Scientific Research Publishing

Agricultural Sciences, 2023, 14, 457-473
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Screen House Assessment of Cowpea [(*Vigna unguiculata* (L.)] Genotypes for Drought Tolerance Using Selection Indices

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How to cite this paper: Sanogo, S.A., Diallo, S., Batieno, T.B.J., Ishola, A.I., Sawadogo, N. and Nyadanu, D. (2023) Screen House Assessment of Cowpea [(*Vigna unguiculata* (L.)] Genotypes for Drought Tolerance Using Selection Indices. *Agricultural Sciences*, **14**, 457-473.
https://doi.org/10.4236/as.2023.144030

Received: February 21, 2023
Accepted: April 4, 2023
Published: April 7, 2023

Abstract

Cowpea [*Vigna unguiculata* (L.)] is one of the most important arid legumes cultivated for pulse and forage production. Drought is one of the most damageable constraints to crop production impacting negatively food security. The potential of cowpea to address food security is well established. However, not much is known about the base index selection method in breeding cowpea for drought tolerance, which is important for yields. Consequently, the present study has been conducted to: 1) evaluate the yield performance of cowpea genotypes under artificial drought and well-watered condition, 2) ranke genotype performance using selection indices, and 3) assess relationship between agronomic traits and yield. The experiment was the 2 watering conditions laid out in a Randomized Complete Block Design (RCBD) with three replications. The experiment was carried out in pots under screen house at the Department of Horticulture at KNUST. The result showed that KPR1-96-73, Simbo, CZ06-4-16, Wilibaly and Agyenkwa were high yielding in well-water condition while Ghana Shoba, Sangaraka, Nketewade, Ghana Shoni and Korobalen were high yielding genotypes in water stress condition. The average yield reduction was 60.6% and 16% for grain and fodder yield respectively. The biplot displays revealed four groups among the genotypes tested which were based on their yielding capacity and drought tolerance. In cluster B high yielding and drought tolerant genotypes were identified, high yielding and drought susceptible have been identified in cluster A, low yielding and drought tolerant in cluster D, and lastly low yielding and drought susceptible in cluster C. Genotypes in cluster B were best due to the fact that it combines high yield and tolerance to drought. They were Ghana Shoni, Nketewade, Sangaraka and Ghana Shoba. These genotypes might be suitably employed in further drought tolerance breeding programs of cowpea. Significant relationships were observed between agronomic trait and yields under drought condition.

Keywords

Cowpea [*Vigna unguiculata* (L.)], Drought, Selection Index

1. Introduction

Cowpea [*Vigna unguiculata* (L.) Walp] is one of the most important food legumes in the drier regions of the tropics and sub-tropics where drought is a major production constraint due to low and erratic rainfall [1]. Cowpea provides a cheap source of protein, vitamins and carbohydrates to small scale farmers in Africa (Sariah *et al.*, 2010). The relatively high protein content of cowpea makes it an essential supplement to the diet of many Africans [2] consuming high carbohydrates but low in protein cereals, root and tuber crops. Cowpea is being cultivated over an area of about 12.5 million hectares with an annual production of over 3 million tons world over [3]. There has been an increasing trend over five decades in the global cowpea cultivation region from 2.41 to 10.68 million ha [4]. Nigeria is the world's largest producer, contributing about 61% and 58% of production in Africa and worldwide, respectively with a yearly production over 2 million tons on 5 million ha of land [4]. Ghana is positioned fifth in terms of production in Africa, with a yearly average production of 143,000 metric tons cultivated on around 156,000 ha of land [5]. Cowpea is second to groundnut in Ghana in terms of production and consumption [6]. Cowpea has the potential yield of around 3 tons/ha yet yields on farmers' field is estimated at around 300 to 500 kg/ha in Savannahs of sub-Saharan Africa [7]. This poor yield can be attributed to an array of limitations that exist in cowpea-producing areas. Both biotic and abiotic constraints impede the production of cowpea. Drought is a potential major constraint to crop production. It can strike at anytime, anywhere. Plants are most prone to damage due to limited water during flowering and pod setting stages [8]. Cowpea is sensitive to soil moisture stress during the vegetative and reproductive growth stages [9] [10]. Although cowpea is considered as being more drought tolerant than many other crops, its productivity is negatively affected by prolonged droughts and high temperatures [11] which are currently attributed to the effects of climate change. Despite the inherent capacity of cowpea to withstand drought, the erratic pattern of rainfall exposes the crop to drought at the onset and at the end of rainy season [12]. Therefore, it has become necessary to improve or identify drought tolerant cowpea varieties that can overcome such conditions. Thus, this study was conducted to assess cowpea genotypes for drought tolerance. Development and adoption of drought tolerant varieties are one of the options to cope with the changing climate [13]. However, the main environmental factor that affects the growth of plants in semi-arid tropical is drought. The study, therefore, sought to identify candidate drought tolerant lines that can be used for future breeding applications using physiological and agro-morphological indicators.

2. Material and Methods

2.1. Plants Material

Twenty-five (25) cowpea genotypes which composed of improved landraces, introduced genotypes and released cultivars were used in the experiment. The list of these genotypes was presented in **Table 1**.

2.2. Study Area

The experiment was carried out from 15th October to 23rd of December 2016 in the greenhouse at the Department of Horticulture, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana with the following geographical coordinates: latitudes 01˚36'N and 01˚43'W.

Table 1. List of 25 cowpea genotypes and their origins used in present study for evaluating drought tolerance under screen house conditions.

Entry	Designation	Origin	Entry	Designation	Origin
1	Dounafana	IER, Mali	14	KPR1-96-73	IER, Mali
2	IT93K-876-12	IER, Mali	15	Yerewolo	IER, Mali
3	CZ06-1-12	IER, Mali	16	Simbo	IER, Mali
4	Korobalen	IER, Mali	17	Agyenkwa	CRI-CSIR, Ghana
5	CZ06-1-05	IER, Mali	18	N'Barawa	IER, Mali
6	Hansadua	CRI-CSIR, Ghana	19	Acar 1	IER, Mali
7	Sanoudaoulen	IER, Mali	20	KPR1-96-54	IER, Mali
8	Asomdee	CRI-CSIR, Ghana	21	Hawaba	IER, Mali
9	Gorom-gorom	IER, Mali	22	CZ06-4-16	IER, Mali
10	Wilibaly	IER, Mali	23	Cinzana Telimani	IER, Mali
11	Ghana Shoba	IER, Mali	24	Amari Sho	IER, Mali
12	Nketewade	CRI-CSIR, Ghana	25	Ghana Shoni	IER, Mali
13	Sangaraka	IER, Mali			

2.3. Experimental Design

The experiment was a 25 × 2 factorial laid out in a Randomized Complete Block Design (RCBD) with three replications. The factors investigated were genotypes (25 levels) (**Table 1**) and water regime (2 levels; drought and well-watered condition). Each plot consisted of three plastic pots for both well-watered and drought-stress conditions. A total of 450 plastic pots were used, and the well-watered and drought-stress experiments were conducted separately in the same screen house.

2.4. Watering Condition

The experiment was conducted under two moistures condition in the same screen house; the water stress and the well-watered conditions. For the whole experimental time, plants received water twice or thrice each week (based on the visual observation of soil moisture state) until flowering time. Thereafter, the water-stress pots did not receive water until harvest, whereas well-watered were kept at the same watering condition (two times per week) till harvest.

2.5. Data Collection

2.5.1. Trial Soil Physical Analysis

The soil particle size was analyzed using the hydrometer method (Day, 1953).

$$\text{Calculation: \% sand} = 100 - [(A/W) \times 100]$$

$$\text{\% Clay} = 100 \times (B/W)$$

$$\text{\% Silt} = 100 - (\text{\% sand} + \text{\% clay})$$

where A = corrected hydrometer reading at 40 seconds.

B = corrected hydrometer reading at 3 hours.

W = weight of dry soil.

The textural class of the soil analyzed was then obtained from the textural triangle.

2.5.2. Agro-Morphological and Yield Traits

- Days to 50% flowering

For each plot the days to 50% flowering was measured individually when 50% of the plants were in a fully flowered state.

- Days to 50% maturity
- Plant height

The first plant height was taken at 15 DAP in order to assess plant growth. The second measurement was taken 30 DAP and at each sampling date, the height of each genotype was taken. Plant heights were measured from the base of the plant to the tip using a metallic measuring tape. Then, the average of three pots for each cowpea genotype was determined.

- Number of pods per plant

The number of pods per plant was recorded for each genotype two weeks after imposing the water stress and the average number was determined for each cowpea variety.

- Leaf senescence

Leaf senescence was scored visually two weeks after the termination of irrigation. By this time drought-sensitive checks showed rolled, wilted, or burned leaves in the drought plots. The state of leaf greenness/damage was rated on a scale from 1 to 5, with 1 = totally green and turgescent, 2 = green and slightly wilted, 3 = green-yellow and wilted, 4 = yellow-green and severely wilted, and 5 = completely yellow to brown (almost dead) (Figure 1).

NB: The scoring was done on both the drought and the well-watered cowpea plants.

2.5.3. Use of Indices for Selection of Genotypes

For both drought and normal condition cowpea genotypes, data on yield and other important agronomic traits were taken per plot on individual plant basis. For data on individual plant basis, the three plants of each plot for each genotype were used [14].

$$\text{Mean productivity (MP)} = \frac{Y_p + Y_s}{2} \quad (1)$$

$$\text{Tolerance index (TOL)} = Y_p - Y_s \quad (2)$$

$$\text{Stress intensity (SI)} = \frac{\bar{Y}_p - \bar{Y}_s}{\bar{Y}_p} \quad (3)$$

$$\text{Stress susceptibility index (SSI)} = \frac{Y_p - Y_s}{Y_p \times \text{SI}} \quad (4)$$

$$\text{Geometric mean productivity (GMP)} = \sqrt{Y_p \times Y_s} \quad (5)$$

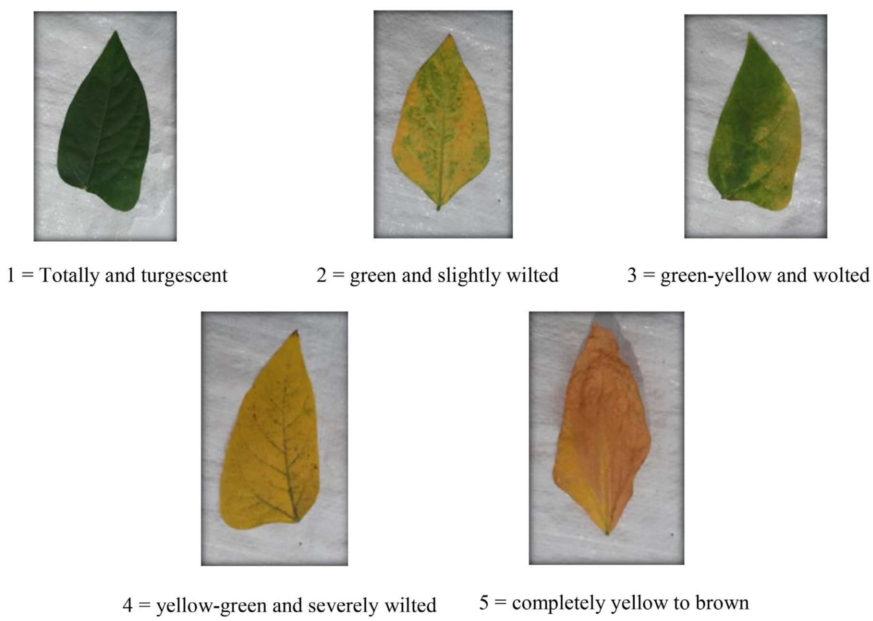

Figure 1. Cowpea under drought and well-watered condition a week after flowering.

$$\text{Stress tolerance index (STI)} = \frac{Y_p \times Y_s}{\bar{Y}_p^2} \quad (6)$$

where: Y_p and Y_s are the yields of each genotype under non-stressed and drought-stressed conditions, $\bar{Y}_p$ and $\bar{Y}_s$ are the mean yields of all genotypes under non-stressed and drought-stressed conditions, respectively.

- Then mean productivity (MP) is defined as the average yield of genotypes under drought and well water condition. Stress tolerance index (TOL) is defined as the difference between drought and well water yield.
- Stress intensity (SI) is classified into mild, moderate and severe. Stress intensity is mild when the stress intensity is situated between zero and twenty-five percent of yield reduction, moderate when the stress intensity is situated between twenty-five and fifty percent yield reduction and severe when the stress intensity is more than fifty percent yield reduction.
- Stress susceptibility index (SSI) estimates the level of yield reduction or susceptibility. The genotypes with SSI less than one are more resistant under drought condition.
- Geometric mean productivity (GMP) and stress tolerance index (STI) are used to identify the genotypes with high yielding ability under both drought and non-stress condition. More STI value of the given genotype under drought condition is large, the higher is its stress tolerance and its yield potential. The higher value of geometric mean productivity (GMP) for a given genotype indicates that it is high yielding genotypes under both drought and non-stress condition.

2.6. Statistical Analysis

Analysis of variance (ANOVA) was performed for all data collected using GenStat (version 12.0 Software). Tukey's honest test was performed to separate genotypic means. Correlation analysis was computed using yield and yield components and the calculated quantitative indices of drought. The quantitative indices for drought were calculated using (Excel 2013). Principal Component biplot Analysis (PCA) has been done by using data on yield and the quantitative indices of drought stress.

3. Results

3.1. Drought on Yield and Yield Components

The results of the analysis of variance (ANOVA) on yield and yield components of the 25 genotypes are presented in **Table 2**. The result of the ANOVA indicated a significant interaction between Genotype × Water Stress level for leaf senescence (LS) and hundred seed weight (HSW) ($p < 0.05$) (**Table 2**). For remaining parameters studied, the Genotype × Water Stress level interaction was not significant ($p > 0.05$) (**Table 2**).

Differences among the genotypes was highly significant ($p < 0.01$) for days to 50% flowering (DFF), days to 50% maturity (DFM) and fodders yield (FY) and it

Table 2. Analysis of variance for yield and yield components of 25 cowpea genotypes evaluated under watered and drought conditions at KKNUST under screen house conditions in 2016.

		Mean squares								
Sources of variation	*df*	DFF	LCC	LS	NPP	PY	GY	FY	HSW	DFM
Rep	2	1.26	33.5	0.2124	7.831	114,915	2,552,073	377,561	4.24	12.213
Genotype	24	24.007**	221.6*	0.7568*	14.738*	324,799*	404,763ns	371,842**	39.35ns	236.84**
Water treatment	1	12.327ns	3048.2**	50.2669**	198.759**	24,338,071**	38,681,101**	1,650,216**	0.14ns	416.667**
Genotype × Water	24	3.479ns	121.3ns	0.6797*	5.805ns	276,394ns	341,591ns	67,952ns	54.71*	13ns
Error	98	3.906	109.1	0.4063	8.18	171,026	334,611	85,748	30.82	338.453
Total	149									

Note: *, ** = Significant at 5% and 1%, respectively; ns = not significant; *df* = degree of freedom; DFF = days to 50% flowering, LCC = Leaf chlorophyll content; LS = Leaf senescence; NPP = number of pods per plant; PY = Pods yield; GY = Grain yield; FY = Fodders Yield, HWS = 100 seed yield, DFM = days to 50% flowering.

was significant ($p < 0.05$) for leaf chlorophyll content (LCC), leaf senescence (LS), number of pods per plant, and pods yield (PY) (Table 2).

The water stress level was highly significant ($p < 0.01$) for all parameters studied including leaf chlorophyll content, leaf senescence, number of pods per plant, pods yield, grain yield and fodders yield except days to 50% flowering and hundred seed weight (Table 2).

3.2. Performance of 25 Cowpea Genotypes under Drought-Stressed and Watered Conditions

There were significant differences in yield and yield components between genotypes in both well-watered and water-stressed conditions (Table 3). The mean yields of genotypes under non-stressed and stressed conditions were 1568.89 and 553.3 kg·ha^{-1}, respectively. The mean yield of all genotypes under well-watered condition was three times higher than the water stress condition.

The grain yield of genotypes ranged between 449.3 to 2513.5 kg·ha^{-1} and from 82.8 to 1101.5 kg·ha^{-1} under well-watered and water stress condition, respectively. Under well-watered condition the lowest and the highest mean grain yield were recorded for IT93K-876-12 and for KPR1-96-73 respectively. Also, under water stress condition, the lowest and the highest mean grain yield were recorded for Acar 1 and for Ghana Shoba, respectively.

The high yielding groups of genotypes were KPR1-96-73, Simbo, CZ06-4-16, Wilibaly and Agyenkwa, with each more than 1850 kg·ha^{-1} of grain yield. However, the low yielding groups of genotypes were Dounafana, Korobalen, Amari Sho, N'Barawa, Cinzana-Telimani, IT93K-876-12, with each less than 1300 kg·ha^{-1} (Table 3).

Under water-stress condition, the high yielding genotypes were Ghana Shoba, Sangaraka, Nketewade, Ghana Shoni and Korobalen, with each producing more

Table 3. Mean grain yield, pod yield and number of pods per plant of 25 cowpea genotypes evalueted under both water stress and well-watered conditions and their percentage losses.

Yield Potential	Genotype	Grain Yield (kg·ha^{-1})			Number of pod per plant			Pod yield (kg·ha^{-1})		
		Watered	Stressed	Loss (%)	Watered	Stressed	Loss (%)	Watered	Stressed	Loss (%)
HIGH	KPR1-96-73	2513.5	641.1	74.49	6	3	50.00	1823.0	955.0	47.61
	Simbo	2346.3	527	77.54	6	5	16.67	1823.3	1160.9	36.33
	CZ06-4-16	1978.5	294.6	85.11	8	4	50.00	2016.3	852.2	57.73
	Wilibaly	1930.2	565.6	70.7	8	5	37.50	1984.6	812.2	59.07
	Agyenkwa	1869.8	550.2	70.58	9	6	33.33	2574.1	1080.0	58.04
	Nketewade	1796.1	926.7	48.41	8	6	25.00	1501.1	1225.6	18.36
	KPR1-96-54	1774.8	655	63.09	7	6	14.29	2026.6	1159.6	42.78
	Ghana Shoni	1768.2	833.5	52.86	6	4	33.33	1828.7	895.9	51.01
	Sanoudaoulen	1734.8	673	61.21	6	5	16.67	1505.7	999.5	33.62
	Hawaba	1704.6	430.6	74.74	4	2	50.00	897.2	869.1	3.14
	Gorom-gorom	1686.9	108.2	93.59	5	2	60.00	1261.1	286.9	77.25
	Sangaraka	1613.3	945	41.43	6	4	33.33	1846.5	950.1	48.55
	Yerewolo	1498.2	279.8	81.32	6	2	66.67	2199.7	571.6	74.02
	CZ06-1-05	1404.4	677.8	51.74	6	2	66.67	1466.5	693.4	52.71
	Ghana Shoba	1394.3	1101.5	21	6	6	0.00	1592.0	1367.9	14.08
	Acar 1	1387.2	82.8	94.03	9	3	66.67	2168.0	642.0	70.39
	Asomdee	1368.1	481.7	64.79	2	5	−150.00	1626.3	732.2	54.98
	Hansadua	1335.7	510.6	61.78	5	3	40.00	1807.3	766.9	57.57
LOW	Dounafana	1254.8	464.6	62.97	5	3	40.00	1866.2	606.7	67.49
	Korobalen	1240.7	732.8	40.94	6	6	0.00	1598.5	1197.2	25.10
	Amari Sho	1235.9	565.2	54.27	6	3	50.00	1499.8	825.8	44.94
	N'Barawa	1113.7	310.6	72.11	6	5	16.67	1544.4	957.2	38.02
	Cinzana Telimani	985.6	243.9	75.25	4	3	25.00	1130.7	512.2	54.70
	IT93K-876-12	449.3	653.5	−45.47	14	7	50.00	1429.5	1340.0	6.26
	MEAN	**1568.9**	**553.3**		**6**	**4**		**1708.1**	**902.4**	
	LSD (5%)	**1161.6**	**454.6**		**5.7**	**3.028**		**725.0**	**12.2**	
	CV (%)	**22.1**	**27.5**		**21.2**	**24.1**		**25.9**	**25.6**	

than 700 kg·ha^{-1}. However, the low yielding groups of genotypes were N'Barawa, CZ06-4-16, Yerewolo, Cinzana Telimani, Gorom-gorom, and Acar1, with each less than 400 kg·ha^{-1}.

Although water stress reduced yield and yield component, the genotypes responded differently to the stress. Percentage yield reduction ranged between −45.47% and 94%. The high yielding group of genotypes (KPR1-96-73, Simbo, CZ06-4-16, Wilibaly and Agyenkwa) under well-watered condition recorded severe yield reduction with more than 70% each. Moreover, some moderate group yielding genotypes received more than 90% yield reduction such as Acar1 and Gorom-gorom. Acar1 recorded the highest yield reduction 94% and IT93K-876-12 recorded the least yield reduction −45%. The average yield reduction was 60.6%. In addition, the highest number of pods per plant (NPP) reduction was recorded for Acar1, CZ06-1-05 and Yerewolo with 66.67% each and the least number of pods per plant (NPP) reduction recorded for Asomdee was −150%. In general, the performance of the high yielding genotypes was not greatly reduced compared to the moderate and low yielding genotypes (Table 3).

The result of the ANOVA per water treatment (Table 3 and Table 4) showed significant difference in fodder and pod yield between genotypes under both well-watered and drought conditions.

The mean pod yield under well-watered and drought conditions were 1708.1 and 902.4 kg·ha^{-1}, respectively (Table 3).

The mean of pod yield for the genotypes ranged from 254.1 to 897 kg·ha^{-1} under well-watered condition and from 1367.9 kg·ha^{-1} to 286.9 kg·ha^{-1} in stress condition.

Drought reduced pod yield and fodder yield on an average of 45.13% and 16.52%, respectively (Table 3 and Table 4). The mean fodder yields of genotypes underwell-watered and stress conditions were respectively 1210.1 kg·ha^{-1} and 1000.3 kg·ha^{-1} (Table 4). The mean of genotypes fodder yield ranged from 1935 kg·ha^{-1} to 729 kg·ha^{-1} under well-watered condition and from 1679 kg·ha^{-1} to 617 kg·ha^{-1} for stress condition (Figure 2).

(a) (b)

Figure 2. Cowpea under drought and well-watered condition a week after flowering. (a) KPR-96-54 well water condition, KPR-96-54 water-stressed condition; (b) Ghana Shoni well-water condtion, Ghana Shoni water-stressed condition.

Table 4. Fodder yield performance of 25 cowpea genotypes under water-stress and well-watered conditions at KNUST.

Yielding ability	Fodder yield ($kg \cdot ha^{-1}$)			
	Genotypes	Watered	Stressed	% Reduction
HIGH	KPR1-96-73	1230.0	761.0	38.13
	Simbo	1000.0	889.0	11.10
	CZ06-4-16	1179.0	886.0	24.85
	Wilibaly	1308.0	1045.0	20.11
	Agyenkwa	1348.0	1137.0	15.65
MODERATE	CZ06-1-12	1169.0	1077.0	7.87
	Nketewade	1176.0	951.0	19.13
	KPR1-96-54	1190.0	667.0	43.95
	Ghana Shoni	1143.0	801.0	29.92
	Sanoudaoulen	1368.0	1264.0	7.60
	Hawaba	827.0	679.0	17.90
	Gorom-gorom	943.0	720.0	23.65
	Sangaraka	1264.0	768.0	39.24
	Yerewolo	1649.0	1136.0	31.11
	CZ06-1-05	1077.0	1025.0	4.83
	Ghana Shoba	947.0	809.0	14.57
	Acar 1	1285.0	1319.0	−2.65
	Asomdee	1352.0	1169.0	13.54
	Hansadua	1935.0	1679.0	13.23
LOW	Dounafana	1269.0	1069.0	15.76
	Korobalen	1126.0	1487.0	−32.06
	Amari Sho	757.0	617.0	18.49
	N'Barawa	729.0	786.0	−7.82
	Cinzana Telimani	1639.0	1014.0	38.13
	IT93K-876-12	1342.0	1252.0	6.71
	MEAN	**1210.1**	**1000.3**	
	LSD (5%)	**537.5**	**451.3**	
	CV (%)	**27.1**	**27.5**	

3.3. Correlations between Yield and Yield Components

3.3.1. Correlations between Yield and Yield Components under Watered Condition

Correlation analysis of yield and yield components under watered condition is presented in (Table 5). Significant weak correlation ($r = -0.269$, $p < 0.05$), was

Table 5. Correlations among seven traits of 25 cowpea genotypes evaluated under well-watered condition.

	DFF	LCC	LS	NPP	PY	GY	FY
DFF	-						
LCC	0.216	-					
LS	−0.269*	−0.048	-				
NPP	−0.169	−0.155	0.165	-			
PY	−0.083	−0.151	0.078	0.413**	-		
GY	−0.114	−0.106	−0.128	0.188	0.495**	-	
FY	0.118	0.036	0.087	0.204	0.275*	0.024	-

Note: ** = Significant 1% and * = Significant 5% DFF = days to 50% flowering, LCC = Leaf chlorophyll content LS = Leave senescence NPP = number of pods per plant; PY = Pod Yield; GY = Grain Yield, FY = Fodder Yield.

found between days to 50% flowering (DFF) and leaf senescence (LS). There was significant positive relationship ($r = 0.413$, $p < 0.05$), between the number of pods per plant (NPP) and pod yield (PY). The pod yield (PY) and grain yield (GY) showed a significant association ($r = 0.495$, $p < 0.01$) and between grain yield (GY) and fodder yield (FY) there was a weak relationship ($r = 0.275$, $p < 0.05$).

3.3.2. Correlations between Yield and Yield Components under Drought Condition

Correlation analysis of yield and yield components under drought condition is presented in (Table 6). The result of correlation analysis indicated that there was a significant negative association between days to 50% flowering (DFF) ($r = -0.329$, $p < 0.01$) and leaf senescence (LS) and there was also a significant negative relationship between days to 50% flowering) ($r = -0.323$, $p < 0.01$) and pod yield (PY). The correlation analysis also showed a significant negative correlation between days to 50% flowering (DFF) ($r = -0.450$, $p < 0.01$) and grain yield (GY) and then negative weak association ($r = -0.280$, $p < 0.01$) with number of pods per plant (NPP).

There was a weak significant relationship between leaf chlorophyll content ($r = -0.324$, $p < 0.01$) and number of pods per plant (NPP) and then negative weak association ($r = -0.274$, $p < 0.01$) with pod yield (PY) (Table 7). The association between leaf senescence (LS) and fodder yield ($r = -0.327$, $p < 0.01$) was also significant and negative. The correlation analysis showed a strong significant positive relationship between the number of pods per plant (NPP) and pod yield (PY) ($r = 0.786$, $p < 0.01$). There were a significant positive association between the number of pods per plant (NPP) and grain yield (GY) ($r = 0.470$, $p < 0.01$), fodder yield (FY) ($r = 0.235$ $p < 0.05$). Lastly there was a strong significant relationship between pod yield (PY) ($r = 0.513$, $p < 0.05$) and grain yield (GY).

Table 6. Correlations among seven traits 25 cowpea genotypes evaluated under drought conditions.

	DFF	LCC	LS	NPP	PY	GY	FY
DFF	-						
LCC	0.080	-					
LS	−0.329**	0.013	-				
NPP	−0.280*	−0.324**	−0.120	-			
PY	−0.323**	−0.274*	−0.086	0.786**	-		
GY	−0.450**	−0.039	−0.094	0.470**	0.513**	-	
FY	0.065	−0.115	−0.327**	0.235*	0.151	−0.004	-

Note: ** = Significant 1% and * = Significant 5%. DFF = days to 50% flowering, LCC = Leaf chlorophyll content LS = Leave senescence NPP = number of pods per plant; PY = Pod Yield; GY = Grain Yield, FY = Fodder Yield.

Table 7. Principal component loading scores for yield under both drought and well-watered conditions and indices of drought tolerance.

Percentage of variation explain							
Component	Y_p	Y_s	MP	GMP	TOL	SSI	STI
PC1 (57.44%)	39.25	34.26	49.11	47.65	17.45	2.33	47.89
PC2 (39.47%)	36.28	−43.31	9.2	−15.82	55.54	56.13	−15.42

Y_p = non-stressed yield; Y_s = Stressed yield; MP = Mean Productivity; GMP = Geometric Mean Productivity; TOL = Tolerance Index; SSI = Stress Susceptibility Index; STI = Stress Tolerance Index.

3.4. Principal Component and Biplot Analysis

The result of the principal component analysis and biplot of the 25 cowpea genotypes by seven indices data matrix are presented in Table 7 and Figure 3, respectively.

The first two principal components explained 96.92% of the total variation in the data matrix. The first principal component (PC1) explained 57.44% of the total variation while the principal component (PC2) explained 34.47% (Table 7). Well-watered yield (Y_p), stress tolerance index (STI), geometric mean productivity (GMP) and mean productivity (MP) had higher loading scores for PC1 than PC2 (Table 7). Hence, they were positively associated with PC1. Similarly, stressed yield (Y_s), stress susceptibility (SSI) and tolerance index (TOL) were related to PC2 according to their loading scores (Table 7). Stressed yield (Y_s) were however negatively related to PC2.

This biplot confirmed and indicated how close the vectors (quantitative indices) were. STI and GMP had no angle between them while SSI and Y_s were the most distant apart (Figure 3).

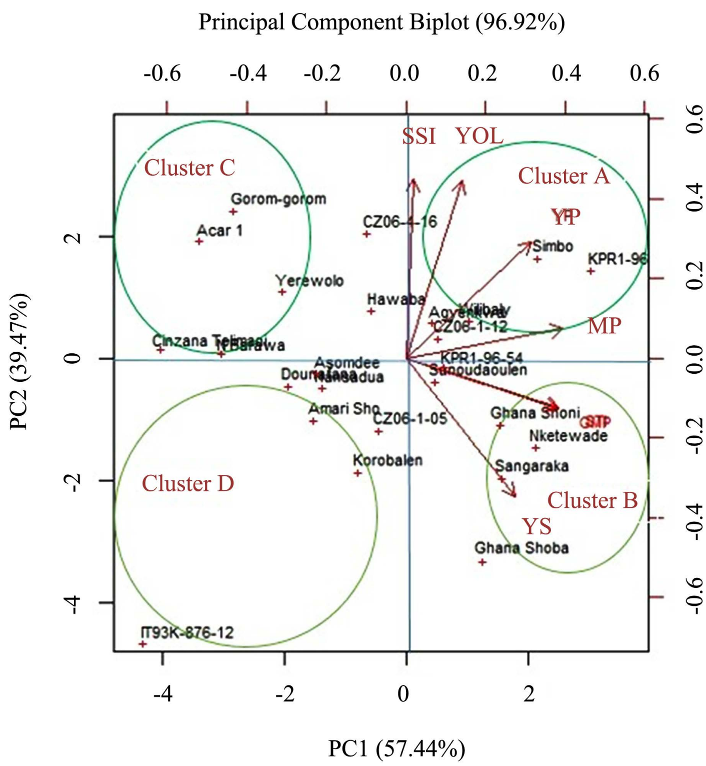

Figure 3. Biplot display of stressed yield (Y_s), non-stressed yield (Y_p) and quantitative indices of drought tolerance of 25 cowpea genotypes grown under water stress and well-watered conditions.

The genotypes were scattered on the biplot based on their stress tolerance and yield ability. Four unique cluster clusters could be identified on the biplot that agree to their yield potentials and stress-tolerance. The MP, Y_p, TOL and SSI, were correlated with genotypes in cluster A. Genotypes in cluster A are Simbo, KPR1-96-73, Wilibaly, Agyenkwa, CZ06-1-12.

Y_s, GMP and STI were correlated with genotypes in cluster B. These genotypes were Ghana Shoni, Nketewade, Sangaraka and Ghana Shoba. Genotypes such as Acar 1, Cinzana Telimani, Gorom-gorom and Yerewolo belonging to cluster C were characterized by low values of Y_s, GMP and STI. Cluster D was characterized bay low values of MP, Y_p, TOL, SSI and was made up of IT93K-876-12, Korobalen, Amari Sho and Dounafana.

4. Discussion

4.1. Effect of Adverse Moisture Condition on Yield and Yield Components

The significant positive association between grain and pod yield suggested that improvement in grain yield could be realized by selecting genotypes based on the yield of pod. These findings are in concord with those of [14] who found that there were significant and positive relationships between grain yield (GY) and number of pods per plant (NPP) and suggested that improvement should be achieved by using those germplasms.

The production of high yielding genotype under ideal condition was five times more than the low yielding genotypes in ideal condition, but under drought conditions, some low yielding was stable across both environments than some of high yielding genotypes. As a consequence, [15] advised that yield's selection is more efficient under drought condition than ideal conditions. The stress intensity applied to this study was around 64%, which was high.

This was certainly due to the low capacity of the soil to hold water and the important rate of evaporation during the experimental period. This stress intensity caused a considerable yield loss of genotypes. The grain yield formation was more sensitive to drought than the vegetative growth. This could be explained by the fact that genotypes experienced the identical water treatment in the drought and watered condition until initiation of flower buds. These findings are in agreement with those of [16] who found that cowpea grain yield was reduced by 65% and fodder yield by 35% under water stress environment.

The significant correlation among yield and yield component under drought condition indicated that grain yield was significantly related to number of pods per plant. This implies that the selection for number of pods per plant might improve the grain yield. By evaluating the genotypes of cowpea under both drought and well-watered condition indicated there was a relationship between grain yield and number of pods per plant [17]. [18] said that the number of pods per plant was principal reducer of grain yield due to the association between them.

The number of pods per plant under stress environment was low. This diminution in number of pods per plant was strictly associated with floral abortion due to the moisture stress [17]; [19] also mentioned that floral abortion leads to the reduction of number of pods per plant.

4.2. Principal Component and Biplot Analysis

The first two principal components (PC1 and PC2) explained around 96.92% of the total variations. The highest variation (57.44%) was explained by PC1 and was associated with Y_p, mean productivity, geometric mean productivity, and stress tolerance index. Thus, this dimension was named the yield potential – mean productivity component [18] [20]. The high yielding genotypes were separated from the low yielding genotypes by PC1. The second principal component (PC2) was also positively related to stress susceptibility index and tolerance index and negatively related to stress Y_s. This second dimension is, thus separating drought tolerant genotypes from susceptible genotypes and can be named the stress tolerance dimension [18] [20].

As shown in **Figure 3**, the genotypes have been scattered over the principal biplot space based on their Y_p and Y_s and drought tolerance quantitative indices. The cosine of the angle between two vectors designs the correlation coefficient between them on the principal biplot. [18] reported that the smaller the angle between two vectors is, the more these vectors are associated. According to **Fig-**

ure 3, the angle formed by stress tolerance index and geometric mean productivity was zero. This suggests a strong association between these two indices. This could be due to the fact that stress tolerance index is derived from geometric mean productivity.

Four clusters were identified in this study as shown in **Figure 3** on cluster A, we have high yielding and drought susceptible genotypes which were negatively impacted by water stress. Genotypes such as Ghana Shoni, Nketewade, Sangaraka and Ghana shoba in cluster B were high yielding and drought tolerant. Cluster C was made up of low yielding genotypes and drought susceptible ones.

In cluster D genotypes such as korobalen, Amari Sho, Dounafana were low yielding but drought tolerant.

5. Conclusions

The present study has been conducted to: 1) evaluate the yield performance of cowpea genotypes under artificial drought and well-watered conditions, 2) develop a base index using multiple traits for ranking genotype performance and 3) assess relationship between agronomic traits and yield. The following findings were made:

A large genotypic variability for drought tolerance exists among the tested genotypes given their differential response to drought. Using a biplot display of yield and quantitative indices for stress tolerance, four clusters of genotypes have been identified based on yielding capacity and drought tolerance. In cluster B, high yielding and drought tolerant genotypes have been identified, high yielding and drought susceptible have been identified in cluster A, low yielding and drought tolerant in cluster D and lastly low yielding and drought susceptible in cluster C. Genotypes in cluster B were the best due to the fact that they combine high yield and tolerance to drought ability. These were Ghana Shoni, Nketewade, Sangaraka and Ghana Shoba.

Stress tolerance was the best among the quantitative indices of drought tolerance because it enables the identification of cluster B genotypes. Promising genotypes that combine terminal drought tolerance with high yielding ability were Ghana Shoni and Nketewade. Some genotypes from CRI-CSIR in Ghana already identified as drought tolerant were validated in the present study. NKetewade was drought tolerant and high yielding genotype and Agyenkwa high yielding and drought susceptible genotype. The genotypes from IER-Mali, Ghana Shoni, Ghana Shoba and Sangaraka were found to be drought tolerant and high yielding genotypes. These genotypes might be suitably employed in further drought tolerance breeding programs of cowpea. Significant relationships were observed between agronomic trait and yields under drought condition.

Acknowledgements

We wish to thank the staff of the Department of Horticulture, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana in various aspects of this work. This research was supported by a grant from AGRA Master Scholarship. Our gratefulness is to the staff of the Cowpea Breeding Program at the Institut d'Economie Rural (IER) for their support. The design, execution and interpretation of the research remain wholly the responsibility of the authors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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