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Field Assessment of Cowpea Genotypes for Drought Tolerance

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Abstract

Drought is one the most damageable constraints to crop production impacting negatively food security. The potential of cowpea to address food security is well established. However, drought due to limited rainfall is causing important yield losses. This study was conducted to assess cowpea genotypes for variability to drought tolerance at Saria Research Station, Burkina Faso, in 2012. Fifty cowpea genotypes were grown under drought stressed and non-stressed conditions.

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Plants grown under non-stressed conditions were watered regularly from sowing to maturity while those in the stressed conditions were watered from sowing to 50% flower bud initiation and thereafter, irrigation was withheld till harvest. Selection indices and principal component biplot were used to differentiate genotypes.A wide genotypic variability among the tested germplasm was found. In the Biplot displayed, genotypes were grouped into four categories according to their drought tolerance and yielding ability as indicated below: high yielding-drought tolerant (group A), high yielding-drought susceptible (group B), and low yielding-drought tolerant (group C), and low yielding-drought susceptible (group D). The stress tolerance index was the best criterion for assessing genotypes for variability to drought tolerance because it enabled the identification of high yielding and drought tolerant genotypes.

Keywords: Cowpea genotypes; drought tolerance; yield; quantitative indices; Burkina Faso.

1. Introduction

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 [1]. Semi-arid zones including Burkina Faso are regularly facing drought due the scarcity and bad distribution of rainfalls. The recent drought episodes were recorded in 1984, 1991, 2004, and 2011 in the region resulting important crop yield losses and famine in Burkina Faso and other parts of West Africa like Niger and Mali. In 2011, a deficit of about 154462 tons was recorded in crop production in Burkina Faso.

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 [2]. 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.

To estimate tolerance to drought stress, a number of criteria have been used in crop plants. The stability analysis criterion for identifying environmentally sensitive and insensitive genotypes when they are evaluated under series of environments has been used [3]. Other selection criteria also known as stress tolerance indices have been used for genotypes selection based on the performance in stressed and non-stressed conditions [4, 5]. Tolerance index (TOL), relative yield of genotypes under stressed (Ys) and non-stressed conditions (Yp or Yw), stress susceptibility index (SSI), stress intensity (SI), and mean productivity (MP) were defined and used in selecting genotypes for drought tolerance [4, 5]. In addition, geometric mean productivity GMP) and stress tolerance index (STI) were proposed in drought studies [6]. These stress tolerance indices were reported to be the most suitable for screening genotypes for drought tolerance because it enables the identification of high yielding and drought tolerant genotypes [6]. A limited number of authors have used these quantitative indices for stress tolerance to assess drought tolerance genotypes in cowpea [7, 8].

In this study, quantitative indices of stress tolerance such as stress intensity, mean productivity, tolerance index, stress susceptibility index, geometric mean productivity and stress tolerance index were used to differentiate genotypes based on their ability to withstand water stressed conditions.

2. Materials and Methods

2.1. Field experiment and data collection

Fifty cowpea genotypes were screened in the field to meet natural condition during the off-season 2012 at Saria research station. Before planting, the land was ploughed and fertilized with organic manure (2.5 t/ha) to remove nutrient deficiency as a limiting factor.

Two days before planting, the field was watered to field capacity. After sowing, the plants were maintained at near field water capacity until the emergence of flower buds (50 % flower buds emergence). The plants were then subjected to two soil moisture regimes (water-stressed and well-watered or control). The experimental unit consisted of 2 row plots, 3 m long with about 10-20 plants per row.

The spacing between rows was 0.8 m and the spacing between hills on the same row was 0.20 m with two plants per hill. The experimental design was an alpha lattice design with three (03) replications, ten (10) blocks per replication and five (05) genotypes per blocks. Grain yield, pods yield, hundred seed weight were recorded and quantitative indices of stress tolerance were calculated using yield data from the field experiment. Mean productivity (MP), tolerance index (TOL), stress susceptibility index (SSI), geometric mean productivity (GMP), and stress tolerance index (STI) were the stress tolerance indices estimated.

2.2. Data analysis

Analysis of variance of collected data was done for the following environments: (1) irrigated throughout the experiment (well-watered) and (2) irrigated with imposed drought stress from during flower bud initiation period (water-stressed). The selection indices of stress tolerance such as mean productivity (MP), tolerance index (TOL), stress susceptibility index (SSI), stress intensity (SI), geometric mean productivity (GMP) and stress tolerance index (STI) were calculated for the field experiment using the following formulae:

- Mean productivity (MP): $MP=(Ys+Yw)/2$
- Tolerance index (TOL): $TOL= Yw-Ys$
- Stress susceptibility index (SSI): $SSI=[1-(Ys/Yw)]/[1-(\bar{Y}s/\bar{Y}w)]$
- Stress intensity (SI): $SI=1-(\bar{Y}s/\bar{Y}w)$
- Geometric mean productivity (GMP): $GMP= \sqrt{(Ys) \times Yw}$
- Stress tolerance index (STI): $STI=(Ys \times Yw)/\bar{Y}^2w$

Where Ys and Yw (known as Yp [6] are the yields of each genotype under drought-stressed and non-stressed conditions. $\bar{Y}s$ and $\bar{Y}w$ are the mean yields of all genotypes under drought-stressed and non-stressed conditions.

Stress intensity (SI) is classified into mild, moderate and severe. Stress intensity is mild when yield reduction is between 0 and 25%, moderate when yield reduction is situated between 25 and 50% and severe when yield reduction is between 50 and 100%.

Correlation analyses were conducted using yield and yield related traits data and calculated quantitative indices for stress tolerance. Principal Component biplot Analysis (PCA) was done using data on yield and the quantitative indices for stress tolerance to graphically display genetics relationships in GenStat 14.0.

3. Results

3.1. Yield performance of cowpea genotypes under water-stressed and well-watered conditions

There were significant differences in yield and yield related traits between genotypes under non-stressed conditions while under stressed conditions only 100-seed weight showed significant difference (Table 1). The mean grain yields of genotypes under stressed and non-stressed conditions are respectively 542.59 kg/ha and 871.53 kg/ha. The mean of genotypes ranged from 277.55 kg/ha to 1543.00 kg/ha under non-stressed conditions and from 194.77 kg/ha to 729.19 kg/ha under stressed conditions. Under non-stressed conditions, genotypes at the top of Table 1 to the first line were high yielding and produced more than 900 kg/ha while genotypes at bottom of the table starting from the second line were low yielding and produced less than 600 kg/ha (Table 1).

Drought stress reduced grain yield but the genetic materials reacted differently to the stress. The grain yield of a number of genotypes like Kaya local, IT93K-503-1, IT95K-1479, Apagbaala, Iron Clay, KVx396-4-5-2D, KVx780-4, Melakh, and IT98K-317-2 was reduced by more than 45% while that of KVx745-11P, KVx525, KVx414-22-2, Pobe local, and Djouroum local was not affected. Larger grain yield reductions were mostly recorded in high yielding genotypes under well-watered conditions under stress conditions. In general, genotypes with high performance under normal conditions yielded poorly under stress conditions. Low grain yielding genotypes were not severely affected by the yield reduction (Table 1).

3.2. The stress tolerance indices for cowpea genotypes

The stress tolerance indices of the forty nine genotypes are indicated in Table 2. Genotypes that combined lower tolerance index and stress susceptibility index and higher mean productivity and stress tolerance index were drought tolerant. Examples of these genotypes are KVx404-8-1, Gorom Local, IT93K-693-2, CB27, IT98K-1111-1, and Djouroum local.

In contrast, genotypes that combined higher tolerance index and stress susceptibility index and lower mean productivity and stress tolerance index were drought susceptible.

Examples of these genotypes are IT99K-573-2-1, Kaya local, Moussa Local, F8/SR, IT99K-499-39, and Bambey-21 (Table 2).

The stress intensity applied to this experiment was considered as moderate. The intensity of drought measured by the stress intensity (SI) was 0.38 (38%) and was then between the interval of 25% to 50%.

3.3. The Principal component analysis from the tolerance indices

Principal component analysis and biplot displays of 49x7 data matrix is illustrated in Figures 1. The total variation explained by the two axes is 91.49%. The PC1 explained 67.31% of the total variation in the data matrix and had high correlation among non-stressed yield (Yw), stress tolerance index (STI), geometric mean productivity (GMP) and mean productivity (MP).

Table 1: Yield performance of cowpea genotypes under water-stressed and well-watered conditions at Saria research station

		Grain Yield (kg/ha)			100-seed weight (g)			Pod Yield (kg/ha)		
Yielding ability	**Genotypes**	**NStress**	**Stress**	**Reduct (%)**	**NStress**	**Stress**	**Reduct (%)**	**NStress**	**Stress**	**Reduct (%)**
HIGH	**KVX396-4-5-2D**	1543,00	620,04	59,82	17,34	16,84	-28,81	1999,67	770,70	-75,13
	KVX775-33-2	1338,92	702,52	47,53	23,30	23,39	6,47	1832,97	958,82	28,42
	TN88-63	1228,30	676,88	44,89	12,39	12,73	4,35	1408,37	811,58	16,00
	MELAKH	1184,97	459,08	61,26	19,18	13,72	7,07	1567,04	645,58	14,28
	KVX61-1	1169,64	716,87	38,71	18,25	13,94	-7,42	1561,37	645,66	11,78
	BulkF7/SR	1161,49	623,11	46,35	20,49	22,80	7,09	1301,84	765,79	22,57
	MOURIDE	1144,11	671,28	41,33	18,52	17,21	25,03	1596,78	680,65	23,52
	GOROM LOCAL	931,15	648,77	30,33	21,33	21,30	8,31	1158,14	770,60	10,25
	KN1	904,36	522,70	42,20	14,51	15,82	5,02	1435,04	826,29	37,65
MODERATE	**58-57**	874,68	579,78	33,72	13,03	12,37	0,83	1214,22	757,10	50,49
	Djouroum local	785,43	672,37	14,39	22,90	21,28	-4,29	988,56	847,35	55,40
	IT84S-2049	784,25	553,79	29,39	17,59	17,08	-2,74	1051,43	843,74	42,37
	IT99K-573-2-1	771,71	328,74	57,40	23,57	24,48	1,08	1169,89	419,24	49,40
	CB46	695,92	506,29	27,25	21,97	19,55	-0,38	924,29	605,55	47,69
	Kaya local	636,66	329,07	48,31	16,15	18,25	-13,02	872,05	467,92	46,34
	Pobe local	610,47	589,16	3,49	16,41	17,91	-13,65	768,09	797,47	56,17
LOW	**KVX414-22-2**	589,87	582,18	1,30	20,73	19,83	14,82	899,96	755,93	60,56
	MOUSSA LOC	584,37	374,41	35,93	16,73	14,35	17,44	896,49	528,44	59,07
	KVX525	578,47	612,11	-5,81	22,56	21,10	-3,89	696,56	498,58	64,16
	KVX745-11P	472,17	729,19	-54,44	14,30	18,43	28,50	597,60	1046,59	58,80
	Bambey-21	277,55	194,77	29,83	20,44	21,43	-43,56	381,04	592,46	65,37
MEAN		**871,53**	**542,59**		**19,44**	**18,69**		**1172,21**	**698,98**	
CV(%)		**29,34**	**32,34**		**8,69**	**15,87**		**28,84**	**32,06**	
Significance		*******	**ns**		*******	*******		*******	**ns**	

***: significant at p<0.001 and ns: not significant

Table 2: Stress tolerance indices (TOL, MP, GMP, SSI, and STI) of the fifty cowpea genotypes

Yielding ability	Genotypes	TOL[a]	MP[b]	GMP[c]	SSI[d]	STI[e]
HIGH	KVX396-4-5-2D	922.96	1081.52	978.12	0.03	1.26
	KVX775-33-2	636.40	1020.72	969.85	1.20	1.24
	TN88-63	551.42	952.59	911.82	1.19	1.09
	IT96D-610	538.72	948.61	909.57	1.17	1.09
	KVX61-1	452.77	943.25	915.68	1.11	1.10
	MOURIDE	472.83	907.70	876.37	1.09	1.01
	KVx404-8-1	369.06	906.75	887.77	0.54	1.04
MODERATE	BulkF7/SR	538.38	892.30	850.72	1.23	0.95
	KVX30-309-6G	418.78	891.10	866.15	1.58	0.99
	IT93K-693-2	230.96	843.84	835.90	0.64	0.92
	MELAKH	725.90	822.03	737.56	1.62	0.72
	IT95K-1479	557.39	795.92	745.53	1.37	0.73
	IT98K-1111-1	197.91	793.75	787.56	0.59	0.82
	GOROM LOCAL	282.38	789.96	777.24	0.80	0.80
	CB27	194.45	781.31	775.24	0.59	0.79
	KVX442-3-25	358.49	778.81	757.90	1.03	0.76
	APAGBAALA	538.22	750.79	700.91	1.40	0.65
	KVx780-3	191.56	740.89	734.67	1.62	0.71
	IT84S-2246	260.01	728.95	717.26	0.80	0.68
	Djouroum local	113.06	728.90	726.71	0.38	0.70
	58-57	294.90	727.23	712.12	0.89	0.67
	ITOOK-901-6	243.26	719.39	709.03	0.77	0.66
	KN1	381.66	713.53	687.53	1.01	0.62
	IRON CLAY	534.61	706.95	654.47	1.45	0.56
	KVx780-4	620.10	704.50	632.61	1.01	0.53
	KVx780-1	411.08	702.40	671.66	0.61	0.59
	KVX771-10	361.52	682.93	658.57	0.90	0.57
	IT98K-317-2	715.94	676.79	574.37	1.83	0.43
	IT84S-2049	230.46	669.02	659.03	0.78	0.57
	IT97K-207-15	167.39	657.15	651.80	0.60	0.56
	KVx780-6	309.24	656.27	637.79	1.28	0.54
	Donsin local	266.91	655.40	641.67	0.90	0.54
	IT95M-190	374.65	649.86	622.28	1.19	0.51
	UC-524B	511.28	642.25	589.18	1.51	0.46
	IT93K-503-1	430.71	616.74	577.92	1.37	0.44
	CB46	189.63	601.10	593.58	0.72	0.46
	KVX745-11P	-257.03	600.68	586.77	1.26	0.45
LOW	Pobe local	21.31	599.81	599.72	0.09	0.47
	KVX525	-33.64	595.29	595.05	-1.44	0.47
	KVX414-22-2	7.69	586.02	586.01	0.99	0.45
	UCR-P-24	146.40	562.41	557.62	0.61	0.41
	KVX421-2J	124.24	551.49	547.98	-0.15	0.40
	IT99K-573-2-1	442.97	550.22	503.68	1.52	0.33
	IT98K-205-8	113.16	511.55	508.41	0.53	0.34
	Kaya local	307.58	482.86	457.72	1.12	0.28
	MOUSSA LOCAL	209.97	479.39	467.75	0.95	0.29
	F8/SR	359.26	455.13	418.18	1.50	0.23
	IT99K-499-39	248.16	433.59	415.46	1.18	0.23
	Bambey-21	82.78	236.16	232.50	0.79	0.07

a : Tolerance index; b: Mean productivity; c: Geometric mean productivity; d : stress susceptibility index; e: Stress tolerance index

This dimension can be named as the yield potential-mean productivity component, which separates the high yielding from the low yielding genotypes. Because the angles and the directions between the attribute vectors indicate the strength and the direction of the correlation between two attributes, the biplot displayed indicates that there was significant and positive correlation between stress tolerance index and geometric mean productivity, stress tolerance index and mean productivity, and stressed yield, and stress tolerance index and yield potential.

The PC2 explained 24.17% of the total variation and had positive correlation with stressed yield (Ys), tolerance index (TOL), and stress susceptibility index (SSI). Thus, this dimension can be called stress tolerance dimension and it separates stress tolerant from stress susceptible genotypes. In relation to the two components of the biplot, the genotypes fell into distinct clusters that corresponded to their yield potentials and stress-tolerance. Stress tolerant attributes STI, GMP, MP and Yw were correlated with Djouroum local, KVx404-8-1, IT98K-1111-1, Gorom, local, CB27, IT93K-693-2, Mouride, and KVx61-1 which represent the group of higher yielding and stress tolerant genotypes. The stress tolerant attributes SSI and TOL were correlated with high yielding and stress susceptible genotypes such as KVx396-4-5-2D, Melakh, Apagbaala, KVx775-33-2, BulkF7/SR, and IT95K-1479. Genotypes were distributed over the biplot space according to their yielding ability and adaptation to stress or non-stress environments.

4. Discussion

Genetic variability is essential for the establishment of breeding programme in crop. In this study, genotypes tested reacted differently to water stress indicating the existence of genetic variability for drought tolerance amongst the tested germplasm indicating that improvement can be achieved using such germplasm. In the case of the performance testing, high yielding genotypes produced three times more than low yielding genotypes in normal conditions but under stressed conditions some low yielding remained stable across environment than some high yielding genotypes that yielded low. Selection for yield is more efficient under stressed conditions than under non-stressed conditions. The stress intensity applied to this study was around 38%. This kind of stress is considered as moderate stress intensity.

The yield of some genotypes was severely reduced as compared to other with an important reduction in yield when stressed. The reduction in grain yield is in general linked with reduction in pod yield. This is in agreement with the findings of [9] who indicated that the reduction in grain yield of cowpea was a result of reduction in number of pods and seed weight due to detrimental effects of drought on pod set and grain filling, and [7] who found that, the reduction in yield was a result of reduction in number of pods per plant. Reference [1] indicated that plants are most prone to damage due to limited water during flowering and pod setting stages.

However, in this study hundred seed weight was less affected and most of the genotypes showed greater hundred seed weight under stressed conditions and lower hundred seed weight under non-stressed conditions. As reported by [10, 7], the difference in response of cowpea genotypes to drought is not surprising since the tested germplasm consisted of genotypes adapted to different growing conditions including the dry and high temperature areas of the Sahel and semi-arid of Africa, and hot areas of California in USA.

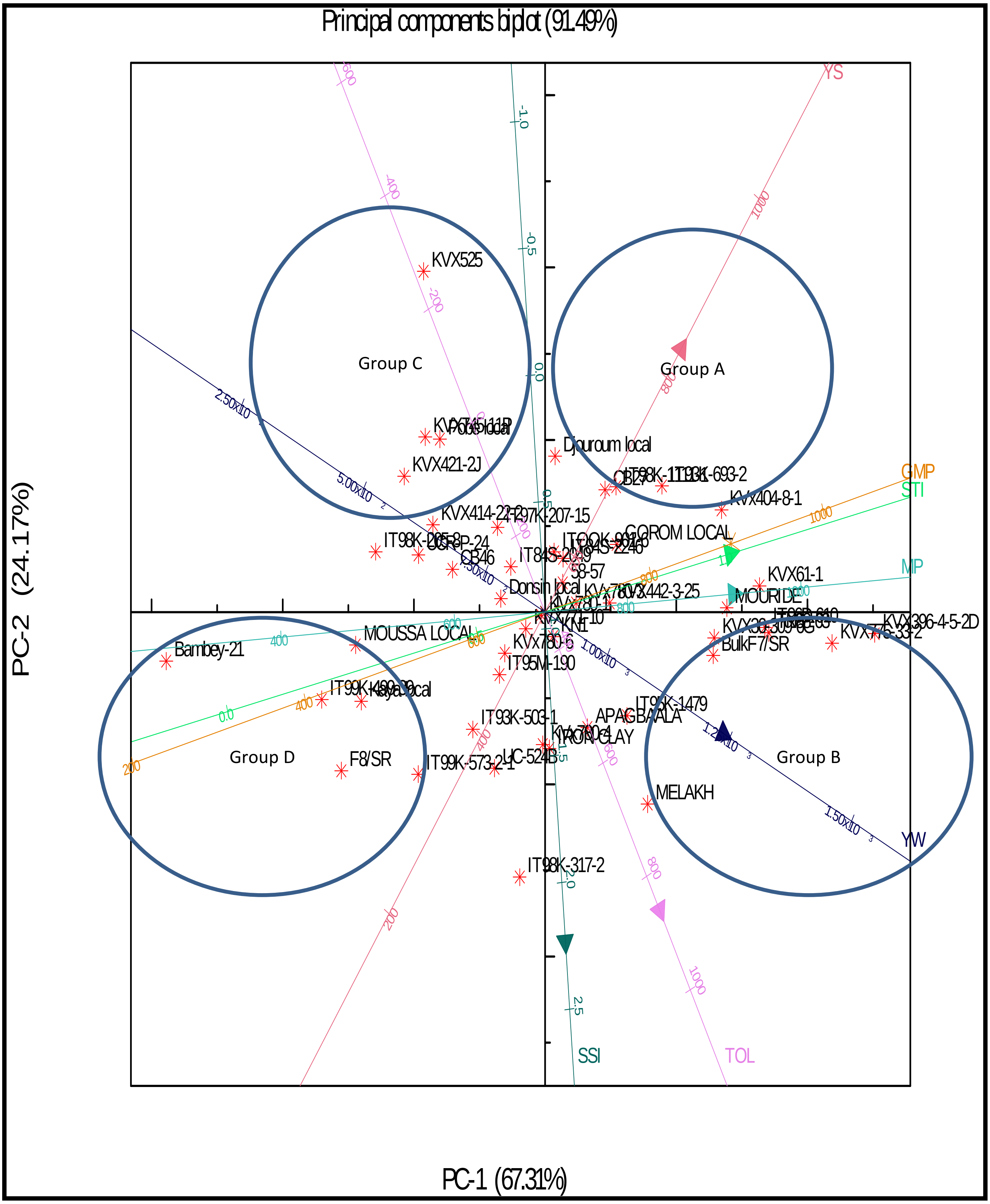

Figure 1: Biplot display of mean productivity (MP), geometric mean productivity (GMP), tolerance index (TOL), stress susceptibility index (SSI), stress tolerance index (STI), and yields of forty nine cowpea genotypes under stressed (Ys) and non-stressed (Yw) conditions.

These results suggested that selecting genotypes based on yield potential would improve yield only under non-stressed environments. The result is in agreement with that of [5] who reported that for most of the yield trials, if the correlation between stressed and non-stressed yield is smaller it indicates that selection for yield potential would only increase yield under non-stressed environments while the selected genotypes would perform poorly under stressed conditions. The result is also consistent with the findings of [7] who reported that, it was better when looking for yield improvement for late maturing genotypes in cowpea to select under non-stressed conditions. Reference [8], also reported that seed yield increases by 3.9 kg/ha with every mm increase in rainfall.

The correlation among drought tolerance quantitative indices and stressed and non-stressed yield indicated that stress tolerance index (STI) was correlated with stressed (Ys) and non-stressed (Yw) yield, mean productivity (MP) and geometric mean productivity (GMP) suggesting that selection based on this index would improve both stressed and non-stressed yield. In addition, stress tolerance index (STI) enabled identification of high yielding and stress tolerant genotypes, suggesting that this index was the best for selecting genotypes for drought tolerance. This statement is consistent with that of [6] indicating that yield would be improved under both stressed and non-stressed environments when using stress tolerance index for selection.

For [11], the calculated gain from indirect selection from moisture stress environment would improve yield in moisture stress environment better than selection from non-moisture stress environment. Nevertheless, these author’s conclusions about the positive correlations among Yw, STI, MP, and GMP are in concordance with our results that showed that the significant and positive correlation for Yp and MP, GMP and STI showed that these indices were more effective in identifying high yielding cultivars under different moisture conditions. In wheat selection, Reference [12] indicated that SSI was a useful indicator when the stress is severe while MP, GMP, TOL and STI were useful indicators when the stress is less severe. Looking at the level of the stress intensity (SI= 38%) applied in this study which is moderate, the conclusions of [12] can explain the fact that MP, GMP, TOL and STI were useful indicators for selection.

Principal component analysis indicated that the PC1 explained most of the variation observed in yield. The PC1 was correlated with non-stressed yield (Yw) and mean productivity (MP) while PC2 was correlated with stress tolerance suggesting that PC1 was a yield potential dimension while the PC2 stress tolerance dimension. Plotting the genotypes over the PC1 and PC2 with quantitative indices of stress tolerance and stressed and non-stressed yield, genotypes were distributed over the coordinate space indicating different drought adaptation and yielding ability. Different clusters of genotypes were identified as described by [6].

High yielding and drought tolerant genotypes (yield not significantly reduced by drought) (group A), high yielding and drought susceptible genotypes (reduced by drought) (Group B), low yielding and drought tolerant genotypes (group C) and low yielding and drought susceptible genotypes (group D). Genotypes like Djouroum local, KVx404-8-1, IT98K-1111-1, Gorom Local, CB27, IT93K-693-2, Mouride, and KVx61-1 were clustered in group A. Genotypes like KVx396-4-5-2D, Melakh, Apagbaala, KVx775-33-2, BulkF7/SR, and IT95K-1479 were found in group B. KVx745-11P, KVx525, KVx414-22-2, Pobe local, KVx421-2J, and IT98K-205-8 were clustered in group C while Bambey 21, Moussa Local, F8/SR, Kaya local, and IT99K-499-39 were in group D.

The biplot displays showed a clear indication of genetic variability for yield under drought conditions for the screened cowpea genotypes suggesting that improvement for yield under drought conditions could be achieved. From the literature reviewed, some genotypes identified as drought tolerant across countries seem to confirm their status in this study. This is the case of Gorom Local also known as Suvita2 [13, 14, 15], KVx61-1 [14, 15], IT98K-1111-1 identified as type 2 drought tolerant [3]. Some other confirmed their susceptibility to drought. This is the case of Bambey 21 [14, 16], Moussa Local [16]. Some genotypes identified as drought tolerant in other part of the world and in Burkina Faso were drought susceptible in this study. This is the case of UC-524B, IT99K-499-39, Apagbaala [16, 7]. The used of stress tolerance index in the identification of drought tolerant material is efficient. From the indices used the stress tolerance index (STI) is the best. It helps in cutting the population into groups.

5. Conclusion

Based on the results obtained there is genotypic variability for drought tolerance existed amongst the tested genotypes. From the biplot displays of yields and quantitative indices for stress tolerance, four clusters of genotypes were identified based on yielding ability and drought tolerance; high yielding and drought tolerant genotypes were in group A, high yielding and drought susceptible genotypes in group B, low yielding and drought tolerant genotypes were in group C and low yielding and drought susceptible genotypes in group D. The stress tolerance index (STI) was the best because it enabled identification of group A genotypes amongst the quantitative indices. Some genotypes already identified as drought tolerant confirmed their tolerance status whilst new drought tolerant genotypes were identified.

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