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Grain yield and stability of selected early and medium duration cowpea in Ghana

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Changes in climate are a major driver for climate-smart crops with short duration on-field and adaptation to diverse growing conditions. This study evaluated the performance of nine early duration and 10 medium duration cowpea genotypes at six locations within the Guinea and Sudan savanna zones of Ghana. Genotypes for each maturity group were laid out in a Randomized Complete Block Design with three replications for each location. There were significant (p<0.001) genotype, environment and genotype x environment effects of the cowpea genotypes of both maturity groups for grain yield. Among the early duration cowpea tested, GGE biplot analysis revealed SARI-2-50-80, SARI-13-17-2, IT99K-1122, SARI-3-11-80, and IT07K-299-6, respectively, as having high yield and stable performance across the six test environments; and out-performed the check variety, Kirkhouse Benga. With the medium duration trials, IT86D-610, IT10K-837-1, and SARI-6-2-6 had high yields, which were comparable to the check, Padituya. IT10K-837-1 was the most stable and had a relatively shorter maturity period. Grain yield performance of early duration cowpea was discriminated by three mega environments while only two mega environments discriminated grain yield of medium duration cowpea. The selected genotypes could be used in hybridizations or released as cowpea varieties in the country.

Key words: Genotype x environment, maturity period, multi-location, biplot analysis, genetic variability.

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp) is one of the most important cultivated grain legumes in sub-Saharan Africa, possibly because of its relatively wide adaptation to drought and ability to give appreciable yields on low-nutrient soils, where other crops would fail (Pule-Meulenberg et al., 2010). It has key importance in ensuring food and income security of smallholder farmers in sub-Saharan Africa (Langyintuo et al., 2003). It is widely cultivated in all ecologies and it is a constituent crop in most farming systems, grown either as intercrop or relay crop, particularly in the northern parts of Ghana (Quaye et al., 2011). At different places and times in Africa, the grain, the green pods, the dried leaves, and hay all command good market prices. The most important factor driving its demand is the high protein it offers which could be as high as 40 % in both fodder and grains

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(Dakora and Belane, 2019). Cowpea can derive a substantial amount of its nitrogen nutrition from symbiotic nitrogen fixation (Pule-Meulenberg et al., 2010) and N-fixation in cowpea has been reported to vary from 16.6-23.0 kg/ha in Northern Ghana (Naab et al., 2009).

The yield of cowpea in Ghana is, however, still the lowest in the world averaging 0.5 t/ha despite the numerous importance of this crop (Langyintuo et al., 2003; Ofosu-Budu et al., 2008). Yield is a quantitative trait that is influenced by the environment. Cowpea production is constrained by various field pests, disease infestation, amount of rain, drought, and photoperiod and this varies from one agroecology to another. This differential environmental condition resulting in differing yield responses of cowpea genotypes can be attributed to genotype-by-environment interaction (Odeseye et al., 2018). To identify high-yielding and well-adapted cowpea genotypes, multi-location evaluation of a large number of diverse improved cowpea genotypes must be carried out within the different agro-ecologies of the region. Multi-environment evaluation trials of crop cultivars are essential as genotype performance will be determined across different environments. Through this, the genotype by environment analysis can be conducted to help identify high yielding and stable genotypes for the test environments (Asio et al., 2009; Horn et al., 2018; Sousa et al., 2018). Since genotype-by-environment interaction (GEI) limits selection response there is a need to investigate its presence. Previous studies have dwelt on using conventional methods of analysis to determine the genotype x environment interaction and these methods provide little information on the patterns in the interaction (Kempton, 1984). A simple crop physiological model to study the yield basis and environmental effects of cowpea genotypes was reported in a multilocational study (Marfo and Waliyar, 1997). Recently AMMI and GG-Biplot analysis have been conducted on most crops to understand the genotype x environment effects. The GG-Biplot however, offers more advantages, as it is much easier to understand, identify high performing and stable genotypes, identify mega environments, and select discriminative and representative environments for the traits of interest (Dos Santos et al., 2016; Sousa et al., 2018). The GG-Biplot methodology has, however, not been much exploited in identifying high-yielding and stable cowpea genotypes in Ghana.

This study aims at evaluating cowpea genotypes across six locations in the Guinea and Sudan savanna agroecological zones of Ghana, identifying high-performing cowpea genotypes and making recommendations for its utilizations in either hybridizations or future release. Specifically, this study sought to: (i) Evaluate the genotype x environment interaction, (ii) Identify high-yielding and stable cowpea genotypes, and (iii) Identify mega-environments, as well as discriminative and representative environments for cowpea grain yield in Northern Ghana.

MATERIALS AND METHODS

Experimental materials and location of study

A total of 19 cowpea advanced breeding lines and two checks were used in this study. This includes nine early duration lines with Kirkhouse Benga as a check variety, and 10 medium duration genotypes with Padituya as check variety (Table 1). Evaluations were conducted in the 2018 cropping season in six environments namely, Nyankpala, Yendi, Damongo, Manga, Wa, and Tumu.

Experimental design and analysis

The experiment was laid out in a Randomized Complete Block Design with three replications. Two separate experiments were set up for each location, one for early duration genotypes and another for medium duration genotypes. Experimental design consists of 4 rows of 4 m length with spacing 20 cm within rows and 60 cm between rows. Crops were established under rainfed conditions with no irrigation. Rainfall pattern during the growing period is described in Table 2. Field pests were controlled using K-Optimal (Cyhalothrin 15 g/L + Acetamiprid 20; EC) at the rate of 500 ml per ha at vegetative, flowering, and podding stages. Weeds were manually controlled as, and when, necessary. Data on agronomic performance such as days to 90 % maturity, grain yield and 100 seed weight were taken for the various trials. Two middle rows were harvested (net plots) to estimate grain yield per plot and this was converted to t/ha

Data were subjected to analysis of variance (ANOVA) using the GENSTAT 12th edition (Payne, 2002). Means were separated using LSD at 5 %. The combined analysis was also conducted to test for the presence of genotype by environment interaction effect. This led to genotype x environment interaction analysis using the genotype-by-environment interaction (GGE) -biplot model (Yan et al., 2000, 2007) done using GENSTAT.

RESULTS

Days to 90% maturity, 100 seed weight, and grain yield

There were variations in days to 90 % maturity among early maturing genotypes (Table 3), and medium maturing genotypes (Table 4) performance within locations and across locations. Among the early maturing category, SARI-5-5-5, SARI-6-2-9, SARI-2-50-80, and SARI-1-3-90 attained 90 % maturity in less than 65 days after planting (DAP); while the check variety (Kirkhouse Benga) took 65 days (Table 3). All the nine medium maturing lines evaluated reached mean maturity of 67 DAP, which was much earlier than the check variety, Padituya which reached maturity at 69 DAP (Table 4).

Variations were also observed in 100 seed weight of cowpea genotypes. SARI-2-50-80 had the highest seed weight and the only genotype that outperformed the check variety in terms of 100 seed weight (Table 5). Apart from the check variety with an average 100 seed weight of 20.86 g, IT10K-837-1 had the highest 100 seed weight among the other medium maturing lines with a weight of 18.4 g (Table 6). There were significant differences (P<0.05) in the grain yield of early maturing

Table 1. List of genotypes used for the study.

Genotype	Source	Maturity group	Market class
IT99K-1122	IITA	Early (60-70 DAP)	Brown seeded
IT07K-298-15	IITA	Early (60-70 DAP)	White seeded
SARI-1-3-90	CSIR-SARI	Early (60-70 DAP)	Mottled
SARI-5-5-5	CSIR-SARI	Early (60-70 DAP)	White seeded
IT07K-299-6	IITA	Early (60-70 DAP)	Medium size, white seeded with black hilium
SARI-13-17-2	CSIR-SARI	Early (60-70 DAP)	White seeded
SARI-1-50-81	CSIR-SARI	Early (60-70 DAP)	Whites seeded
SARI-6-2-9	CSIR-SARI	Early (60-70 DAP)	White seeded with brown eye
SARI-3-11-80	CSIR-SARI	Early (60-70 DAP)	Large, white seeded with black eye
SARI-2-50-80	CSIR-SARI	Early (60-70 DAP)	Large, white seeded with black eye
Kirkhouse-Benga (check)	CSIR-SARI	Early (60-70 DAP)	Large, white seeded with black eye
IT06K-137-1	IITA	Medium (70-75 DAP)	White seeded
IT07K-298-15	IITA	Medium (70-75 DAP)	White seeded
IT07K-299-69	IITA	Medium (70-75 DAP)	White seeded
IT08K-126-19	IITA	Medium (70-75 DAP)	White seeded
IT09K-456	IITA	Medium (70-75 DAP)	White seeded
IT10K-837-1	IITA	Medium (70-75 DAP)	Large, white seeded with black eye
IT86D-610	IITA	Medium (70-75 DAP)	Brown seeded
IT98K-628	IITA	Medium (70-75 DAP)	White seeded
SARI-6-2-6	CSIR-SARI	Medium (70-75 DAP)	Mottled
Padituya (check)	CSIR-SARI	Medium (70-75 DAP)	Large, white seeded with black eye

Table 2. Description of trial location and rainfall pattern in 2018 cropping season.

Environment	Agroecology	Latitude	Longitude	Mean Precipitation (mm)		
				July	August	September
Nyankpala	Guinea savanna	09° 23' N	01° 00' W	150	190	220
Yendi	Guinea savanna	09° 30' N	00° 01' W	180	220	250
Damongo	Guinea savanna	09° 01' N	01° 36' W	160	220	250
Manga	Sudan savanna	11° 01' N	00° 16' W	180	230	170
Tumu	Guinea savanna	10° 54' N	01° 95' W	280	270	170
Wa	Guinea savanna	10° 04' N	02° 30' W	140	190	195

cowpea genotypes grown at each of the six locations (Table 7). Grain yield of SARI-2-50-80 (1.92 t/ha), SARI-13-17-2 (1.91 t/ha), IT99K-1122 (1.84 t/ha), SARI-3-11-80 (1.76 t/ha) and IT07K-299-6 (1.75 t/ha) were higher than the check, Kirkhouse Benga (1.69 t/ha). The highest grain yields were obtained for trials conducted at Damongo (2.09 t/ha) and the lowest was obtained for in trials conducted at Tumu (1.32 t/ha). There were significant ($p<0.05$) differences in grain yield of medium maturing lines (Table 8). Yields of IT86D-610 (2.06 t/ha), IT10K-837-1 (1.94 t/ha) and SARI-6-2-6 (1.82 t/ha) were comparable the Padituya (2.09 t/ha). There was no significant difference ($p<0.05$) between the yield of IT10K-837-1 and Padituya in five out of the six locations. Damongo had the highest grain yields (1.91 t/ha) and the lowest grain yields were obtained in Tumu (1.47 t/ha).

Genotype by environment effect and stability analysis for grain yield

Environment, Genotype, and Genotype x Environment were significant ($p<0.001$) and respectively explained 45.91, 25.74, and 13.47% of yield variance (Table 9). The environment was the most important source of variation. SARI-2-50-80, SARI-13-17-2, IT99K-1122, SARI-3-11-80, and IT07K-299-6 out-performed the check in terms of yield and had stable performance across the six test environments (Figure 1). Environment, Genotype, and Genotype x Environment were significant ($p<0.001$) and respectively explained 10.02, 56.67, and 30.11 % of yield variance (Table 10). The genotype was the most important source of variation. The grain yield of IT10K-837-1 was the most stable across the six environments

Table 3. Days to 90 % maturity of early maturing lines.

Genotype	Days to 90 % maturity						
	Damongo	Nyankpala	Yendi	Wa	Tumu	Manga	Mean
IT99K-1122	65.67^{bc}	64.33	62.67^{ab}	68.33^{e}	70.33^{cd}	60	65.22
IT07K-298-15	66^{bc}	64.67	64.33^{de}	61.67^{abc}	69^{cd}	59.67	64.22
SARI-1-3-90	67.67^{bc}	64	62.33^{a}	62.33^{abc}	66.33^{a}	59	63.61
SARI-5-5-5	61^{a}	64	63.33^{bc}	63^{bc}	71^{d}	60	63.72
IT07K-299-6	65.33^{bc}	65	65^{e}	63.33^{bc}	70.33^{cd}	59.33	64.72
SARI-13-17-2	64.33^{b}	64.33	66f	67.33^{de}	69.67^{cd}	59.33	65.17
SARI-1-50-81	68.67^{c}	64	65^{e}	64^{cd}	68.67^{bc}	59	64.89
SARI-6-2-9	66^{bc}	64.33	63.33^{bc}	59^{a}	67^{ab}	59	63.11
SARI-3-11-80	67.33^{bc}	65	66.67^{f}	62.33^{abc}	69^{cd}	59	64.88
SARI-2-50-80	65^{b}	65	63.67^{cd}	59.67^{ab}	69.33^{cd}	59	63.61
Kirkhouse-Benga	65.67^{bc}	64.67	63.67^{cd}	67.33^{de}	70.33^{cd}	59.33	65.17
Mean	65.7	64.485	64.182	63.48	69.18	59.33	
cv%	2.7	0.9	0.8	3.2	1.5	1.2	

CV: Coefficient of variation. Genotypes with different letters are significantly different at P<0.05.

Table 4. Days to 90 % maturity of medium maturing lines.

Treatment	Days to 90 % maturity						
	Damongo	Nyankpala	Yendi	Wa	Tumu	Manga	Mean
IT06K-137-1	67.33^{cd}	69^{cd}	64.67^{ab}	66.67^{ab}	68.67^{d}	64.67^{c}	66.84
IT07K-298-15	67^{c}	65^{a}	65.67^{bc}	65.33^{a}	70^{e}	63.67^{a}	66.11
IT07K-299-69	64.33^{a}	69.33^{cd}	65.67^{bcd}	68^{cd}	72.67^{g}	65.67^{d}	67.61
IT08K-126-19	68^{cde}	69.33^{cd}	65.33^{b}	66.33^{ab}	67.33^{bc}	66.67^{e}	67.17
IT09K-456	65.67^{b}	70^{d}	66.67^{c}	66.33^{ab}	66.33^{ab}	67.67^{f}	67.11
IT10K-837-1	64.67^{ab}	67.33^{b}	64^{a}	68.33^{cd}	68.33^{cd}	68^{fg}	66.78
IT86D-610	68.33^{de}	68.33^{bc}	64.67^{ab}	65.33^{a}	65.67^{a}	63.67^{ab}	66
IT98K-628	65.67^{b}	67.67^{b}	63.67^{a}	67.33^{bc}	69.33^{de}	64.67^{ac}	66.39
SARI-6-2-6	67.33^{cd}	67.33^{b}	66.67^{cd}	68.67^{cd}	69^{de}	68.67^{g}	67.95
Padituya	69^{e}	67.67^{b}	69.33^{e}	69.33^{d}	71.33^{g}	70h	69.44
Mean	66.73	68.1	65.63	67.17	68.87	66.33	
cv%	0.9	0.9	0.9	1.1	1	0.8	

and its yield was not significantly different from the check, Padituya in 5 out of the 6 environments (Figure 3).

GGE biplot analysis shows the relative performance of cowpea genotypes for grain yield across six environments (Figures 1 and 3). The GGE biplot for early maturing lines shows a high proportion of total GGE variance (82.96 %) of which PC1 accounts for 72.69% and PC2 accounting for 10.27 % (Figure 1). The GGE biplot for medium maturing genotypes also shows a high proportion of total GGE (81.96) with PC1 accounting for 69.89% and PC2 accounting for 12.07% (Figure 3). The Average Environment Coordination (AEC) axis, as indicated by the two arrows pointing in the opposite direction of the Biplot origin separates the genotypes that are below the average from those that are above the average. Only four genotypes have below-average grain yield for early duration cowpea (SARI-6-2-9, SARI-1-3-90, SARI-1-50-81, SARI-5-5-5) and seven genotypes have above-average grain yield (SARI-2-50-80, SARI-13-17-2, IT99K-1122, SARI-3-11-80, IT07K-299-6, Kirkhouse Benga and IT07K-298-15) (Figure 1). In terms of stability and high grain yield, SARI-2-50-80 and SARI-13-17-2 were the most outstanding. Four genotypes had below-average grain yield (IT06K-137-1, IT98K-628, IT07K-298-15, and IT09K-456) and six genotypes had above-average grain yield (Padituya, IT86D-610, IT10K-837-1, SARI-6-2-6, IT07K-299-69 and IT08K-126-19) for the medium duration cowpea genotypes (Figure 3). IT10K-837-1 and IT86D-

Table 5. 100 seed weight of early maturing cowpea lines.

Genotype	100 seed weight (g)						Mean
	Damongo	Nyankpala	Yendi	Wa	Tumu	Manga	
IT99K-1122	12.00^{a}	13^{a}	10.67^{aa}	13.5^{a}	10.67^{a}	14.33^{ab}	12.36
IT07K-298-15	15.33^{bc}	12.67^{a}	14^{b}	17.5^{de}	14^{b}	14^{a}	14.58
SARI-1-3-90	15.33^{bc}	14.67^{b}	14.67^{bc}	15^{abc}	14.67^{bc}	14.67^{abc}	14.84
SARI-5-5-5	14.33^{b}	14.67^{b}	15^{bcd}	14.33^{ab}	15^{bcd}	15.67^{abcd}	14.83
IT07K-299-6	15.33^{bc}	14.67^{b}	15.33^{cde}	14.6^{abc}	15.33^{cde}	15.33^{abc}	15.10
SARI-13-17-2	17^{d}	17.33^{c}	16^{de}	14.8^{abc}	16^{de}	16.33^{bcde}	16.24
SARI-1-50-81	16.67^{d}	15.67^{b}	16.33^{ef}	15.67^{bcd}	16.33^{ef}	15.67^{abcd}	16.06
SARI-6-2-9	16^{cd}	15^{b}	16.33^{ef}	15.5^{bc}	16.33^{ef}	16.67^{cde}	15.97
SARI-3-11-80	18.67^{ef}	17.33^{cd}	18^{gh}	16.33^{cd}	18^{gh}	16.67^{cde}	17.5
SARI-2-50-80	19.67^{f}	18.67^{ce}	18.67^{h}	17.43^{de}	18.67^{h}	18.33^{e}	18.57
Kirkhouse-Benga (check)	18.33^{e}	18.67^{e}	17.33^{fg}	18.73^{e}	17.33^{fg}	17.67^{de}	18.01
Mean	15.24	15.67	15.67	15.76	15.67	15.94	
cv%	3.6	4.7	4.5	6.5	4.5	7.5	

Table 6. 100 seed weight of medium maturing lines.

Genotype	100 seed weight (g)						Mean
	Damongo	Nyankpala	Yendi	Wa	Tumu	Manga	
IT06K-137-1	18.33^{de}	18.33^{bc}	17.33^{c}	18.33^{d}	17.33^{d}	15.7^{b}	17.56
IT07K-298-15	15.33^{ab}	16.33^{ab}	15.67^{b}	17.47^{cd}	16.03^{c}	15^{ab}	15.97
IT07K-299-69	13.67^{a}	16^{ab}	15^{b}	15.63^{b}	15.83^{bc}	14.4^{a}	15.09
IT08K-126-19	17.33^{cd}	16.67^{ab}	15.67^{b}	17.5^{cd}	17.1^{d}	17^{c}	16.88
IT09K-456	16.33^{bc}	15^{a}	13.67^{a}	15.67^{b}	15.67^{bc}	14.33^{a}	15.11
IT10K-837-1	19.33^{e}f	18.33^{bc}	17.67^{c}	19.53^{e}	18.03^{e}	17.67^{c}	18.43
IT86D-610	14^{a}	17.33^{ab}	12.67^{a}	15.23^{ab}	15.23^{b}	14^{a}	14.74
IT98K-628	14.67^{ab}	15^{a}	15^{b}	14.33^{a}	14.13^{a}	15^{ab}	14.69
SARI-6-2-6	17.33^{cd}	17^{ab}	15.67^{b}	17.13^{c}	16.9^{d}	17^{c}	16.84
Padituya (check)	21f	20.33^{c}	21.67^{d}	21.87f	19.97f	20.33^{d}	20.86
Mean	16.73	17.03	16	17.27	16.623	16.04	
CV%	5.9	8.6	4	3.5	2.1	3.6	

610 were the most stable among the high-performing genotypes.

Best environments for genotypes

The results of the biplot who-wins-where showed three mega-environments for grain yield of early duration cowpea. This includes Nyankpala and Wa; Tumu and Yendi; and Damongo and Manga with the best average performers for these environments being IT99K-1122, SARI-13-17-2, and SARI-2-50-80, respectively (Figure 2). Two mega environments were identified for grain yield of medium duration cowpea (Figure 4). Wa, Nyankpala, Manga, and Damongo formed one mega environment with IT86D-610 being the best performing line. Yendi and Tumu were grouped into another mega environment with Padituya being the best performing variety.

Four environments, namely, Nyankpala, Yendi, Damongo, and Manga had relatively longer vectors and therefore discriminated the grain yield of early duration cowpea. Tumu has the least vector length, followed by Wa. Vector angles between Nyankpala and Wa, Tumu and Yendi, Damongo and Manga were less than 90º and are said to be correlated with each other (Figure 5a).

Five out of six environments well discriminated the grain yield of the medium duration cowpea (Figure 5b). Wa had the least vector length, all the other environments had longer vectors. Vectors angles between Nyankpala, Wa, Manga, and Damongo is less than 90º and can be said to be correlated together. Vector angle between Tumu and Yendi are also less than 90º and are also

Table 7. Grain yield of early maturing cowpea advanced breeding lines in six locations.

Genotype	Grain yield (t/ha)						
	Damongo	Nyankpala	Yendi	Wa	Tumu	Manga	Mean
IT99K-1122	2.23 cd	1.9 e	1.53 bc	1.9 cde	1.5 bc	2 bc	1.84
IT07K-298-15	2.23 cd	1.37 bcd	1.57 bc	1.23 a	1.33 bc	1.77 b	1.58
SARI-1-3-90	1.63 b	1.2 bc	1.47 bc	1.56 b	1.1 ab	1.53 ab	1.42
SARI-5-5-5	1.07 a	1 ab	0.53 a	1.2 a	0.7 a	1.03 a	0.92
IT07K-299-6	2.4 d	1.37 bcd	1.57 bc	2.01 de	1.47 bc	1.67 b	1.75
SARI-13-17-2	2.2 cd	1.57 cde	2.13 d	2.07 e	1.37 bc	2.1 bc	1.91
SARI-1-50-81	2.13 cd	0.73 a	1.13 b	1.55 b	1.13 ab	1.53 ab	1.37
SARI-6-2-9	2.23 cd	1.03 ab	1.33 bc	1.53 b	1.17 ab	1.47 ab	1.46
SARI-3-11-80	2.4 d	1.47 bcde	1.73 cd	1.81 cd	1.4 bc	1.73 b	1.76
SARI-2-50-80	2.43 d	1.73 de	1.67 cd	1.72 bc	1.47 bc	2.5 c	1.92
Kirkhouse-Benga (check)	2 c	1.33 bcd	1.7 cd	1.57 b	1.83 c	1.7 b	1.69
Mean	2.09	1.34	1.49	1.65	1.32	1.73	
cv%	7.4	18.3	17.8	7.2	19.9	19.2	

CV: Coefficient of variation. Genotypes with different letters are significantly different at P<0.05.

Table 8. Grain yield of medium maturing cowpea advanced breeding lines in six locations.

Cowpea genotype	Grain yield (t/ha)						Mean
	Damongo	Nyankpala	Yendi	Wa	Tumu	Manga	
IT09K-456	1.2 a	0.77 a	1.4 b	1.3 a	1.28 c	0.9 a	1.14
IT07K-298-15	1.4 b	1.84 d	1.13 a	1.44 ab	0.87 a	1.23 b	1.32
IT06K-137-1	1.63 c	1.36 b	1.38 b	1.83 de	1.15 b	1.45 c	1.47
IT98K-628	1.68 c	1.53 c	1.36 b	1.58 bc	0.85 a	1.45 c	1.41
IT08K-126-19	1.98 d	2.0 de	2.02 cd	1.26 a	1.77 e	1.18 b	1.7
IT10K-837-1	2.12 e	1.92 d	2.17 d	1.87 de	1.53 d	2.04 e	1.94
IT86D-610	2.27 f	2.14 e	2.07 cd	1.69 cd	1.92 f	2.27 f	2.06
SARI-6-2-6	2.27 ef	1.9 d	1.49 b	1.74 cde	1.7 e	1.85 d	1.82
IT07K-299-69	2.34 f	1.23 b	1.92 c	1.62 bc	1.47 d	1.95 de	1.75
Padituya (check)	2.20 ef	1.93 d	2.17 d	1.94 e	2.2g	2.07 e	2.09
Mean	1.91	1.66	1.71	1.628	1.47	1.64	
CV%	4.2	5.5	5.6	6.9	4.9	5.3	

CV: Coefficient of variation. Genotypes with different letters are significantly different at P<0.05.

highly correlated.

DISCUSSION

Field evaluation of advanced breeding materials across multiple environments is one way of identifying high performing genotypes. Parameters such as days to maturity, 100 seed weight, and grain yield are very important in selecting cowpea genotypes for release. In this study, early and medium duration cowpea genotypes were evaluated across six environments in Northern Ghana. The materials evaluated exhibited wide phenotypic variability in terms of maturity, 100 seed weight, and grain yield. These may be due to the inherent genetic variability and environmental differences. SARI-2-50-80, combines earliness with large seed size and high grain yield among the early maturing lines evaluated as it outperformed the check variety, Kirkhouse Benga. Some other genotypes were as early as SARI-2-50-80 but did not give comparable yields. This may be due to inherent genetic differences. In a similar study by Owusu et al. (2020), where the check variety was Bawutawuta, SARI-2-50-80 outperformed the check in terms of grain yield and seed size. These results indicate their utility in breeding programs.

All the medium maturing lines evaluated matured earlier than Padituya (check), but at the same time, they

Table 9. ANOVA results for grain yield of early maturing genotypes.

Source of variation	d.f.	s.s.	s.s. (%)	m.s.	v.r.	F pr.
Environment	5	27.05132	45.91128	5.41026	97.26	<0.001
Environment.Rep	12	2.09213	3.550746	0.17434	3.13	<0.001
Genotype	10	15.16534	25.73849	1.51653	27.26	<0.001
Genotype.Environment	50	7.93652	13.4698	0.15873	2.85	<0.001
Residual	120	6.67555		0.05563		
Total	197	58.92086				

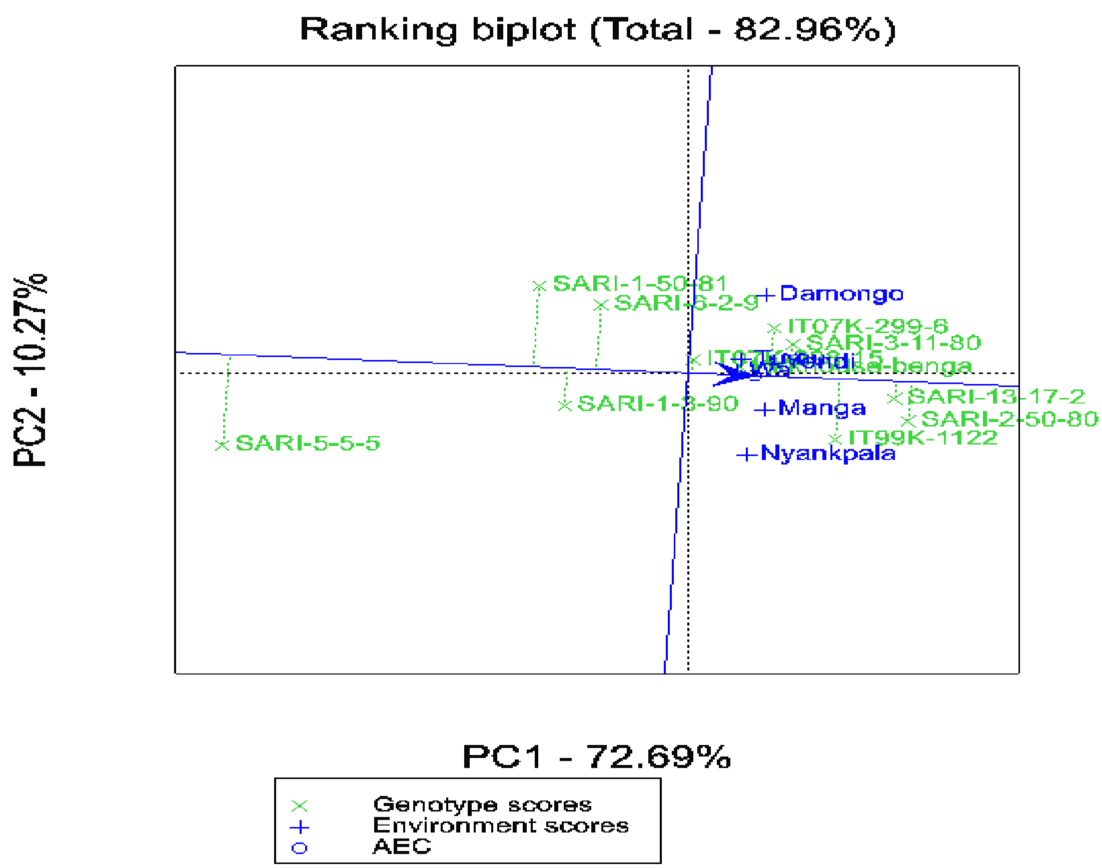

Figure 1. Grain yield and stability of early maturing cowpea genotypes across six environments.

had relatively lower seed weight and grain yield than the check. This could mean the longer the maturity period the larger the grain size and the higher the yield. Despite these, some medium maturing lines IT86D-610 (2.06 t/ha), IT10K-837-1 (1.94 t/ha), and SARI-6-2-6 (1.82 t/ha) had yields comparable to Padituya (2.09 t/ha), the check variety. Among these, IT10K-837-1 had the highest 100 seed weight (18.43 g), white seeded, and will be more preferred by consumers in Ghana. This line, therefore, combines earliness with large seed size and grain yield and will suit the changing climatic conditions than Padituya. High yields were for IT86D-610 and IT10K-837-1 were also reported in a study by Owusu et al. (2020).

The efficiency of genetic gain is reduced through selection by the presence of GxE interaction when genotypes are compared across a range of environments. When there are inconsistencies in the performance of a genotype from one environment to another environment, GxE is said to have occurred. However, if a genotype's performance is consistent across the environments it is said to be stable and therefore shows a general adaptation.

GGE-biplot is an effective tool in evaluating genotypes based on their means and stability (Yan, 2001).

Table 10. ANOVA results of grain yield for medium maturing genotypes.

Source of variation	d.f.	s.s.	s.s (%)	m.s.	v.r.	F pr.
Environment	5	3.000177	10.02452	0.600035	73.54	<0.001
Environment.Rep	12	0.074486	0.248881	0.006207	0.76	0.689
Genotype	9	16.95962	56.66733	1.884402	230.96	<0.001
Genotype.Environment	45	9.012928	30.11497	0.200287	24.55	<0.001
Residual	108	0.881183		0.008159		
Total	179	29.92839		0.167198		

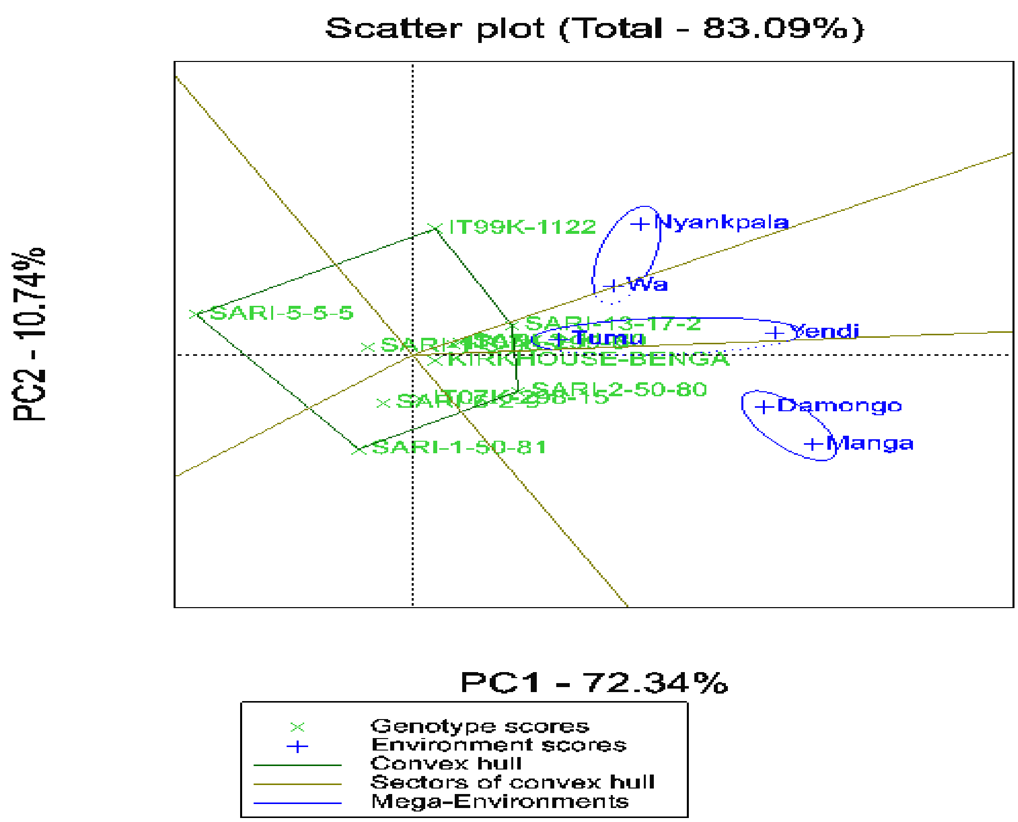

Figure 2. A which-won-where graph and mega environment grouping of early maturing cowpea genotypes.

A type is said to have lower stability if it is greatly projected on PC1 and higher stability if it is closer to the PC2 axis. A high and positive PC score means a higher average value; and a high negative PC score indicates a lower average value (Yan et al., 2000). Thus, SARI-2-50-80, SARI-13-17-2, IT99K-1122, SARI-3-11-80, and IT07K-299-6 have a high yield and stable performance across the six test environments and out-performed the check variety (Figure 1 and Table 7). Also, IT86D-610, IT10K-837-1, and SARI-6-2-6 had high yield and stable performance; but IT10K-837-1 was the most stable (Figure 3). The stability of IT86D-610, IT10-837-1 and SARI-2-50-80 is contrary to what was reported in a recent study in Ghana (Owusu et al., 2020). Desirable genotypes have been selected using this method (Sousa et al., 2018).

The GGE-Biplot method facilitates the selection of superior genotypes by grouping environments into mega-environments and determining which genotypes performed best in these mega-environments. Positively correlated environments in each sector of the polygons are grouped into mega-environments (Yan et al., 2000). This makes it possible to explore GxE, with greater accuracy in identifying mega-environments and selecting stable and adapted genotypes for the environments (Silva and Benin, 2012). The mega-environment

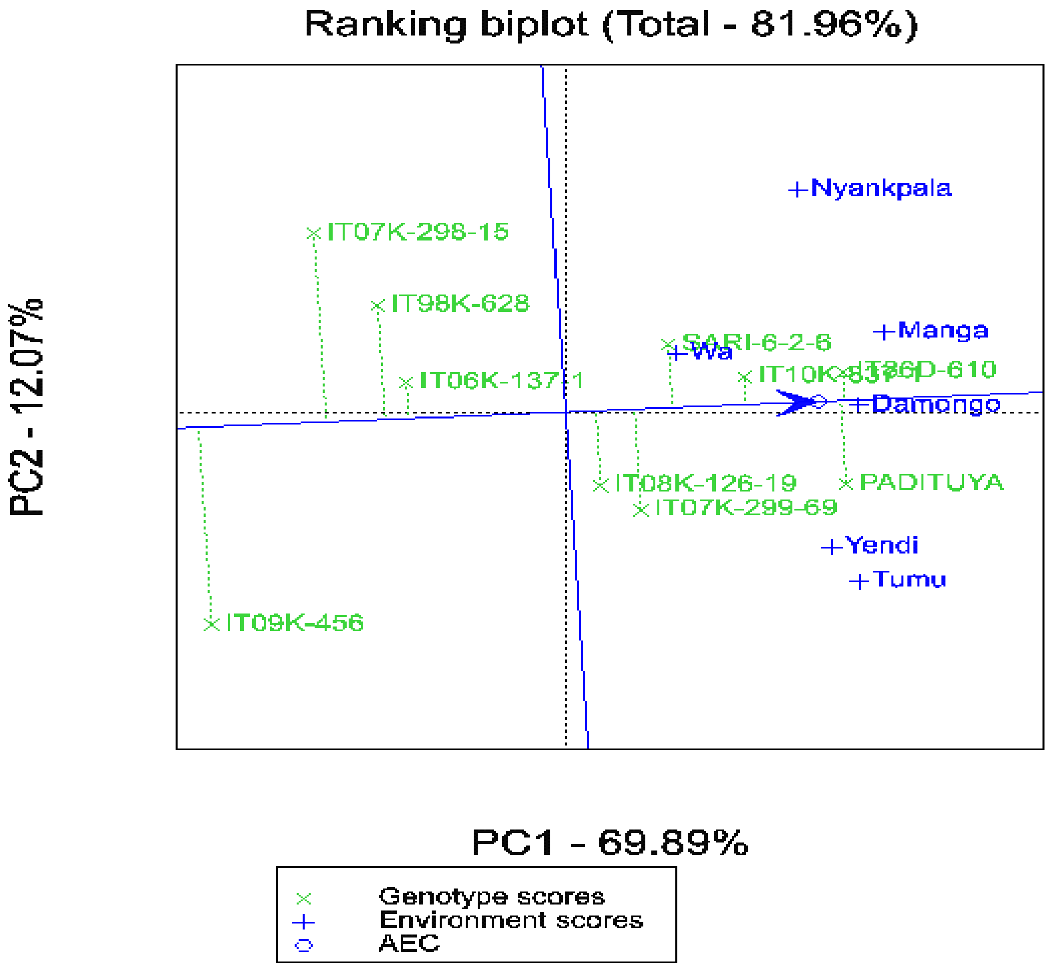

Figure 3. Grain yield and stability of medium maturing cowpea genotypes across six environments.

groupings were discriminative of the grain yield of cowpea. Environments within each mega- environment can be said to be correlated with each other as the angle between the vectors as shown in Figure 5 are less than 90°. The lower the angle between two vectors than 90º the better the correlation (Yan and Tinker, 2006). Similar occurrences of positive correlation of encompassing environments have been reported in other studies (Dos Santos et al., 2016; Sousa et al., 2018). The length of the vector can also be used to tell which of the environments are most discriminating of the target trait. Apart from Tumu which was the least discriminating environment for grain yield of early duration cowpea (Figure 5a) and Wa which was the least discriminating environment for medium duration cowpea (Figure 5b), the rest of the environments well discriminated the genotypes and can be used to select superior genotypes. Tumu being the least performing environment for the early maturing cowpea could be attributed to it receiving the highest mean rainfall. Wa being the least performing environment among the medium duration, genotypes could also be attributed to the region experiencing the least rainfall during the growing season of the crop (Table 2). There is, therefore, evidence that cowpea with different maturity groups differs in their response to water stress. Too much rain will have a more pronounced effect on early duration cowpea than medium duration cowpea and too little rainfall will have a negative impact on grain yield of medium duration cowpea than early duration cowpea.

Some genotypes originated from the vertices of the polygon but contain no clustered environment. Examples of such genotypes are SARI-5-5-5 and SARI-1-50-81 (Figure 2), IT07K-298-15, IT09K-456, IT98K-628, and IT06K-137-1 (Figure 4). These genotypes can be said to be unfavorable to the test environments due to their low grain yields and are therefore not recommended. This similar situation has been reported by other authors (Dos Santos et al., 2016; Karimizadeh et al., 2013). The identification of suitable genotypes and an ideal environment using the GGE-Biplot method could help future evaluation studies as genotypes will be tested in environments with greater GxE.

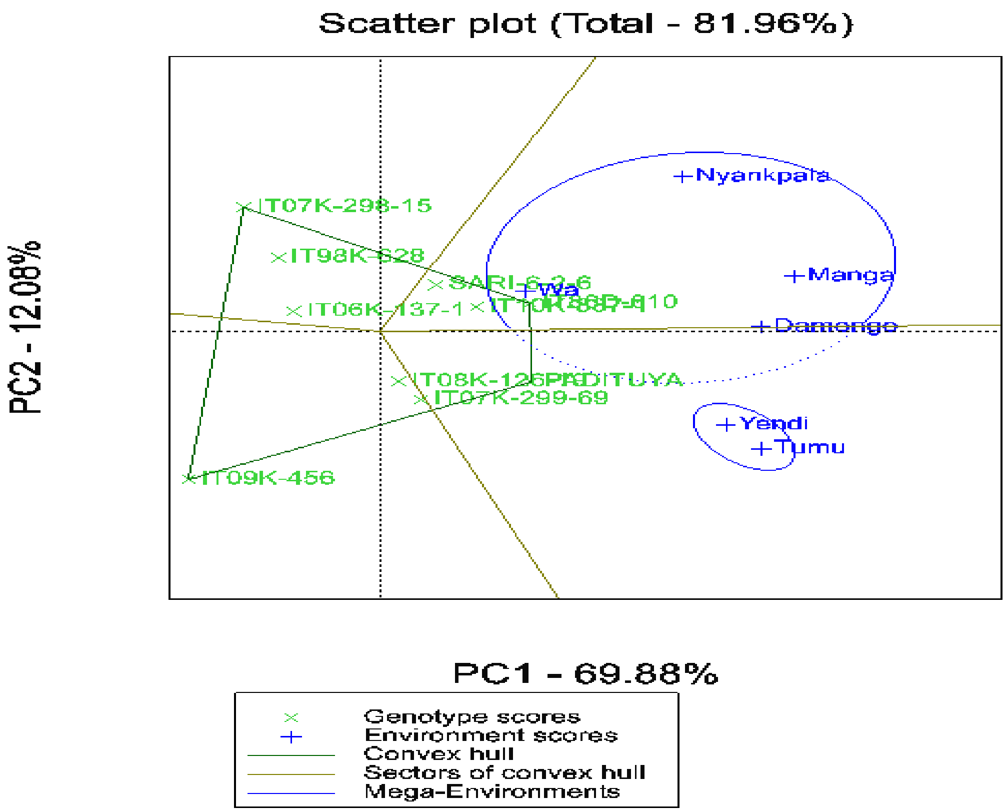

Figure 4. A which won graph and mega environments classification of medium maturing cowpea genotype.

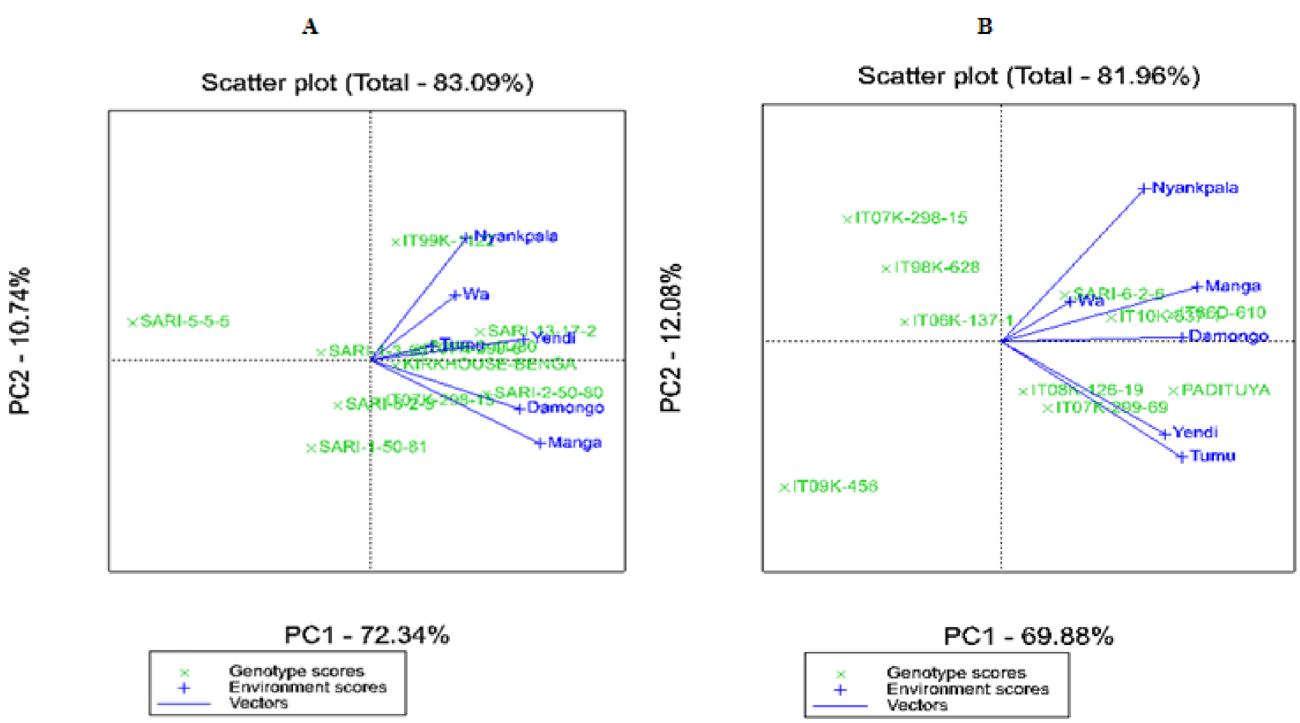

Figure 5. Discrimination and representativeness of grain yield of early duration cowpea genotypes (left) and medium duration cowpea genotypes (right).

Conclusion

Grain yield has consistently been high for Damongo and Yendi for the early maturing and medium maturity cowpea genotypes that were evaluated. For early maturing lines, Tumu was the least performing environment; while Wa was a poor performing environment for medium maturing lines. Notwithstanding that, high yielding and stable early maturing lines (such as SARI-2-50-80, SARI-13-17-2, IT99K-1122, SARI-3-11-80, and IT07K-299-6) outperformed the check (Kirkhouse Benga); and SARI-2-50-80 had the highest 100 seed weight. Medium maturing lines (such as SARI-6-2-6, IT86D-610, and IT10K-837-1) could also be selected as candidate lines, because they matured earlier than the check and have yields comparable to the check. In terms of 100 seed weight, however, only IT10K-837-1 came close to the check. These selected genotypes can further be evaluated on-farms and released as varieties in the future.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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