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

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Abstract

Cowpea [(*Vigna unguiculata* (L.)] is one of the most important arid legumes cultivated for pulse and forage production. However, in cowpea, not much is known about the base index selection method in breeding for drought tolerance. Consequently, the present study has been conducted to: 1) evaluate the yield performance of cowpea genotypes under artificial drought and well-watered condition; 2) develop a base index using multiple traits for ranking genotype performance. The experiment was a 25 × 2 factorial laid out in a Randomized Complete Block Design (RCBD) with three replications. The experiment was carried out in the 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% for grain respectively. The biplot displays revealed four groups among the genotypes tested which was 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 the 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 program of cowpea.

Keywords

Cowpea [(*Vigna unguiculata* (L.)], Post Flowering Drought, Drought Tolerance Index

1. Introduction

Cowpea [*Vigna unguiculata* (L.) Walp] is one of the most economically important indigenous African grain legumes with enriched proteins as source of food for both human and animal nourishment and a major crop in regional trade within West and Central Africa [1]. 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. 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. Ghana is positioned the 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 [4].

Cowpea is second to groundnut in Ghana in terms of production and consumption [5]. Ghana has been reported to have the fastest growing production rate in Africa. Cowpea has the potential yield of around 3 tons/ha yet yields on farmers' field are estimated around 300 to 500 kg/ha in Savannahs of sub-Saharan Africa [6]. 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. The most essential biotic factors that cause heavy yield loss in cowpea production include insect pest. Drought is also known as low soil moisture condition. It is an obstacle established by the environment to the productivity and survival of a crop. This leads directly to economic losses for the farmers who depend on the harvest [7]. [8] reported that the dry stress occurs when soil water intake does not compensate for the loss of water by transpiration. However, the main environmental factor that affects the growth of plants in semi-arid tropical is drought.

2. Material and Methods

2.1. Site of Experiment

The experiment was carried out from 15th October to 23rd of December 2016 in the screen house 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.

2.2. Germplasm

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**.

2.3. 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, the well-watered and drought-stress experiments were done separately in the same screen house.

2.4. Irrigation Schedule

The experiment was done under two research conditions in the same plant 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, drought research condition did not receive water until harvest, whereas well-watered condition, plants were kept well-watered twice per week (**Figure 1**).

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			

(a)

(b)

Figure 1. Cowpea under drought and well-watered condition a week after flowering. (a) Drought condition; (b) Well-watered condition.

2.5. Data Collection

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.

Data were collected on days to 50% flowering and days to physiological maturity which is gotten from the day of planting to when pods turn yellow. Plant height, number of pods per plant was collected on three (3) different plants per plot into replications. Yield per hectare and 100 seed weight was estimated from each plot. Yield based quantitative indices of stress tolerance including: Mean productivity (MP), tolerance index (TOL) [9]; stress susceptibility index (SSI), stress intensity; geometric mean productivity (GMP) and stress tolerance index [10] were calculated using the following formulae:

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

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

3) Stress intensity $\left(\mathrm{SI}\right)=\dfrac{\overline{Y}_p-\overline{Y}_s}{\overline{Y}_p}$

a) Stress susceptibility index $\left(\mathrm{SSI}\right)=\dfrac{Y_p-Y_s}{Y_p\times \mathrm{SI}}$

b) Geometric mean productivity $\left(\mathrm{GMP}\right)=\sqrt{Y_p\times Y_s}$

4) Stress tolerance index $\left(\mathrm{STI}\right)=\dfrac{Y_p\times Y_s}{\overline{Y}_p^2}$

Where: Y_p and Y_s are the yields of each genotype under non-stressed and drought-stressed conditions, $\overline{Y}_p$ and $\overline{Y}_s$ 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 is 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 quantitative indices of drought calculated. 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. 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 2). 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.

Table 2. Mean grain yield and number of pods per plant of 25 cowpea genotypes evaluated under both water stress and well-watered conditions and their percentage losses.

Yield Potential	Genotype	Grain Yield (kg·ha^{-1})			Number of pods per plant		
		Watered	Stressed	Loss (%)	Watered	Stressed	Loss (%)
HIGH	KPR1-96-73	2513.5	641.1	74.49	6	3	50.00
	Simbo	2346.3	527	77.54	6	5	16.67
	CZ06-4-16	1978.5	294.6	85.11	8	4	50.00
	Wilibaly	1930.2	565.6	70.7	8	5	37.50
	Agyenkwa	1869.8	550.2	70.58	9	6	33.33
MODERATE	CZ06-1-12	1837	576.3	68.63	5	4	20.00
	Nketewade	1796.1	926.7	48.41	8	6	25.00
	KPR1-96-54	1774.8	655	63.09	7	6	14.29
	Ghana Shoni	1768.2	833.5	52.86	6	4	33.33
	Sanoudaoulen	1734.8	673	61.21	6	5	16.67
	Hawaba	1704.6	430.6	74.74	4	2	50.00
	Gorom-gorom	1686.9	108.2	93.59	5	2	60.00
	Sangaraka	1613.3	945	41.43	6	4	33.33
	Yerewolo	1498.2	279.8	81.32	6	2	66.67
	CZ06-1-05	1404.4	677.8	51.74	6	2	66.67
	Ghana Shoba	1394.3	1101.5	21	6	6	0.00
	Acar 1	1387.2	82.8	94.03	9	3	66.67
	Asomdee	1368.1	481.7	64.79	2	5	−150.00
	Hansadua	1335.7	510.6	61.78	5	3	40.00
LOW	Dounafana	1254.8	464.6	62.97	5	3	40.00
	Korobalen	1240.7	732.8	40.94	6	6	0.00
	Amari Sho	1235.9	565.2	54.27	6	3	50.00
	N'Barawa	1113.7	310.6	72.11	6	5	16.67
	Cinzana Telimani	985.6	243.9	75.25	4	3	25.00
	IT93K-876-12	449.3	653.5	−45.47	14	7	50.00
	MEAN	*1568.9*	*553.3*		*6*	*4*	
	LSD (5%)	*1161.6*	*454.6*		*5.7*	*3.028*	
	CV (%)	*22.1*	*27.5*		*21.2*	*24.1*	

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 group 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 group of genotypes were Dounafana, Korobalen, Amari Sho, N'Barawa, Cinzana-Telimani, IT93K-876-12, with each less than 1300 kg·ha^{-1} (**Table 2**).

Under water-stress condition, the high yielding genotypes were Ghana-Shoba, Sangaraka, NKetewade, Ghana-Shoni and Korobalen, with each producing more than 700 kg·ha^{-1}. However, the low yielding group 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% to 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 compare to the moderate and low yielding genotypes (**Table 2**).

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 under well-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.

3.2. Yield Based on Quantitative Indices of Drought Tolerance

Table 3 shows the means yield based on quantitative indices of drought tolerance of 25 cowpea genotypes. Across all genotypes the average geometric mean productivity (GMP) was 881.53. Ghana Shoba had geometric mean productivity (GMP) value of 1239.25 being the highest and Acar 1 had 338.87 being the lowest geometric mean productivity (GMP) value. Across genotypes, the mean value

Table 3. Yield based on drought tolerance indices of 25 cowpea genotypes.

Yield Potential	Genotypes	GMP	MP	SSI	STI	TOL
HIGH	KPR1-96-73	1269.43	1577.32	1.15	0.65	1872.41
	Simbo	1112.02	1436.67	1.20	0.50	1819.26
	CZ06-4-16	763.50	1136.58	1.31	0.24	1683.89
	Wilibaly	1044.81	1247.88	1.09	0.44	1364.63
	Agyenkwa	1014.27	1210.00	1.09	0.42	1319.62
MODERATE	CZ06-1-12	1028.92	1206.67	1.06	0.43	1260.74
	Nketewade	1290.12	1361.39	0.75	0.68	869.44
	KPR1-96-54	1078.19	1214.91	0.97	0.47	1119.81
	Ghana Shoni	1214.00	1300.84	0.82	0.60	934.63
	Sanoudaoulen	1080.49	1203.89	0.95	0.47	1061.85
	Hawaba	856.71	1067.60	1.15	0.30	1274.07
	Gorom-gorom	427.12	897.50	1.45	0.07	1578.70
	Sangaraka	1234.75	1279.17	0.64	0.62	668.33
	Yerewolo	647.45	888.98	1.26	0.17	1218.34
	CZ06-1-05	975.65	1041.11	0.80	0.39	726.66
	Ghana Shoba	1239.25	1247.87	0.32	0.62	292.78
	Acar 1	338.87	735.00	1.45	0.05	1304.44
	Asomdee	811.76	924.87	1.00	0.27	886.39
	Hansadua	825.82	923.15	0.95	0.28	825.18
LOW	Dounafana	763.56	859.72	0.97	0.24	790.18
	Korobalen	953.51	986.76	0.63	0.37	507.96
	Amari Sho	835.78	900.56	0.84	0.28	670.74
	N'Barawa	588.11	712.13	1.11	0.14	803.14
	CinzanaTelimani	490.27	614.73	1.16	0.10	741.67
	IT93K-876-12	541.85	551.39	−0.70	0.12	−204.26

Note: GMP = geometric mean productivity; MP = mean productivity; SSI = stress susceptibility Index; STI = stress tolerance index and TOL = tolerance index.

of mean productivity (MP) was 1039.56. The highest mean productivity (MP) 1577.32 was recorded by KPR1-96-73 and the lowest value 551.39 was recorded by IT93K-876-12. The mean value of stress susceptibility index (SSI) across genotypes was 0.93. The lowest (−0.7) and the highest (1.45) of SSI were obtained by IT93K-876-12 and Gorom-gorom, respectively. The values of stress tolerance index (STI) ranged between 0.05 and 0.68 with an average at 0.34. The lowest and highest STI was for Acar 1 and Nketewade, respectively. The tolerance index (TOL) averaged over all genotypes was 1021.72. KPR1-96-73 and IT93K-876-12 had the highest and lowest tolerance index value of 1872.41 and −204.26, respectively.

Table 4. Correlation among stress index scores and yield under stressed (Y_s) and non-stressed yield (Y_p) of 25 cowpea genotypes.

	Y_p	Y_s	MP	GMP	SSI	STI
Y_s	0.097	-				
MP	0.877**	0.563**	-			
GMP	0.581**	0.849**	0.892**	-		
SSI	0.554**	−0.611**	0.165	−0.170	-	
STI	0.591**	0.848**	0.900**	0.987**	−0.168	-
TOL	0.852**	−0.438*	0.496*	0.079	0.821**	0.088

** = Significant 1%; Y_P = non-stressed yield; Y_s = tressed yield; MP = mean productivity; GMP = geometric mean productivity; SSI = stress susceptibility Index; STI = stress tolerance index and TOL = tolerance index.

3.3. Correlation among Stress Index Scores and Yield under Stressed (Y_s), and Non-Stressed (Y_p)

The result of correlation analysis between yield based on quantitative indices of stress tolerance and yields obtained under watered (Y_p) and stressed (Y_s) conditions are presented in (**Table 4**). The yield under well-watered condition (Y_p) was significantly and positively associated with all the quantitative indices. The yield under stress condition (Y_s) was strongly associated with geometric mean productivity (GMP) (r = 0.849, p < 0.01) and mean productivity (r = 0.563, p < 0.01). There was a strong negative relationship between Y_s (r = −0.611, p < 0.01) and stress susceptibility index (SSI). However, a negative significant relationship was also observed between Y_s (r = −0.438, p < 0.05) and tolerance index (TOL). The result of correlation analysis indicated a strong positive association between the mean productivity (MP) and GMP (r = 0.892, p < 0.01) and also SSI (r = 0.900, p < 0.01), respectively but was weakly correlated with TOL. The correlation analysis showed that there was a strong positive relationship between the MP (r = 0.987, p < 0.01) and SSI. Also, a strong positive correlation has been observed between index SSI (r = 0.821, p < 0.01) and TOL.

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 5** and **Figure 2**, 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 5**). 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 5**). Hence, they were positively associated with PC1. Similarly, stressed yield (Y_s), stress susceptibility (SSI) and tolerance index (TOL) were related to

Table 5. 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.

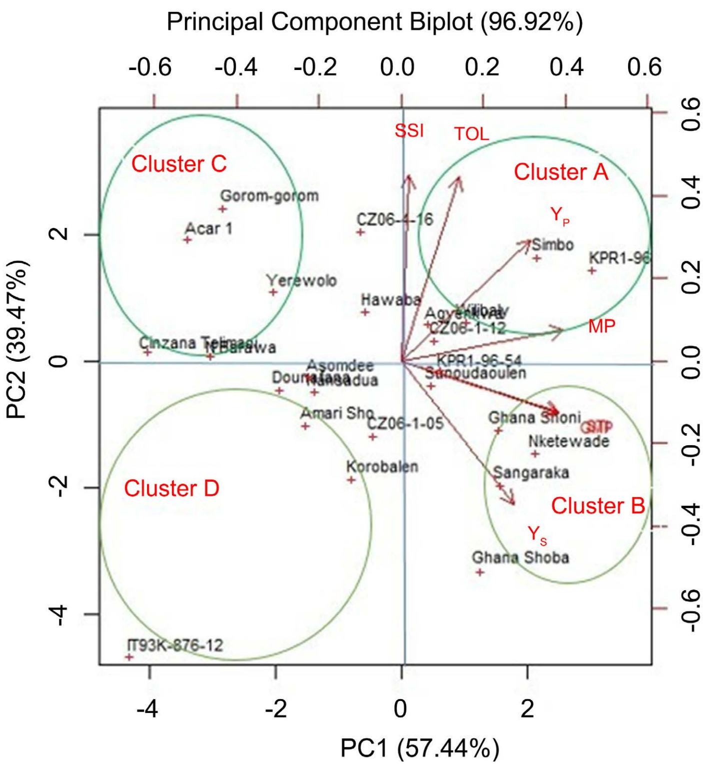

Figure 2. Biplot display of stressed yield (Y_s), non-stressed yield (Y_p) and quantitative indices of drought tolerance of 25 cowpea genotypes grown under water stress and well-watered conditions.

PC2 according to their loading scores (**Table 5**). 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 2**).

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. Yield Based on Quantitative Indices of Drought Tolerance

Generally, in most yield experiments, correlation between yield under stress condition (Y_s) and yield under well-watered condition (Y_p) is between 0 and 0.5 [11] [12]. The correlation between Y_s and Y_p was 0.097 for the tested genotypes. This correlation is low. These results are indicative that selecting genotypes based on yield potential would lead to yield improvement in both drought and normal condition. These results agree with the observation made by [9] that a small relationship between Y_s and Y_p suggest that selection for yield potential just increase yield under optimal condition and the genotypes would perform weakly under stress condition. A similar result was found by [13] who suggested that, a better way for yield improvement for cowpea genotypes (late maturing) is to do the selection under optimal condition.

Correlations analysis showed that there were strong significant and direct association between Y_s, Y_p and mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI). This result is similar to that of [11] on barley and [12] in cowpea, making, geometric mean productivity and stress tolerance index (STI) better predictors of Y_s and Y_p than tolerance index and stress susceptibility index.

In drought tolerance studies in general, STI is regarded as the most appropriate index of drought tolerance [11] [12]. Selection centered on high STI ought to increase grain yield under both drought and optimal condition. It also enables the identification of high yielding and drought tolerant genotypes. The negative correlation between SSI and Y_s signifies those genotypes with high SSI had Y_s. Selection centered on low SSI would only ameliorate yield under drought stressed condition. Tolerance index (TOL) was strongly correlated with Y_p and SSI, and significant with MP and inversely with Y_s. This showed that TOL could only be helpful to increase yield under optimal condition. [14] in working on wheat genotypes reported that, TOL and SSI were appropriate for the identification of low yielding but drought tolerant cultivars.

A combination of indices as basis for selection could be a profitable measure for crop improvement [11]. This may be promising if adequate associations occur among the indices and trait of interest. Despite its importance for the determination of relationship, the correlation analysis is imperfect due to its incapacity to evaluate the association beyond two variables at once. The better method to evaluate the relationship among a lot of variables simultaneously is the use of principal component analysis and biplot [11].

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 [11] [12]. 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 [11] [12].

As shown in **Figure 2**, 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. [12] reported that the smaller the angle between two vectors is, the more these vectors are associated. According to **Figure 2**, 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 2**. On cluster A, we have high yielding and drought susceptible genotypes which were negatively impacted by water stress. Such as Simbo and KPR1-96-73. 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. For example, Acar1, Gorm-gorm and Yerewolo.

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. The following findings were made:

1) Post flowering drought onset affected yield and yield components. KPR1-96-73, Simbo, CZ06-4-16, Wilibaly and Agyenkwa were high yielding in well-watered condition while Ghana Shoba, Sangaraka, NKetewade, Ghana-Shoni and Korobalen were high yielding genotypes in drought condition. The average yield reduction was 60.6% grain.

2) 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.

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Conflicts of Interest

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

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