yield (Mohammed *et al.,* 2014). Kirham *et al.* (1980) noted that in durum wheat, the TDE increases as the surface area expands. A strong correlation was observed between germination time and leaf length (r = 0.736, p<0.01). Thus, the earliest accessions have the longest and widest leaves, indicating that the earlier they germinate, the more organic matter they accumulate. Additionally, the larger the leaf surface area, the higher the growth rate and yield. Cherfia *et al.* (2010) demonstrate a significant relationship between leaf area and yield. Indeed, the greater the leaf area, the higher the yield. Patel *et al.* (2025) found that larger leaflets can exploit more sunlight, resulting in greater biomass accumulation and higher yields**.** Araus *et al.* (1998) report that selecting for large leaf area improves grain yields. Belkharchouche *et al.* (2009) report that leaf area determines drought resistance since high leaf areas lose more water than low leaf areas.

CONCLUSION

The present study was conducted on Bambara groundnut accessions with the objective of evaluating the morphological and physiological characteristics of this species. The results demonstrated significant variability among the accessions under water stress. In regard to physiological parameters, the impact of water stress proved to be highly significant across the majority of the physiological traits that were examined. Water stress was applied to the accessions to identify an accession least sensitive to water stress. Accession V2 was identified as the most resistant, as indicated by lower water loss values, which are indicative of reduced sensitivity to stress.

The diverse morphological responses exhibited by the accessions' genetic material indicated that accession V2 demonstrated the least significant impact, exhibiting the highest 100-pod weight of 26 grams. This is in contrast to accession V1, which exhibited a substantial response to water stress, resulting in the lowest pod weight recorded at 22 grams. However, accession V2 exhibited a substantially higher seed weight compared to the other accessions. Given its notable productivity under conditions of hydric stress, this V2 accession has the potential to be selected for the enhancement of Bambara groundnut production in the Sahelian regions of Cameroon. However, further investigation into the water stress effect at other levels in the field with these accessions could facilitate the completion of these results for their use in breeding and varietal improvement programs.

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Disclaimers

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Informed consent

Not applicable.

Conflict of interest

The authors declare no conflicts of interest.

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