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Response of Cowpea (*Vigna unguiculata* L. Walp) Accessions to Moisture Stress

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Abstract: Cowpea is one of the most important leguminous crops in Sub-Saharan Africa (SSA), and moisture stress is among the constraints affecting its productivity. This study was conducted to understand the response of cowpea accessions to moisture stress. A total of 255 cowpea accessions from Togo and four checks from the International Institute of Tropical Agriculture (IITA), were assessed. The trials were conducted in the glasshouse and an open field (which was divided into moisture-stressed (MS) and non-moisture-stressed fields (NMS)). In the non-moisture-stressed environment compared to the moisture-stressed environment, there was a greater heritability for agronomic traits such as biomass, seed weight, and pod weight. The accessions with the highest seed weights (yield-related traits), surpassing the checks under both moisture-stressed and non-moisture-stressed conditions in the field, were six viz.: RK173 (49.8 g (MS); 90.4 g (NMS)), RP225 (34.6 g (MS); 119.9 g (NMS)), RP232 (33.4 g (MS); 51.9 g (NMS)), RM357 (27.9 g (MS); 62.9 g (NMS)), RK148 (23.9 g (MS); 63.4 g (NMS)), and Vu081_2_2 (21.8 g (MS); 46.7 g (NMS)). The most promising accession was RK173; this was ranked first under the moisture-stressed condition and ranked second under the non-moisture-stressed condition with a loss in weight of 44.9% due to drought stress. Of the top 20 accessions that recovered after watering resumed in the glasshouse screening, only the following 9 had a recovery percentage higher than 5% viz.: RS029 (34.5%), RK014 (14.2%), RS114 (9.6%), RK121 (8.3%), RS007 (7.6%), RK123 (7.3%), RS037 (7.3%), RS101 (5.6%), and RS108 (5.1%). The best line and those with a higher recovery percentage could be exploited further in order to improve them in future drought breeding programs by crossing them with lines susceptible to drought or using other drought breeding techniques.

Keywords: best linear unbiased prediction (BLUP); cowpea accessions; glasshouse; heritability; moisture stress

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1. Introduction

Cowpea (*Vigna unguiculata* L. Walp.), is a warm-season annual herbaceous crop [1]. Its grains are widely consumed by humans and dried haulms are fed to livestock [2]. As a result of its high folic acid and vitamin B contents, which are necessary to prevent birth abnormalities during pregnancy, and its seed protein level, which varies from 23% to 32% of seed weight, cowpea is commonly referred to as "poor man's meat" [3]. Its grains are rich in sodium (16 mg/100 g), potassium (1112 mg/100 g), dietary fiber (~11%), and lipids (<2%) [4], as well as antioxidants, polyunsaturated fatty acids (PUFA), and polyphenols, in addition to other nutrients [5–7]. Cowpea has the potential to contribute significantly to global food and nutritional security. Furthermore, it can be an important component of a sustainable food system as a genetic resource for future crop improvement, contributing to resilience and boosting agricultural sustainability under climate change circumstances [8].

Cowpea production globally is projected to be 4.5–6.5 million tons annually, with West Africa accounting for around 80% of the total production [9] with Nigeria, Niger, and Burkina Faso in the forefront [10,11]. Its productivity in Sub-Saharan Africa (SSA) is poor due to a variety of abiotic and biotic stresses, as well as socio-economic constraints [12]. A major abiotic stress in areas where cowpea is mostly produced is drought, resulting from low and unpredictable rainfall [13].

Cowpea does relatively well in drought circumstances as compared to many other crops. Drought, however, may still have a detrimental effect on yield, especially during the seedling and flowering stages [14,15]. The level of tolerance to drought in varieties that are currently cultivated can be further improved by breeding [15]. Several cultivars with good agronomic features have been discovered to be vulnerable to water scarcity [16]. In effect, cowpea breeding initiatives aimed at boosting the crop's drought tolerance are still needed. Drought stress is usually encountered by cowpea at both the seedling and terminal development phases and has often resulted in significant reductions in grain yield and biomass outputs [7]. During flowering and pod filling, drought stress has a detrimental influence on flower development, pollen viability, pod setting, and grain filling, resulting in fewer pods per plant, lower seed weight, and poorer seed output [13]. According to [17], there is a major need in Africa to screen and breed for drought-tolerant and water-efficient cultivars, as cowpea is largely farmed under rain-fed conditions, with regular exposure to periodic droughts. Recently, a collection of cowpea accessions from Togo was assembled. Togo is one of the countries in West Africa where cowpea is cultivated. The present study sought to determine the responses of cowpea accessions to drought stress in the glasshouse for the seedling stage and in the field for terminal stage drought tolerance.

2. Materials and Methods

2.1. Study Location and Experimental Materials

The study was carried out at the International Institute of Tropical Agriculture (IITA), (latitude 7°30′5″ N, longitude 3°54′36″ E), Old Oyo Road, Ibadan, Oyo state, Nigeria. A total of 255 cowpea accessions from Togo and four checks viz. Vita 7, CB 27, TVu7778 and Danila from IITA were used in the field experiment, while the same 255 accessions and two checks, namely Danila and TVu7778 from IITA, were assessed in the glasshouse for seedling drought tolerance.

2.2. Experimental Design and Procedure

2.2.1. Field

A field experiment was established in the dry season in December 2022. The land was plowed and harrowed. Thereafter, the field was cleared of all vegetation and divided into two, viz. an area to be irrigated (non-stressed) and the other for managed drought stress (moisture-stressed). The cowpea accessions were planted on 5 December 2022 under each of the two moisture regimes using an alpha lattice design with three replications. Twelve blocks were allocated 20 accessions each, while 1 block received 19 accessions. Plots consisted of single rows spaced 0.75 m apart. Seeds of the test lines and the checks were planted at a spacing of 20 cm on each row. Two seeds were planted per hill and thinned to one plant per hill two weeks after planting. No fertilizer was applied. Both the moisture-stressed and non-moisture-stressed blocks were irrigated for the first six weeks after planting. Thereafter, only the non-stressed block was irrigated twice weekly, and this continued till plant maturity. Insects were controlled with termex (active ingredient: chlorpyrifos, 480 g/L) and dynamec (active ingredient: abamectin, 18 g/L).

2.2.2. Glasshouse

The wooden box technique (shown in Figure 1), was used to assess the 255 cowpea accessions and two checks, viz. Danila and TVu7778, in the glasshouse. Each wooden box (length: 60.7 cm; width: 44.8 cm; and height: 11.4 cm) was filled with sieved gutter sand and top loamy soil mixed in a ratio of 3:1. Each tray was filled with 34 kg of the mixed soil. An alpha lattice design with two replicates was used in the glasshouse experiment. Each replicate consisted of 64 boxes. Four accessions were evaluated together with the two checks, viz. TVu7778 and Danila, in each of the 63 boxes. Additionally, one box contained three accessions and the two checks. In all, a total of 128 wooden boxes were used. Planting was carried out on 27 March 2023. The plants were watered to field capacity every 2–3 days. Watering in the glasshouse was suspended two weeks after planting.

Figure 1. Wooden box technique used to screen cowpea accessions for seedling drought tolerance in glasshouse.

2.3. Data Collection

Data were collected in both trials (field and glasshouse). In the field, data on agronomic traits were taken on plants under moisture-stressed and non-moisture-stressed conditions. Days to first flowering were recorded as the number of days from planting to the day when the first flower appeared on the plants in a row. Days to 50% flowering is the number of days from planting to the day when 50% of the plants flowered in a row. Days to 90% pod maturity was defined as the number of days from the date of planting to the day 90% of the pods in a row had become brown. The number of plants in each row was counted. Biomass weight was determined by cutting all the plants in a row at the base of the stem at harvest and then weighed. The weight was divided by the number of plants in each row to obtain biomass weight per plant. The pod weight per plant was determined by weighing all the pods harvested from each row and dividing by the number of plants in the row. Seed weight was determined by weighing all the seeds harvested from each row; this was divided by the number of plants in a row to determine the mean weight per plant. The 100-seed weight was obtained by counting 100 seeds from the bulked seeds of each row and weighing them in grams (g), but if the number of seeds was not up to 100, then the 100-seed weight was estimated as weight in grams of seeds/total number of seeds $\times$ 100.

In the glasshouse, the number of days to first seedling emergence was recorded as the number of days from planting to the day the first seedlings emerged. The number of days to 50% emergence was recorded as the number of days from planting to when 50% of the seedlings emerged and number of days to 90% emergence was obtained as the number of days when 90% of the seeds per row emerged. Stem greenness was determined on 21 and 30 days after stress was imposed (DAS). It was rated on a scale of 1 to 4, where 1 = 25% of the stems are green while 75% are brown, 2 = 50% of the stems are green, 3 = 75% of the stems are green while 25% are brown, and 4 = 100% or all the stems are green. The extent of wilting was scored on a scale of 0 to 4, where 0 = no wilting, 1 = 25% wilting, 2 = 50% wilting, 3 = 75% wilting, and 4 = 100% wilting. This was determined on 15, 21, 30, and 34 days from when watering was suspended. The number of plants was counted for each accession. Days to permanent wilting were obtained by recording the number of days from planting to the day the plants wilted completely. This observation was made for plants that did not regain their turgidity, became shriveled, and every part turned brown, one to two weeks after watering resumed. The number of plants that recovered after three weeks of water deprivation was counted. The percentage (%) of recovered plants was derived by dividing the number of plants that survived by the total number of plants that emerged multiplied by 100. The number of dead plants after watering resumed was also counted.

2.4. Weather Conditions During Field Experiment

The average temperature recorded during the field experiment (December 2022–March 2023) ranged from 21.7 °C to 33.4 °C and relative humidity ranged from 20% to 86%. Rainfall occurred twice in January with an average of 1.3 mm and thrice in February with an average of 13.4 mm. The average day length in December, January, and February 2022 were 8.0 h, 7.6 h, and 6.2 h, respectively.

2.5. Weather Conditions During Glasshouse Experiment

The average temperature within the screen house during the experiment ranged between 27.2 °C and 46.7 °C, while the relative humidity ranged between 39% and 81%.

2.6. Data Analyses

Data were analyzed using mixed models where replicate was considered a fixed effect and block, nested in replicate was considered a random effect. Accession was considered a fixed effect for estimating Best Linear Unbiased Estimators (BLUEs) and a random effect for estimating Best Linear Unbiased Predictions (BLUPs) and heritability. For the field data, we tested whether there was a significant treatment by accession interaction effect, and, where this was the case, we fitted a model for each treatment (stress, non-stress) separately. For analyses of days to 50% emergence, days to 90% emergence, days to 90% plant leaf fall, days to permanent wilting, number of dead plants, number of plants, stem greenness at 21 days after stress (DAS) was imposed, stem greenness at 30 DAS, wilting at 15 DAS, wilting at 21 DAS, wilting at 30 DAS, wilting at 34 DAS in the glasshouse as well as days to 50% flowering, days to 90% maturity, and days to first flower in the field, a generalized linear mixed model [18], was used under the assumption of a Poisson distribution. For percentage of recovered plants, a binomial distribution was considered. All other traits were assumed to be normally distributed. Phenotypic correlations were calculated as Pearson correlations between each pair of traits within the glasshouse dataset and separately for each treatment within the field dataset. All analyses were carried out using R (version 4) [19].

3. Results

3.1. Variation Among Cowpea Accessions for Agronomic Traits Under Moisture-Stressed and Non-Stressed Field Conditions

Accession by moisture conditions interaction effects on biomass, pod_wt, 100 seedwt, and seed_wt per plant were significant, requiring analysis per moisture condition (Table 1). Pod weight had a mean of 14.12 g and ranged from 0.13 g to 85.81 g under moisture stress while having a mean of 21.16 g and ranging from 1.07 g to 203.85 g when not moisture-stressed. The seed weight had a mean of 10.23 g and varied from 0.27 to 61.46 g under water stress and varied from 0.05 to 144.50 g with a mean of 14.95 g under non-water stress. The one hundred seed weight ranged from 5.52 g to 20.01 g with a mean of 12.57 g under moisture stress and ranged from 4.49 g to 27.03 g when not moisture-stressed with a mean of 11.07 g. Under moisture stress, biomass weight was in a range of 0.42 g to 120.13 g with a mean of 19.42 g and was in a range of 1.42 g to 213.95 g under non-moisture stress with a mean of 24.16 g (Table 2). The number of days to first flower varied from 42.0 g to 67.24 g with a mean of 49.35 g under moisture stress and varied from 40.33 g to 60.45 g with a mean of 47.29 g when not moisture-stressed. The number of days to 50% flowering varied from 25.45 g to 70.28 g with a mean of 52.42 g under moisture stress and varied from 41.73 g to 67.46 g under the non-stressed condition with a mean of 51.03 g. Number of days to 90% pod maturity ranged from 61.93 g to 78.18 g with a mean of 68.69 g under moisture stress and 63.01 g to 83.84 g under non-moisture stress with a mean of 69.63 g.

Table 1. The *p* values from the mixed models on agronomic traits of 255 cowpea accessions from Togo and four checks evaluated under moisture-stressed and non-moisture-stressed conditions in the field at IITA Ibadan, Nigeria (December 2022–March 2023).

	df	***p***						
Effects		**DFF**	**D50FL**	**D90MAT**	**PODWT**	**SEEDWT**	**SEED100WT**	**BIOMASS**
NMS								
Rep	2	0.432	0.671	0.093	0.002	0.001	0.038	0.002
Accession	258	0.999	0.999	0.999	<0.001	<0.001	<0.001	<0.001
MS								
Replicate	2	0.420	0.183	0.865	<0.001	<0.001	<0.001	0.004
Accession	258	0.999	0.999	0.999	<0.001	<0.001	<0.001	<0.001

DFF—Days to First Flowering, D50FL—Days to 50% Flowering, D90MAT—Days to 90% Pod Maturity, PODWT—Pod Weight, SEEDWT—Seed Weight, SEED100WT—100 Seed Weight, BIOMASS—Biomass Weight, NMS—Non-Moisture Stress, MS—Moisture Stress.

Table 2. Range of agronomic traits of 255 accessions of cowpea and four checks evaluated for drought tolerance in field at IITA Ibadan, Nigeria, during dry season (December 2022–March 2023).

Traits	**NMS**					**MS**				
	Mean	**SE**	**Min**	**Max**	**CV (%)**	**Mean**	**SE**	**Min**	**Max**	**CV (%)**
Days to First Flower	47.29	4.71	40.33	60.45	9.95	49.35	4.74	42.00	67.24	9.60
Days to 50% Flowering	51.03	4.89	41.73	67.46	9.58	52.42	4.89	25.45	70.28	9.32
Days to 90% Pod Maturity	69.63	5.78	63.01	83.84	8.30	68.69	5.60	61.93	78.18	8.16
Pod Weight	21.16	13.05	1.07	203.85	61.66	14.12	7.81	0.13	85.81	55.32
Seed Weight	14.95	9.33	0.05	144.50	62.40	10.23	5.69	0.27	61.46	55.64
100 Seed Weight	11.07	2.08	4.49	27.03	18.57	12.57	1.92	5.52	20.01	15.27
Biomass	24.16	15.78	1.42	213.95	65.32	19.42	10.52	0.42	120.13	54.13

NMS: Non-Moisture Stress; MS: Moisture Stress.

3.2. Variation in Seedling Traits Among Cowpea Accessions in Glasshouse

The mixed model analysis showed highly significant differences for percentage of recovered plants and days to permanent wilting among the cowpea accessions evaluated in the glasshouse (Table 3). The number of recovered plants ranged from 0.0 to 2.5, with a mean of 0.1. The number of days to 90% emergence varied from 5.0 to 7.2, with a mean of 6.7. The percentage of recovered plants varied from 0.0 to 58.9, with a mean of 0.9. The stem greenness score at 21 DAS ranged from 0.5 to 4.0 with a mean of 2.2. The stem greenness score at 30 DAS ranged from 0.0 to 3.5 with a mean of 1.3. Wilting at 15 DAS ranged from 0.0 to 1.0 with a mean of 0.6. Wilting at 21 DAS was in the range of 0.5 to 3.0, with a mean of 1.3. Wilting at 30 DAS ranged from 1.0 to 4.0 with a mean of 2.6. Wilting at 34 DAS ranged from 1.0 to 4.0 with an average of 3.0 (Table 4).

Table 3. *p* values from mixed models on agronomic traits of 255 cowpea accessions from Togo and two checks from IITA, evaluated at glasshouse in IITA Ibadan, Nigeria (March 2023–May 2023).

	df	***p***												**df**	***p* Value**
Effects		D50E	D90E	D90PLF	DPW	NODP	NOP	SG21 DAS	SG30 DAS	W15 DAS	W21 DAS	W30 DAS	W34 DAS		PPR
rep	1	0.745	0.134	0.004	0.044	0.946	0.893	0.001	0.001	0.003	0.483	0.032	0.002	1	0.799
accession	256	0.999	0.999	0.999	<0.001	0.999	0.999	0.999	0.323	0.999	0.999	0.999	0.999	125	<0.001

D50E—Days to 50% Emergence, D90E—Days to 90% Emergence, DPW—Days to Permanent Wilting, NODP—Number of Dead Plants, NOP—Number of Plants, PPR—Percentage of Recovered Plants, SG21DAS—Stem Greenness at 21 Days after Stress was Imposed, SG30DAS—Stem Greenness at 30 Days after Stress was Imposed, W15DAS—Wilting at 15 Days after Stress was Imposed, W21DAS—Wilting at 21 Days after Stress was Imposed, W30DAS—Wilting at 30 Days after Stress was Imposed, W34DAS—Wilting at 34 Days after Stress was Imposed.

Table 4. Range of agronomic traits of 255 cowpea accessions and two checks evaluated for drought tolerance in glasshouse in IITA Ibadan, Nigeria (March 2023–May 2023).

Trait	**Mean**	**SE**	**Min**	**Max**
Days to 50% Emergence	4.93	1.56	4.00	5.00
Days to 90% Emergence	6.73	1.84	5.00	7.15
Days to 90% Plant Leaf Fall	28.60	3.80	23.50	31.99
Days to Permanent Wilting	45.30	4.71	33.50	60.00
Number of Dead Plants	4.50	1.48	2.50	5.00
Number of Recovered Plants	0.10	0.08	0.00	2.50
Percentage of Recovered Plants	0.87	0.02	0.00	58.59
Stem Greenness at 21 Days after Stress was Imposed	2.15	1.01	0.50	3.99
Stem Greenness at 30 Days after Stress was Imposed	1.29	0.73	0.00	3.48
Wilting at 15 Days after Stress was Imposed	0.57	0.47	0.00	0.99
Wilting at 21 Days after Stress was Imposed	1.31	0.79	0.50	3.00
Wilting at 30 Days after Stress was Imposed	2.58	1.12	1.00	4.00
Wilting at 34 Days after Stress was Imposed	2.96	1.20	1.00	3.99

SE—Standard Error.

3.3. The Seed Weight of the Most Promising Accessions from the Moisture-Stressed and the Non-Moisture-Stressed Field Experiment

Table 5 shows the accessions with the highest seed weight from the moisture-stressed and non-moisture-stressed field environments. With respect to seed weight, six of the twenty accessions with the highest seed weights under non-stressed conditions were among the top twenty accessions under moisture-stressed conditions. These are RK173, RP225, RP232, RM357, RK148, and Vu081_2_2. These six accessions have great potential as the potential cowpea lines in breeding varieties that can produce good yields under non-stressed and moisture-stressed conditions. RK173 is the most promising of all the accessions. It was ranked number 1 under the moisture-stressed and number 2 under the non-stressed conditions. The loss in weight of this accession as a result of moisture stress was 44.9%.

Table 5. BLUP estimates of top 20 most promising accessions for seed weight (grams) from moisture-stressed and non-moisture-stressed field experiments at IITA Ibadan, Nigeria (December 2022–March 2023).

Moisture-Stressed		**Non-Moisture-Stressed**	
Accession	**Seed Weight (g/plant)**	**Accession**	**Seed Weight (g/plant)**
RK173	49.8	RP225	119.9
RP289	39.7	RK173	90.4
RP294	36.6	Vu053	85.6
Vu089_1_2	36.4	RP218	85.1
RP225	34.6	RK148	63.4
RP232	33.4	RM357	62.9

Table 5. *Cont.*

Moisture-Stressed		Non-Moisture-Stressed	
Accession	**Seed Weight (g/plant)**	**Accession**	**Seed Weight (g/plant)**
RP287	31.9	RP232	51.9
RM357	27.9	Vu081_2_2	46.7
RK150	27.2	RM351	42.3
RP282	27.1	RM346	41.9
RP219	26.6	RP259	38.9
RP234	25.6	RP272	37.7
Vu098	24.9	RP276	37.2
RC383	24.7	RP266	35.9
RM352	24.3	RC383	34.6
RK148	23.9	Vu081_AB	34.5
RP266	23.0	Vu031_1	34.5
RC392	22.5	Vu098	34.3
Vu081_2_2	21.8	Vu096_2_1	33.0
RK182	20.9	RS040	32.5

3.4. Correlations Among Traits of Cowpea Accessions Evaluated Under Moisture-Stressed Condition in Field

The correlation results among traits for the moisture-stressed condition are shown in Figure 2. The traits with the highest positive and significant correlations were pod weight vs. seed weight (r = 0.99, $p < 0.001$), biomass vs. seed weight (r = 0.80, $p < 0.001$), and biomass vs. pod weight (r = 0.80, $p < 0.001$). Seed weight had a low negative correlation with days to 50% flowering (r = −0.13, $p < 0.05$) and days to 90% maturity (r = −0.19, $p < 0.01$). Correlation was also high between days to first flower and days to 50% flowering (r = 0.71, $p < 0.001$) while moderate and positive correlation was obtained between days to first flower and days to 90% pod maturity (r = 0.41, $p < 0.001$), and days to 50% flowering vs. days to 90% pod maturity (r = 0.43, $p < 0.001$).

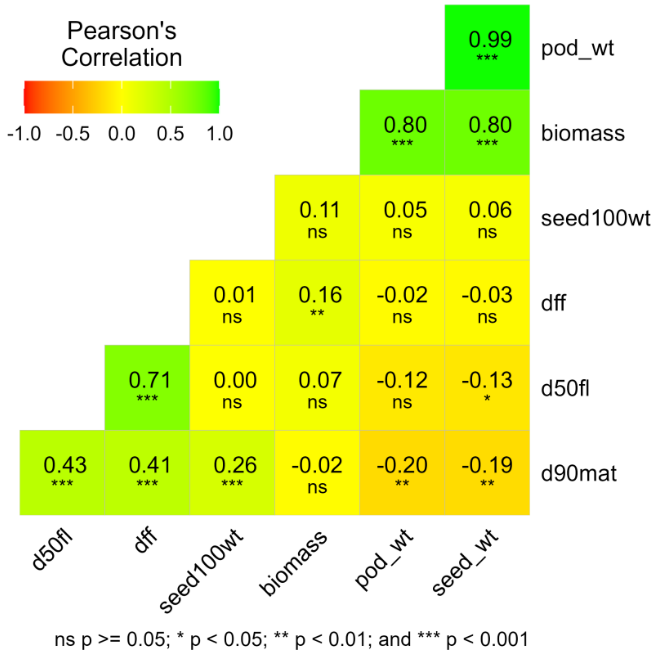

Figure 2. Pearson correlation showing the relationship among cowpea traits evaluated under moisture-stressed conditions in the field. dff—days to first flowering, d50fl—days to 50% flowering, d90mat—days to 90% pod maturity, pod_wt—pod weight, seed_wt—seed weight, seed100wt—100 seed weight, biomass—biomass weight.

3.5. Correlations Among Traits of Cowpea Accessions Evaluated Under Non-Moisture-Stressed Condition in Field

The results of the correlations between pairs of traits under the non-stressed condition in the field are shown in Figure 3. High significant correlations were obtained for pod weight vs. seed weight (r = 0.99, $p < 0.001$), biomass vs. pod weight (r = 0.91, $p < 0.001$), and seed weight vs. biomass (r = 0.91, $p < 0.001$). Days to 50% flowering and days to first flower also showed a high positive and significant correlation (r = 0.75, $p < 0.001$). Correlations were high, positive, and significant for days to 90% maturity vs. days to 50% flowering (r = 0.62, $p < 0.001$) and days to 90% pod maturity vs. days to first flower (r = 0.53, $p < 0.001$). Days to first flower had a low but significant correlation with seed weight and pod weight (r = 0.16, $p < 0.05$).

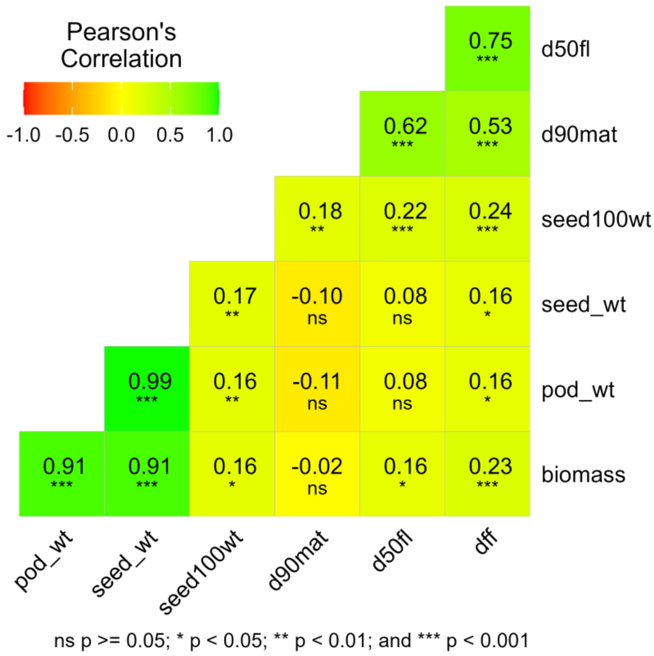

Figure 3. Pearson correlation showing the relationship among cowpea traits evaluated under non-moisture-stressed conditions in the field. dff—days to first flowering, d50fl—days to 50% flowering, d90mat—days to 90% pod maturity, pod_wt—pod weight, seed_wt—seed weight, seed100wt—100 seed weight, biomass—biomass weight.

3.6. Correlations Among Traits of Cowpea Accessions Evaluated in Glasshouse

The correlation results among traits in the glasshouse experiment are shown in Figure 4. Stem greenness 21 DAS had a high positive and significant correlation with stem greenness 30 DAS (r = 0.87, $p < 0.001$), wilting at 30 DAS and wilting at 34 DAS (r = 0.84, $p < 0.001$) were significantly correlated, which is the same for wilting at 21 DAS and wilting at 34 DAS (r = 0.56, $p < 0.001$), and wilting at 21 DAS vs. wilting at 30 DAS (r = 0.69, $p < 0.001$). High significant negative correlations were obtained between stem greenness at 21 DAS and wilting at 34 DAS (r = −0.66, $p < 0.001$); stem greenness at 21 DAS and wilting at 30 DAS (r = −0.61, $p < 0.001$); stem greenness at 21 DAS and wilting at 21 DAS (r = −0.52, $p < 0.001$); wilting at 34 DAS and days to permanent wilting (r = −0.63, $p < 0.001$); and wilting at 30 DAS and days to permanent wilting (r = −0.80, $p < 0.001$).

The correlations were positively significant for stem greenness at 30 DAS and percentage of recovered plants (r = 0.26, $p < 0.001$); and stem greenness at 30 DAS and number of recovered plants (r = 0.38, $p < 0.001$). The results also showed a significantly weak negative correlation between wilting at 34 DAS and percentage of recovered plants (r = −0.18, $p < 0.01$); and wilting at 30 DAS and number of recovered plants (r = −0.15, $p < 0.05$).

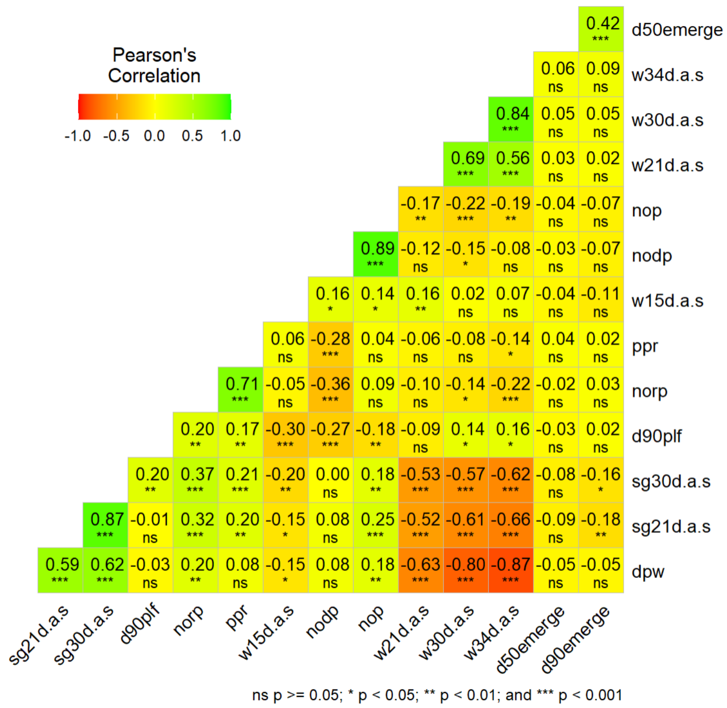

Figure 4. Pearson correlation showing the relationship among cowpea traits evaluated in the glasshouse. d50emerge—days to 50% emergence, d90emerge—days to 90% emergence, dpw—days to permanent wilting, nodp—number of dead plants, nop—number of plants, norp—number of recovered plants, ppr—percentage of plants recovered, sg21das—stem greenness at 21 days after stress was imposed, sg30das—stem greenness at 30 days after stress was imposed, w15das—wilting at 15 days after stress was imposed, w21das—wilting at 21 days after stress was imposed, w30das—wilting at 30 days after stress was imposed, w34daswilting at 34 days after stress was imposed.

3.7. The Heritability Estimates of the Traits Among Cowpea Accessions Evaluated in the Field Under Moisture-Stressed and Non-Stressed Environments

The heritability estimates from the stressed and non-stressed field experiments are shown in Table 6. Heritability for pod weight in the non-moisture-stressed field was 0.73 and 0.68 in the moisture-stressed field condition. Seed weight had a heritability value of 0.73 for non-moisture-stressed while heritability for the moisture-stressed condition was 0.67. One hundred seed weight had a heritability value of 0.57 under non-moisture-stressed field and 0.54 for the stressed field. Heritability for biomass was 0.72 in non-moisture-stressed condition compared to 0.67 in moisture-stressed condition in the field.

Table 6. Heritability estimates of traits among cowpea accessions evaluated in field under moisture-stressed and non-stressed environments in IITA, Ibadan Nigeria.

Traits	Heritability	
	Moisture-Stressed	Non-Stressed
Days to First Flower	<0.01	<0.01
Days to 50% Flowering	<0.01	<0.01
Days to 90% Pod Maturity	<0.01	<0.01
Pod Weight	0.68	0.73
Seed Weight	0.67	0.73
100 Seed Weight	0.54	0.57
Biomass	0.67	0.72

3.8. Heritability Estimates of Traits Evaluated in Glasshouse

The heritability estimates from the glasshouse experiment are shown in Table 7. Traits such as days to permanent wilting, stem greenness at 21 DAS, stem greenness at 30 DAS, wilting at 21 DAS, wilting at 30 DAS, and wilting at 34 DAS had high heritability values of 0.63, 0.62, 0.61, 0.59, 0.62, and 0.61, respectively. Days to 50% emergence, number of recovered plants and percentage of recovered plants, had low heritability values of 0.27, 0.22, and 0.23. The traits with the lowest heritability values were days to 90% emergence (0.01) and wilting at 15 DAS (0.12).

Table 7. Heritability estimates of traits among cowpea accessions evaluated in glasshouse in IITA Ibadan, Nigeria.

Traits	Heritability
Days to 50% Emergence	0.27
Days to 90% Emergence	0.01
Days to Permanent Wilting	0.63
Number of Recovered Plants	0.22
Percentage of Recovered Plants	0.23
Stem Greenness at 21 Days after Stress was Imposed	0.62
Stem Greenness at 30 Days after Stress was Imposed	0.61
Wilting at 15 Days after Stress was Imposed	0.12
Wilting at 21 Days after Stress was Imposed	0.59
Wilting at 30 Days after Stress was Imposed	0.62
Wilting at 34 Days after Stress was Imposed	0.61

3.9. The Percentage of Recovered Plants from the Glasshouse Experiment

A total of 20 of the accessions evaluated in the glasshouse experiment proved to have the highest percentage recovery from the imposed moisture stress in the glasshouse (Table 8). These plants wilted during the drought stress but were able to recover when watering resumed, indicating that they were able to withstand the drought.

Table 8. BLUP analysis showing the top 20 accessions with the highest percentage recovery following moisture stress in the glasshouse experiment.

S/N	Accession	Percentage of Recovered Plants (%)
1	RS029	34.5
2	RK014	14.2
3	RS114	9.6
4	RK121	8.3
5	RS007	7.6
6	RK123	7.3
7	RS037	7.3
8	RS101	5.6
9	RS108	5.1
10	RP309	4.7
11	RS002	4.7
12	RS024	4.7
13	RS038	4.7
14	RS082	4.7
15	Vu111	4.7
16	RP320	4.7
17	RP239	3.3
18	RS060	2.8
19	RS063	2.8
20	RS030	2.5

4. Discussion

An increasing threat to crop production globally is drought [20–22]. Cowpea growth and development are affected negatively by drought stress at the vegetative stage [23,24]. It also affects development of cowpea at the reproductive stage and causes a significant reduction in morphological traits at the flowering stage [14,25]. Efforts should be undertaken to produce drought-tolerant cowpea varieties that can withstand future climate change projections better than those presently available [26]. Screening for drought tolerant genotypes is a critical step in improving cowpea yield [27]. The results from this study revealed that the mean days to flowering were slightly higher under the moisture-stressed field condition than under the non-moisture-stressed field condition. This contradicted the findings of [28,29], which stated that flowering occurred earlier in grain legumes during moisture stress as an escape mechanism to adapt to the moisture stress situation. Lower mean values were also observed for pod weight and seed weight under the moisture-stressed condition as opposed to the non-stressed condition. The findings from this study (Table 2) indicated that the imposed drought lowered seed and pod weights by an average of 33%. Reduction in seed and pod weights in the moisture-stressed environment applied to the majority of the accessions. This suggests that drought situations may have an impact on seed yield and supports the finding of [15] that drought conditions may affect cowpea yields, particularly if they occur during the seedling and flowering stages. The outcomes corroborate earlier findings [13,27], that considerable reductions were observed for yield-related traits under drought stress. [30] also stated that crop yields are reduced by drought stress through reduction in radiation efficiency, harvest index, and photosynthetic active radiation [30]. According to [31], 40% of the world's chickpea losses each year is caused by drought stress. These observations show that moisture stress negatively affects yield in grain legumes.

The positive significant correlation between seed weight and pod weight is consistent with results obtained by [10,11,32,33]. The high positive correlation between biomass and yield-related parameters (pod weight and seed weight) implies that a reduction in biomass could ultimately lead to a reduction in yield and related traits. This corroborates reports by [34] that a reduction in shoot biomass results in a decreased yield under drought conditions. Correlation between biomass on one hand and pod weight and seed weight on the other hand were higher under the non-stressed than under the moisture-stressed condition ($r = 0.91$ vs. $r = 0.80$). This is also true for days to first flower and days to 50% flowering ($r = 0.75$ vs. $r = 0.71$), days to first flower and days to 90% pod maturity ($r = 0.53$ vs. $r = 0.41$), and days to 50% flowering vs. days to 90% pod maturity ($r = 0.62$ vs. $r = 0.43$). This could be an indication that the correlation among some traits is lower under drought conditions as shown from this study. More research should be conducted to ascertain this. The correlation between pod weight and seed weight was the same under the non-stressed condition than under the moisture-stressed condition ($r = 0.99$ vs. $r = 0.99$). The negative correlation obtained in this study for wilting vs. stem greenness, recovery, and percentage recovery are in consonance with the findings of [35]. This implies that stem greenness diminishes as plants continue to wilt due to water stress. [14,35] reported positive correlations between stem greenness and recovery which was also determined in this study. However, further studies are needed to unravel the bases of such correlations.

When highly heritable traits are linked to an important trait like yield, the former are good candidates to exploit for yield improvement [36]. Heritability was slightly higher among the traits evaluated under the non-stressed field condition than those evaluated under the moisture-stressed condition for pod weight, seed weight, 100 seed weight, and biomass weight as shown in this study. Further research might help to explain this. Pod weight, seed weight, 100 seed weight, and biomass weight had the highest heritability values under both moisture-stressed and non-stressed conditions. These traits can be useful for further cowpea improvement. The traits with high heritability values could be due to a higher genotypic variance than environmental variance, resulting in a broad sense of heritability [10]. This implies that the environment had little influence on these traits [37]. With regard to biomass weight, [38] reported a low heritability as opposed to the result obtained in this study. Traits such as permanent wilting, stem greenness at 21 days, stem greenness at 30 days, wilting at 21 days, wilting at 30 days, and wilting at 34 days after stress was imposed had the highest heritability values from the glasshouse experiment.

The most promising accession from the field experiment, RK173, was ranked number 1 under the moisture-stressed condition and number 2 under the non-stressed condition with reduction in weight of 44.9%. This accession can serve as an asset in future drought breeding experiments. In the glasshouse, only nine accessions had a recovery percentage higher than 5%, viz. RS029 (34.5%), RK014 (14.2%), RS114 (9.6%), RK121 (8.3%), RS007 (7.6%), RK123 (7.3%), RS037 (7.3%), RS101 (5.6%), and RS108 (5.1%). These accessions are coming mainly from the Savanna and Kara regions of Togo and can be utilized in the development of drought tolerant cowpea cultivars.

5. Conclusions

To evaluate the response of 255 cowpea accessions from Togo and four checks from IITA, for drought tolerance, trials were conducted on the field and glasshouse at IITA. The results revealed that significant variations for agronomic traits existed among the cowpea accessions evaluated under moisture-stressed and non-stressed conditions in the field and in the glasshouse. The positive correlations obtained for seed weight vs. biomass weight and seed weight vs. pod weight implies that improving biomass and pod weight will directly increase seed yield. The accessions RK173, RP225, RP232, RM357, RK148, and Vu081_2_2 were among the twenty cowpea accessions with higher seed weights that surpassed the checks and were found under both moisture-stressed and non-stressed conditions in the field. These six promising accessions have great potential to produce good yields under drought conditions. There were nine accessions with percentage recovery higher than 5% in the glasshouse, viz. RS029 (34.5%), RK014 (14.2%), RS114 (9.6%), RK121 (8.3%), RS007 (7.6%), RK123 (7.3%), RS037 (7.3%), RS101 (5.6%), and RS108 (5.1%). These should be exploited further for improvement in drought tolerance breeding programs by crossing the lines with higher percentage recovery to the lines with lower percentage recovery to improve their drought tolerance capabilities.

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