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Productivity Variables for Adaptability of Cowpea Varieties under Strip Intercropping in Three Locations in Limpopo Province, South Africa

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ABSTRACT

Background: The performance of five improved cowpea varieties under strip intercropping has been conducted in specific locations to assess their yield but their adaptability has not been determined. This paper presents results that assessed the adaptability of the improved cowpea varieties under strip intercropping in three locations in Limpopo province.

Methods: Five cowpea varieties (TVu 13464, IT86D-1010, Glenda, IT82E-16 and IT87K-499-35) and maize were planted under strip intercropping in three locations (UL-Farm, Bela-Bela and Ga-Thaba) and two seasons. Data were collected on maturity, grain yield, land equivalent ratio, pods plant^{-1}, plant height and seed size and were analysed using Genstat 20.1.

Result: The ranking plot of grain yield indicates that the principal components (PC1 and PC2) explained 96.33% of the total sum of square variation. The results indicate that IT86D-1010 and IT82E-16 matured early and were best yielders. The LER from IT82E-16, IT86D-1010, TVu 13464 and IT87K-499-35 exceedingly performed better that from Glenda (Control) thus indicating that they are superior in adaptation and in resource utilization. The performance and adaptation of the varieties varied across locations: IT82E-16 is adapted to UL-Farm and Bela-Bela while IT86D-1010 and IT87K-499-35 are adapted to Ga-Thaba and their production should be based on their best location(s).

Key words: Bela-Bela, Environment, Land equivalent ratio, Syferkuil, *Vigna unguiculata,* Yield.

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp] is a vital source of protein in South Africa. The largest production of this crop is in sub-Saharan Africa, where it is a staple food and feed for animals (Asiwe, 2022). Strip intercropping is gaining popularity in Limpopo province over the mixed intercropping because of it is more productive in terms of grain yield, cash return and LER (Asiwe and Maimela, 2021; Asiwe and Nkuna, 2021). The productivity of strip intercropping has been conducted in different locations in Limpopo province using improved varieties (Asiwe and Maimela, 2021) but the adaptability of the varieties in multi-locations is not well known as different varieties are not suited for all location or agrozones. This paper presents results obtained from improved cowpea varieties tested under strip intercropping in three locations in Limpopo province. Screening, selection and on-farm testing of promising cowpea varieties for adaptation to locations are critical to the sustainability of food security and nutrition in South Africa. Cultivars that perform well across a wide range of testing locations and years are usually recommended and released.

MATERIALS AND METHODS

The study was conducted at University of Limpopo (UL) Farm (Syferkuil; 23°53′ 9.6″ S, 29°43′ 4.8″ E), Towoomba, Bela-Bela (24°25′S, 28°21′E) and Ga-Thaba (24°01′ 59″ S, 29°47′ 5″ E) during 2016-17 (Year 1) and 2017-18 (Year 2). The locations are characterised by erratic low rainfall between 450-650 mm per annum for annual cowpea production. The experimental materials consisted of five cowpea varieties (Glenda (check), IT87K-499-35, IT82E-16, IT86D-1010 and TVu-13464, a maize cultivar PAN 6479). The experiment design used was split-plot design with three replications. The trial was planted in two seasons: 2016-2017 (Year1) and 2017-2018 (Year2). N:P:K fertilizer in the ratio of 3:2:1 respectively, at the rate of 50 kg ha^{-1} was applied as basal application immediately after planting. Roundup and Dual were applied at the rates of 3 L ha^{-1} and 0.5 L ha^{-1}, respectively, to control weeds before crop emergence. Subsequent weed control was effected manually. Karate and Aphox were sprayed at the rate of 1 L and 500 g ha^{-1} to control insect pests from seedling stage

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until full podding stage. The trial was conducted under rain-fed conditions and no irrigation was applied.

Variables measured across locations and seasons were number of days to 90% maturity, plant height, pods plant^{-1} and grain yield as described by Asiwe and Maimela, 2021. Land equivalent ratio (LER) was calculated from the relative yield of cowpea and maize with their monocropping variables as described by Asiwe and Maimela, 2021. Data were collected manually during the two years and were subjected to analysis of variance procedure using the GenStat Version 20.1 to assess variation among treatments, seasons and locations (Table 1). Treatment means were then summarized by location as described by Yan and Tinker (2006) and Yan and Kang (2003) and used to perform G × E Biplot (Table 2).

RESULTS AND DISCUSSION

Weather variables

Fig 1-3 show that average monthly rainfall distributions for Bela-Bela, UL-Farm and Ga-Thaba varied from 41.55 to 50.48 mm, 40.63 to 70.60 mm and 0.03 to 3.08 mm, respectively. The distribution was best at Bela-Bela than UL-Farm which has the highest rainfall. The least rainfall and poorest distribution was obtained at Ga-Thaba. The average maximum monthly temperature did not show any significant variation among the locations. It ranged from 25 to 31°C during the crop growth period (Dec-Mar).

Performance of varieties

The results of the study showing the productive traits across locations and seasons are shown in Table 1 while the summary of the means across the locations are indicated in Table 2. The data indicate that significant interaction (variety × location) was obtained for grain yield, LER and plant height (Table 2). This indicates an inconsistent performance of varieties across locations or environments (Asiwe *et al*., 2021; Zakir, 2018). This implies that some varieties performed well in one environment but poor in another (Sabaghnia, 2015).

Which Variety Won Where? The variety that "won-where" was identified graphically using GGE biplots. Fig 4 shows the bi-plot of number of days to maturity of five cowpea varieties across three locations. The ranking plots indicate that the principal components (PC1 and PC2) explained 96.14% of the total sum of square variation for the number of days to 90% maturity. The plot shows that TVu 13464, IT82E-16 and IT86D-1010 are placed on the left side of GGE biplot, which represents below-average performance or early maturity while Glenda and IT87K-499-35 are placed on the right-side of the biplot which represents above-average performance or late maturity. The findings imply that TVu 13464, IT82E-16 and IT86D-1010 matured earlier than IT87K-499-35 and Glenda. According to Piebiep *et al*. (2017), early maturity are important economic traits preferred by farmers in that the traits enable the crop to evade terminal drought. Concerning the locations, varieties matured earliest at Bela-Bela, followed by Ga-Thaba and lastly, UL-Farm. The late maturity at UL-Farm was associated to high rainfall which must have triggered asynchrony of flowering and maturity of the varieties (Asiwe and Maimela, 2021). This suggests that varieties are more adapted to Bela-Bela location where rainfall and temperature enhanced their early maturity.

The plant height and number of pods per plant (Fig 5 and 6, Table 2) indicate that the principal components (PC1 and PC2) explained 96.50% and 93.17% of the total sum of square variation, respectively. The plot shows that

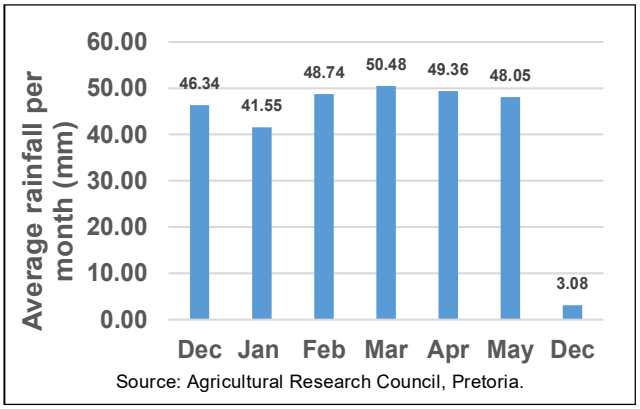


Fig 1: Average monthly rainfall (2017-2018) at Bela-Bela.

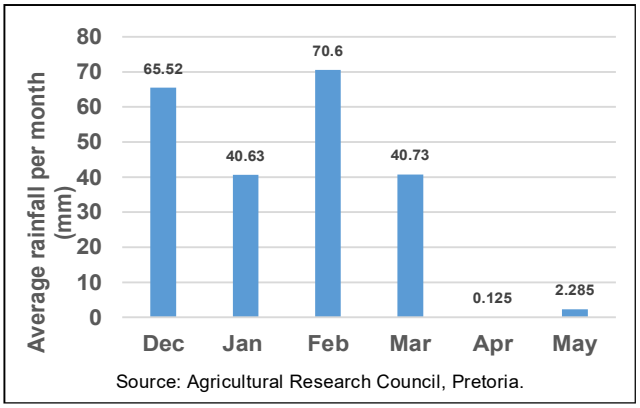


Fig 2: Average monthly rainfall (2017-2018) at UL-Fram.

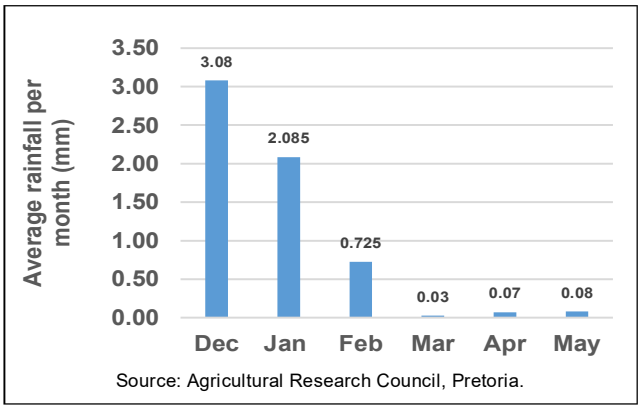


Fig 3: Average monthly rainfall (2017-2018) at Ga-Thaba.

Table 1: Productive traits taken on the five improved varieties across locations and two years.

Variety	90% maturity (days)			Grain yield kg ha^{-1}			LER strip			Plant height (cm)			100 seed weight (g)			Pods plant^{-1}		
	2017	2018	Mean	2017	2018	Mean	2017	2018	Mean	2017	2018	Mean	2017	2018	Mean	2017	2018	Mean
Bela-Bela																		
GLENDA	85.67	90.22	87.95	420.00	1514.40	967.20	.	1.13	1.13	22.47	59.60	41.03	14.17	15.22	14.70	11.53	15.87	13.70
TVu 13464	73.37	77.89	75.63	766.57	1784.40	1275.49	.	2.16	2.16	26.53	29.60	28.07	13.31	13.76	13.54	8.60	16.08	12.34
IT82E-16	77.00	76.11	76.56	693.33	2564.40	1628.87	.	2.43	2.43	21.07	35.87	28.47	14.25	16.70	15.48	11.20	17.13	14.17
IT86D -1010	84.00	81.56	82.78	576.67	2425.70	1501.19	.	2.30	2.30	23.77	33.40	28.58	15.03	17.23	16.13	12.80	15.33	14.07
IT87K-499-35	82.00	85.67	83.84	410.00	1577.80	993.90	.	2.25	2.25	22.27	41.07	31.67	15.83	18.30	17.07	12.07	17.67	14.87
Ga-Thaba																		
GLENDA	91.67	87.33	89.50	576.67	820.00	698.34	2.13	1.33	1.73	57.73	36.92	47.33	14.44	13.76	14.10	18.93	18.53	18.73
TVu 13464	82.00	88.67	85.34	410.00	393.00	401.50	2.03	1.00	1.52	51.20	32.33	41.77	13.07	13,39	13.07	15.27	12.80	14.04
IT82E-16	82.67	79.33	81.00	766.57	897.00	831.79	2.46	1.67	2.07	47.33	40.27	43.80	15.98	14.83	15.41	20.73	13.27	17.00
IT86D -1010	85.00	79.67	82.34	693.33	730.00	711.67	2.98	1.33	2.16	60.13	35.11	47.62	16.38	15.61	16.00	22.20	11.20	16.70
IT87K-499-35	91.00	85.00	88.00	420.00	987.00	703.50	2.70	2.00	2.35	39.93	23.98	31.96	17.48	16.32	16.90	23.73	10.20	16.97
UL-Farm																		
GLENDA	91.67	103.67	97.67	635.00	573.00	604.00	1.25	2.29	1.77	57.73	51.80	54.77	14.47	14.76	14.62	15.00	16.00	15.50
TVu 13464	82.00	96.33	89.17	850.00	680.00	765.00	1.59	2.15	1.87	39.93	29.53	34.73	14.21	13.68	13.95	18.00	14.00	16.00
IT82E-16	82.67	98.00	90.34	1140.00	1025.00	1082.50	1.48	1.81	1.65	51.20	34.47	42.84	15.16	15.36	15.26	19.00	16.00	17.50
IT86D -1010	85.00	88.00	86.50	1052.00	1124.00	1088.00	1.58	1.98	1.78	47.33	38.07	42.70	16.27	15.54	15.91	18.00	17.00	17.50
IT87K-499-35	91.00	101.00	96.00	815.00	887.00	851.00	1.65	1.97	1.81	60.13	41.27	50.70	16.91	15.64	16.28	16.00	16.00	16.00

Glenda is above-average performer which exhibited higher plant height than IT82E-16 and IT86D-1010, TVu 13464 and IT87K-499-35 that are placed on the left side of GGE biplot (below-average yield performance). In the case of pods per plant, the scatter plot shows that TVu 13464 exhibited the least number of pods in the three locations while IT82E-16 and IT86D-1010 produced the highest number of pods while IT87K-499-35 was the most stable for pod production being the closest to the X-axis (Fig 6). The placement of the locations based on the comparison and scatter GGE biplots show that Ga-Thaba is the best location for the expression of plant height and pods per plant followed UL-Farm while Bela-Bela achieved the lowest for both traits. The findings indicate that the

Table 2: Mean of productive traits taken on five improved cowpea varieties across locations.

Variety	Location	90% maturity (days)	Grain yield kg ha^{-1}	Land equivalent ratio	Plant height (cm)	100 seed weight (g)	Pods plant^{-1}
GLENDA	Bela-Bela	87.95	967.20	1.13	41.03	14.70	13.70
TVu 13464	Bela-Bela	75.63	1275.49	2.16	28.07	13.54	12.34
IT82E-16	Bela-Bela	76.56	1628.87	2.43	28.47	15.48	14.17
IT86D-1010	Bela-Bela	82.78	1501.19	2.30	28.58	16.13	14.07
IT87K-499-35	Bela-Bela	83.84	993.90	2.25	31.67	17.07	14.87
GLENDA	Ga-Thaba	89.50	698.34	1.73	47.33	14.10	18.73
TVu 13464	Ga-Thaba	85.34	401.50	1.52	41.77	13.07	14.04
IT82E-16	Ga-Thaba	81.00	831.79	2.07	43.80	15.41	17.00
IT86D-1010	Ga-Thaba	82.34	711.67	2.16	47.62	16.00	16.70
IT87K-499-35	Ga-Thaba	88.00	703.50	2.35	31.96	16.90	16.97
GLENDA	UL-Farm	97.67	604.00	1.77	54.77	14.62	15.50
TVu 13464	UL-Farm	89.17	765.00	1.87	34.73	13.95	16.00
IT82E-16	UL-Farm	90.34	1082.50	1.65	42.84	15.26	17.50
IT86D-1010	UL-Farm	86.50	1088.00	1.78	42.70	15.91	17.50
IT87K-499-35	UL-Farm	96.00	851.00	1.81	50.70	16.28	16.00
SEM ±	-	6.18	334.61	0.36	8.64	1.20	1.77
P-level (V × L)		0.84	0.05	0.04	0.05	0.73	0.61

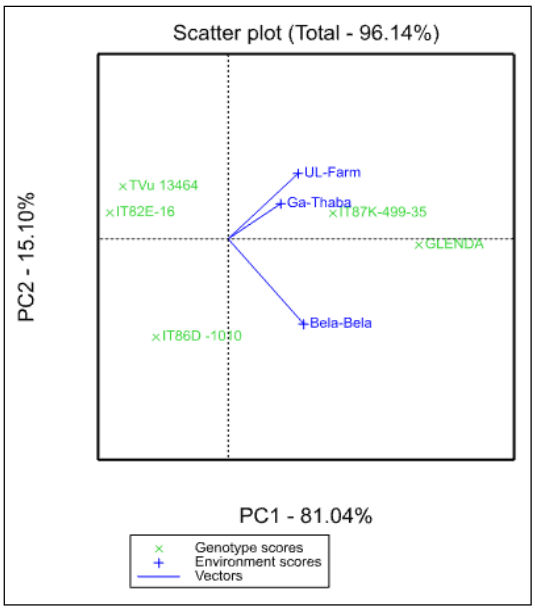


Fig 4: Average environment coordination (AEC) views of the GGE-biplot based on genotype-focused scaling which shows the mean number of days to maturity and adaptability of five cowpea varieties tested at three locations (2017-2018).

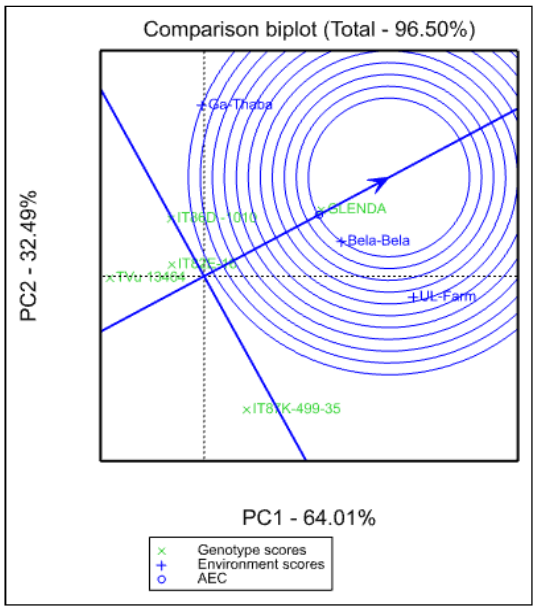


Fig 5: Average environment coordination (AEC) views of the GGE-biplot based on genotype-focused scaling which shows the mean plant height and adaptability of cowpea varieties tested at three locations (2017-2018).

inconsistent expressions of plant height and number of pods per plant across locations due to G × E interaction limits the stability and adaptability of the varieties in the locations hence only IT82E-16 and IT86D-1010 consistently produced good number of pods. Varieties that are well adapted to the environment tend to produce higher grain yield which is a direct function of other agronomic attributes.

The scatter plot GGE biplot of seed size (Fig 7, Table 2) indicate that the principal components (PC1 and PC2) explained 99.85% of the total sum of square variation. The results showed that no significant (P≤0.05) interaction was obtained between the varieties and locations. This indicate that seed size is under genetic control with minimal effect by environment. However, TVu 13464 and Glenda) exhibited the least seed weight while IT82E-16 and IT86D-1010 and IT87K-499-35 are placed on the above-average performance hence they exhibited larger seed size. Concerning the locations, varieties exhibited more stability on seed size at Ga-Thaba and UL-Farm as compared to Bela-Bela because they are closest to the X-axis. This suggests that varieties are more adapted for seed size at Ga-Thaba and UL-Farm. Seed weight is an important quality trait that determines seed size which greatly influences consumers' preference (Gondwe *et al*., 2019). In South Africa, large seed size is often preferred by consumers because they cook faster and attain better cooking quality and texture. On this basis, IT82E-16, IT86D-1010 and IT87K-499-35 are regarded as prime varieties for consumers as their seed sizes are larger than the local control (Glenda) and Ga-Thaba and UL-Farm exhibited more consistent seed size of the varieties.

The ranking plot of grain yield indicates that the principal components (PC1 and PC2) explained 96.33% of the total sum of square variation ((Fig 8, Table 2). The direction of the higher mean grain yield performance of the varieties is indicated by arrow on the abscissa. The graph also indicates that Glenda exhibited the least grain yield while IT86D-1010 and IT82E-16 were the best yielders and most adapted because they were closest to X-axis. According to Santos *et al*. (2017), varieties that fell into sectors that contained no environments, are not adapted for the test environments, therefore are considered un-adapted. The placement of the locations shows that Bela-Bela is the highest yielding location than UL-Farm and Ga-Thaba. Bela-Bela enhanced the grain yield of elite cowpea genotypes and is a more suitable location for cowpea production because of its adequate temperature and good rainfall distribution during crop growth. The biplot also suggests that varieties are more adapted to UL-Farm and Bela-Bela locations because they are closest to the X-axis and where rainfall and temperature enhanced the genetic potentials of the varieties. However, according to Yan and Tinker (2006) and Horn *et al*. (2018), when the test environments are clustered in one sector, it suggests that they did not differ significantly in their discriminating capacity so that deploying the genotypes in any one of those environments would give similar results. In this, regard, Ga-Thaba and UL-Farm fall in one sector.

The land equivalent ratio (LER) shows that the principal components (PC1 and PC2) explained 98.52% of the total sum of square variation (Fig 9, Table 2). The plot shows that Glenda and TVu 13464 are placed on the left side of

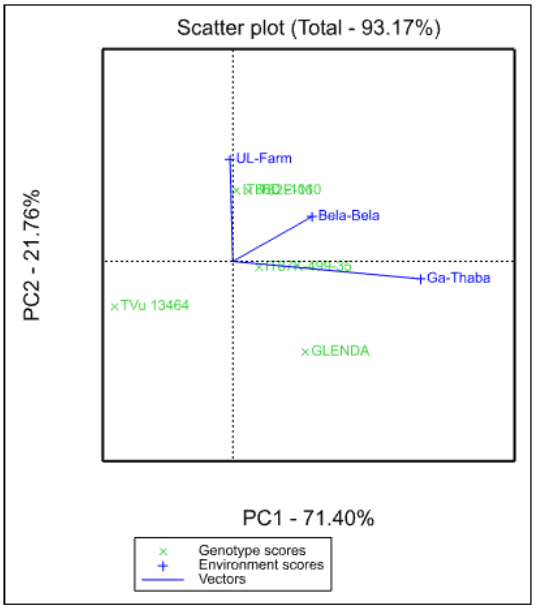


Fig 6: Average environment coordination (AEC) views of the GGE-biplot based on genotype-focused scaling which shows the mean number of pods per plant and adaptability of five cowpea varieties tested at three locations (2017-2018).

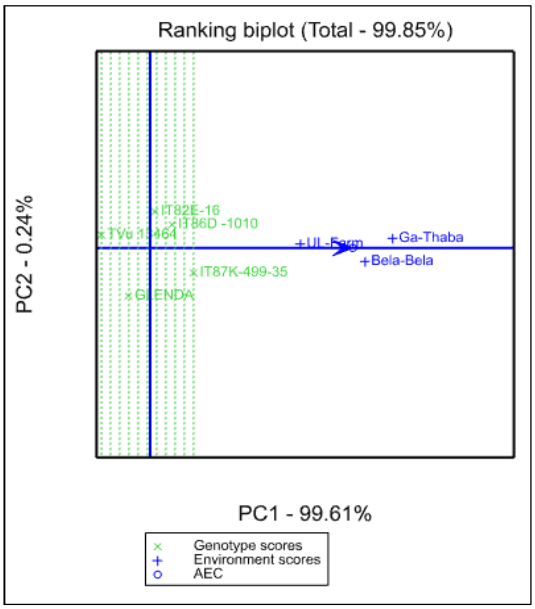


Fig 7: Average environment coordination (AEC) views of the GGE-biplot based on genotype-focused scaling of mean hundred seed weight performance and adaptability of cowpea varieties tested at three locations (2017-2018).

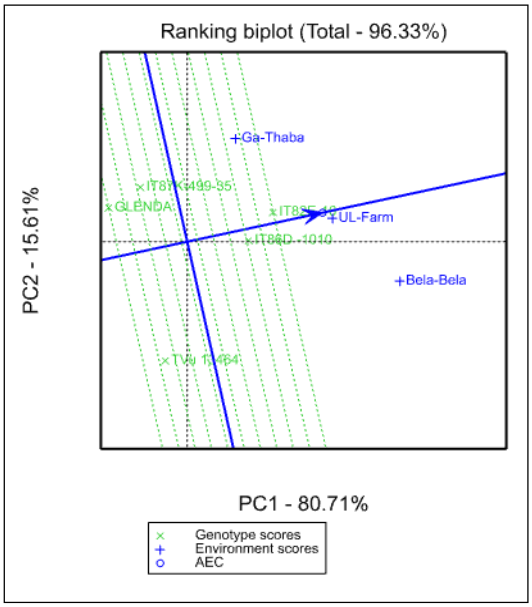


Fig 8: Average environment coordination (AEC) views of the GGE-biplot based on genotype-focused scaling which shows the mean grain yield performance and adaptability of five cowpea varieties tested at three locations (2017-2018).

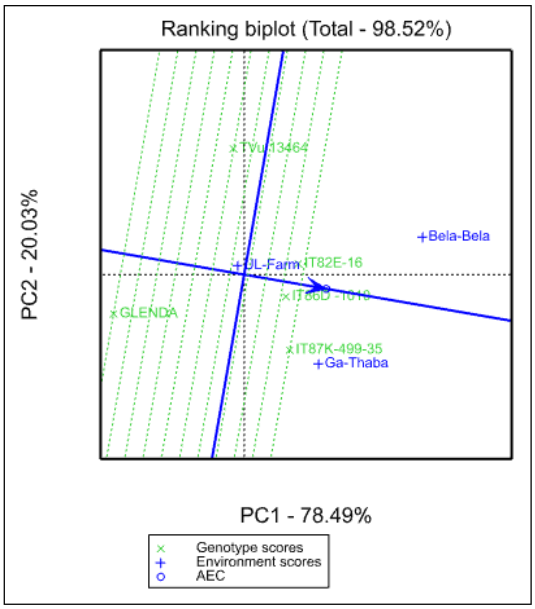


Fig 9: Average environment coordination (AEC) views of the GGE-biplot based on genotype-focused scaling which shows the mean LER performance and adaptability of five cowpea varieties tested at three locations (2017-2018).

GGE biplot, which represents below-average yield performance while IT82E-16, IT86D-1010 and IT87K-499-35 are placed on the right-side of the biplot which represent above average performance of LER. According to Santos *et al*. (2017), the varieties that fell into sectors that contained no environments are not adapted for the test environments and are considered un-adapted. Therefore, Glenda and TVu 13464 are un-adapted. The graph also indicates that Glenda exhibited the least LER while IT82E-16 and IT86D-1010 were the best achievers, respectively and most stable because they were closest to X-axis and well adapted to Bela-Bela and UL-Farm locations. IT87K-499-35 attained the highest LER at Ga-Thaba and is well adapted to this location. Bela-Bela is the highest performing location followed Ga-Thaba while UL-Farm achieved the lowest LER, being placed on left side of the origin. LER is a function of summative effects and overwhelming performance of cowpea varieties in association with maize in various yield components such as plant height, pod length, number of pods, seed size and grain yield (Asiwe and Maimela, 2021). In this study, the LER arising from IT82E-16, IT86D-1010, TVu 13464 and IT87K-499-35 exceedingly performed better than Glenda thus indicating that the former are superior over Glenda in adaptation to strip intercrop environment as well as better resource utilization. Based on this, it implies that Glenda and TVu 13464 are un-adapted. Adoption of these resource-use efficient and high yielding varieties (IT82E-16, IT86D-1010 and IT87K-499-35) will enhance food security and nutrition in the region (Nkhoma *et al.*, 2020; Thanga *et al.*, 2019). The stability of this productive traits in Bela-Bela and UL-Farm locations implies that the same area of land under strip intercropping will produce about two-fold grain yield or financial return than the same area of land under monocropping (Asiwe and Maimela, 2021).

CONCLUSION

The adaptations of the varieties across the locations varied among the productive traits or variables determined in the study. The findings imply that TVu 13464, IT82E-16 and IT86D-1010 matured early while IT87K-499-35 and Glenda matured late. The study also found that that Glenda exhibited the least grain yield while IT86D-1010 and IT82E-16 were the best in grain yield and LER and are regarded as most adapted. The performance and adaptation of the varieties varied across locations: IT82E-16 is adapted to UL-Farm and Bela-Bela while IT86D-1010 and IT87K-499-35 are adapted to Ga-Thaba and their production should be based on their best location(s). Bela-Bela and UL-Farm proved to be the most suitable locations for grain production and should be used as comparative advantage sites for cowpea production. IT82E-16 and IT86D-1010 should be registered, release and promoted for production in the region.

Conflict of interest

All authors declare that they have no conflict of interest.

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