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Assessing yield stability and adaptability of Andean common bean genotypes in the semi-arid environment of Botswana

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Common bean (*Phaseolus vulgaris* L.) is a vital source of nutrients worldwide. It is one of the most consumed grain legume in Botswana. Fourteen Andean common bean genotypes were evaluated in four environments (two seasons and two diverse agro-ecologies) to determine the effect of genotype and environment interaction and yield stability. The genotypes were grown in a randomized complete block design with three replications. Grain yield data was analyzed on additive main effects and multiplicative interaction (AMMI), cultivar superiority index, Wricke's ecovalence and Finlay and Wilkinson regression. There was a lack of variation among the selected genotypes, while environment and genotype × environment interaction (GEI) was significant (P <0.01), which is an opportunity to select stable genotypes across environments. AMMI model for total variation revealed that the environment effect was dominant at 36.83%, genotype × environment interaction at 19.82%, while genotype alone was 3.38%. The cumulative sum of squares of the first two interaction principal component axes (IPCAs) accounted for 76.13% of interaction. Stability coefficients consistently identified genotypes DAB494, CAL96 and DAB541 as the most stable and well adapted, besides the low yield realized. These genotypes are useful for stability breeding purposes and for introduction to the semi-arid environment of Botswana.

Key words: Additive main effects and multiplicative interaction (AMMI), genotype × environment interaction (GEI), interaction principal component axes (IPCA), *Phaseolus vulgaris*.

INTRODUCTION

Common bean (*Phaseolus vulgaris L.*) is an important grain legume and a major source of nutrients worldwide (Gepts et al., 2008). It is mainly used as a food crop around the world particularly in Latin America, Africa and

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Asia (Gómez, 2004; Gepts et al., 2008). Common bean has several health benefits as the bean seed protein provides essential amino acids such as lysine and minerals especially iron and zinc, and this makes beans a good complement to cereal based diets (Borough et al., 2003; Buruchara et al., 2011). Besides these benefits it is a constant source of income for many rural household, and is rapidly gaining ground in Africa and changing from a traditional subsistence to a market-oriented crop (Buruchara et al., 2011; Beebe et al., 2013). The high nutritive value and commercial potential of common bean posed as an opportunity which prompted Ministry of Agricultural Development and Food Security (Botswana) to come up with the initiative to introduce the crop into the cropping system of the country. Collaboration was initiated with International Institute of Tropical Agriculture (CIAT), to source for funding and expertise in the production of the crop. Improved common bean from CIAT is shared with National Research Institution for further evaluation and selection of suitable genotypes (Buruchara et al., 2011).

Introduction of new common bean genotypes into the country requires testing in various locations and for several years to ensure that they have a stable performance over a range of environments. Positive interaction of genotype and environment has been noticed when the responses of genotypes to different environmental conditions are not the same (Allard and Bradshaw, 1964). Plant breeders have keen interest in genotype and environment interaction, when testing genotypes across different environment, in order to identify best performing genotypes for target environment (Akash et al., 2009). Studies focusing on the stability, and genotype (G) × environment (E) interactions, is vital for plant breeders to develop best performing varieties across environments (Blanche et al., 2007). Understanding genotype (G) × environment (E) interaction in common bean lead to a better way of allocation of resources in multi-environment studies and is an important component before recommendations for selection in large scale production (Gebeyehu and Assefa, 2003; Horn et al., 2017). Several statistical techniques are available and commonly used in genotype *versus* environment analysis to estimate the response of genotype to changes in environment such as additive main effects and multiplicative interaction (Zobel et al., 1988), linear regression (Finlay and Wilkinson, 1963), Wricke's ecovalence (Wricke, 1962) and cultivar superiority index (Lin and Binns, 1988).

In Botswana, the total area planted for pulses doubled from 15,819 ha in 2004 to 32,383 ha in 2015, while production increased tremendously by 230% from 2.18 to 7.19 metric tonnes within the same period (Statistics Botswana, 2015). However, the Statistics Botswana (2015) records do not differentiate between *Phaseolus* species from other legumes to be able to discern the actual production of common bean. There is little or no record of common bean production in Botswana, but the consumption levels are generally high as it is consumed in primary schools and in clinics. Generally, most of the common bean consumed in the country is imported from other countries, approximately 6 279 022,79 metric tonnes of beans, valued at more than 60 044 921.90 Botswana Pula were imported from 2015 to 2017, mostly from Zimbabwe, Malawi, South Africa, Kenya and China (unpublished, Statistics Botswana). The significant amount of importation and consumption of common bean is a strong indication for the need to explore possibilities of introducing the crop into the country. Therefore, the objective of this study is to evaluate the effects of genotype and environment interaction and yield stability among the selected Andean common bean varieties based on additive main effects and multiplicative interaction (AMMI), Wricke's ecovalence, cultivar superiority index, and Finlay and Wilkinson.

MATERIALS AND METHODS

Plant

Screening of thirty-six Andean bean genotypes was conducted at field experimental research stations of Pandamatenga and Sebele in 2013-2014 season, where 14 Andean common bean genotypes were selected based on lower crop loss, higher plant height, higher pod weight, higher shelling percentage and higher seed yield per hectare (data not presented). The common bean genotypes used in the study were sourced from CIAT- Malawi.

Sites description

The selected 14 Andean common bean varieties were evaluated in four environments (2 seasons and 2 sites), for two consecutive seasons 2014-2015 and 2015-2016 across two varying agro-ecologies which are the major pulses producing regions in the country. Pandamatenga Agricultural Research station (18°33'S, 25°38E), is located on the north of the country and representative of the region. The other location was Sebele Agricultural Research station (24°35'S, 25°56E), which represents the southern part of the country both regions are considered semi-arid. Information of coordinates, climatic data and soil characteristics are shown in Table 1. The soil classification for Pandamatenga and Sebele were described by Moganane et al. (1990) and Sekwakwa and Dikinya, (2012) respectively. The average rainfall received in Pandamatenga was 390 mm for 2014-2015 and 480 mm for 2015-2016, while in Sebele it was 327 mm (2014-2015) and 180 mm (2015-2016). Some supplementary irrigation was provided in Sebele when rainfall failed to supply enough moisture for normal growth to stabilize yield, especially during flowering, while in Pandamatenga the crop relied only on rainfed.

Experimental design and data analysis

The experiment was laid out in a randomized complete block design with three replications, in plots sizes of 3 m × 8 m with four rows. Grain yield was estimated from harvests from two middle rows of each plot and later converted to kg/ha. Grain yield was subjected to combined analysis of variance to investigate the effects of genotype, environment and their interactions. The

Table 1. Geographic description, average rainfall and temperature of study locations of Pandamatenga and Sebele in Botswana.

Location	Site coordinates		Altitude (m.a.s.l)	Average annual temperature (°C)	Average annual rainfall (mm)	Soil
	Latitudes	Longitudes				
Pandamatenga	18°33'S	25°38'E	945	21.6	650	Clayey vertisols
Sebele	24°35'S	25°56'E	941	23.9	500	Sandy loam

Source: Moganane et al. (1990) and Sekwakwa and Dikinya (2012).

analysis of variation across the four environments was conducted based on additive main effect and multiplicative interaction (AMMI) (Crossa et al., 1990), Wricke's ecovalence (1962), cultivar superiority measure (1998) and Finlay and Wilkinson (1963) regression. AMMI was useful in segregating genotype × environment interactions (GEI) by interaction principal component axes (IPCAs), AMMI model further assisted in visualizing the interaction of genotype and environments graphically (Crossa et al., 1990). The same data was also used to estimate stability parameter of Wricke's ecovalence, which is considered a contribution of each genotype to genotype × environment interaction (GEI) sum of squares across environment (Wricke, 1962). Cultivar superiority measure (Pi), defined as mean square distance between cultivar's response and the maximum response over locations, where the genotype with lower Pi values are desirable (Lin and Binns, 1988). Finlay and Wilkinson (1963), is useful as it provides response of genotype to different environment by fitting a regression of the environment means for each genotypes on the average environmental means. To determine the effects of genotype, environment and their interaction, data on grain yield was subjected to analysis of variance using SAS version 9.4, while Genstat version 18.0 was used in the analysis of each stability coefficient and development of AMMI biplots.

RESULTS AND DISCUSSION

The analysis of variance for grain yield of 14 selected common bean was tested in four environments, and revealed a significant difference between environments (P<0.01), which is an indication of the mean yield differences from one environment to another (Table 2). The results also indicated a significant genotype and environment interaction which shows that genotypes responded differently to various location and seasons. Other researchers also reported a significant effect of genotype, effect of environment and, genotype and environment interaction on common bean (Zeleke and Berhanu, 2016; Carbonell et al., 2004). In this study, however, there was no significant difference between genotypes, which could be attributed to the fact that the 14 Andean common bean were selected among the 36 lines based on lower crop loss, higher plant height, higher pod weight, higher shelling percentage and higher seed yield per hectare (Table 2).

Additive main effects and multiplicative interaction (AMMI) analysis

AMMI model total variation showed that yield variation of the genotype across the environment revealed the larger portion of variation was exhibited by environment to the 14 common bean genotypes at 36.83% (Table 2). Genotypes and genotype × environment interaction (GEI) accounted for 3.38 and 19.82% of the total variation explained, respectively. The large environmental effects indicated that the environment had a great influence on common bean production in these areas. Similar observations were recorded in common bean in which most of the variation (38.33%) was attributable to environmental effects in southeastern Ethiopia (Tadesse et al., 2018a). The present results also revealed, AMMI analysis for IPCA1 and IPCA2 explained 46.85 and 28.18% of the genotype × environment interaction (GEI), respectively, with high significant difference in the first axes. The cumulative sum of squares for both axes was in agreement with another study on common beans (71.2%) recorded by Tadesse et al. (2018b). The above 70% cumulative sum of squares is considered a satisfactory explanation of variation to produce reliable results (Pereira et al., 2009) and useful in the production of biplot (Table 2).

Crop yield among the selected varieties varied from 64.5 (DAB564) to 695.6 kg/ha (DAB541), which shows a wide range of variation and implies a better crop genetic improvement. This also reflects the divergent environments mainly looking at the geographical differences between the sites used in the study. The best yield performance was obtained by DAB541, DAB514, DAB317, and CAL96 (Table 3). The research was conducted under drought conditions, this could be one factor that led to low genetic expression of the genotypes, and this potentially affects the overall performance of the crop. Similarly, Rao et al. (2013) and Polania et al. (2016) recorded reduced harvest index, seed weight and seed yield in common bean under drought stress. Relatively higher yield of common bean of 600 to 700 kg/ha were recorded in the semi-arid regions of Ethiopia and Kenya (Shenkut and Brick, 2013; Katungi et al., 2011). However, common bean has the potential to yield even higher yields of 1500 to 3000 kg/ha under rain-fed conditions and good crop husbandry (Hillocks et al., 2006).

Stability and adaptability analysis

The stability and adaptability analysis is initially revealed using the graphical presentation of the two AMMI biplots

Table 2. ANOVA of AMMI model for common bean seed yield (kg/ha) from four environments during 2014 - 2016 seasons on field trials in Pandamatenga and Sebele.

Source	d.f.	S.S.	M.S.	% explained	%TSS
Genotypes	13	201663	15513ns	-	3.38
Environments	3	2194107	731369***	-	36.83
Interactions	39	1180961	30281**	-	19.82
Block	8	356184	44523**	-	5.97
Treatments	55	3576730	65031***	-	60.04
IPCA 1	15	553304	36887**	46.85	-
IPCA 2	13	332739	25595ns	28.71	-
Residuals	11	294918	26811	24.93	-
Total	167	5956934	35670	-	-
Error	101	2024020	20040	-	-

***Significant at 0.001 level; **significant at 0.01 level.

Table 3. Mean separation of grain yield (kg/ha) of 14 common bean varieties evaluated in four environments 2014-2016 in field trials in Pandamatenga and Sebele.

Cultivar	Panda E1	Panda E2	Average (kg/ha)	Sebele E3	Sebele E4	Average (kg/ha)
CAL143	336.2	347.0	**341.6**	496.5	220.0	**358.3**
CAL96	539.1	330.7	**434.9**	526.7	398.3	**462.5**
DAB261	475.4	234.2	**354.8**	310.7	246.1	**278.4**
DAB286	330.4	344.2	**337.3**	433.3	465.5	**449.4**
DAB302	504.0	181.6	**342.8**	516.9	316.0	**416.5**
DAB317	626.1	230.7	**428.4**	354.7	308.4	**331.6**
DAB494	597.1	230.4	**413.8**	408.0	353.6	**380.8**
DAB504	513.1	136.2	**324.7**	419.6	335.6	**377.6**
DAB514	666.7	241.6	**454.2**	259.6	370.4	**315.0**
DAB520	591.3	248.5	**419.9**	308.6	318.5	**313.6**
DAB532	550.7	130.2	**340.5**	443.1	308.4	**375.8**
DAB541	695.6	238.9	**467.3**	459.5	222.3	**340.9**
DAB549	469.6	325.6	**397.6**	392.5	65.6	**229.1**
DAB564	515.9	64.5	**290.2**	553.3	233.0	**393.2**
Average	**529.4**	**234.6**	**382.0**	**420.2**	**297.3**	**358.8**

E1 = Pandamatenga 2014-15, E2 = Pandamatenga 2015-16, E3 = Sebele 2014-15, E4 = Sebele 2015-2016. Bold column is an average of each location.

shown in Figures 1 and 2. Biplot of IPCA1 versus mean yields of the 14 common bean tested from four environments is shown in Figure 1. The lowest values of IPCAs were observed for genotypes DAB302, DAB261, DAB564, DAB504 and DAB532 which indicated their higher stability and lower genotype and environment interaction (GEI) (Figure 1). These genotypes are followed by those with medium stability such as DAB549, CAL96, DAB494, and DAB520 (Figure 1). However, genotypes with higher yield than mean were CAL96 and DAB494 that are considered ideal for selection. In contrast, genotypes DAB514, DAB286 and CAL143 had a higher interaction of genotype and environment, since there are far away from center and thus considered unstable, and are specifically adapted to certain environments (Figure 1). In this study the higher yielding environment was E1, but has larger IPCA scores. While environments E2 and E4 with lower IPCA values and closer to the origin are lower yielding environments and considered more stable environments. Most of the genotypes seem to perform well under environment E1, as most of them are found within the same quadrat. Pandamatenga is generally more favourable for crop production due to relatively low temperature and higher rainfall (Abdullahi, 2004). But floods events which often occur at the start of growing season in the area, due to

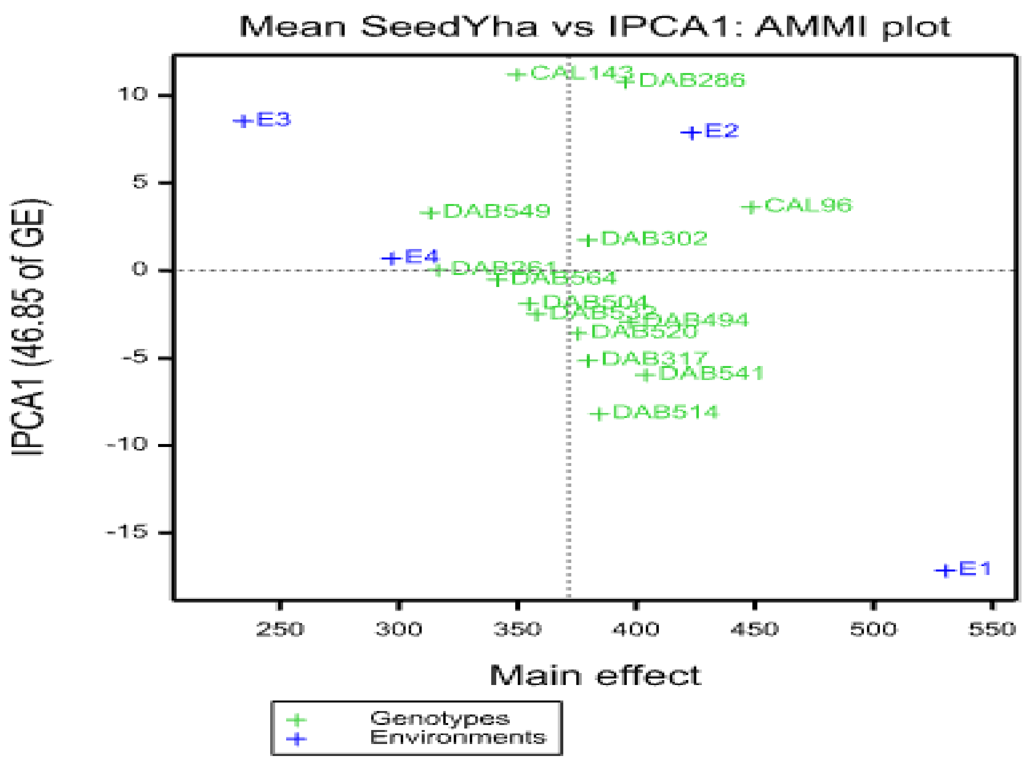

Figure 1. Biplot of IPCA1 *vs* mean yields of the 14 common beans tested in four environments (E1=Pandamatenga 2014-2015, E2 = Pandamatenga 2015-2016, E3 = Sebele 2014-2015, E4 = Sebele 2015-2016).

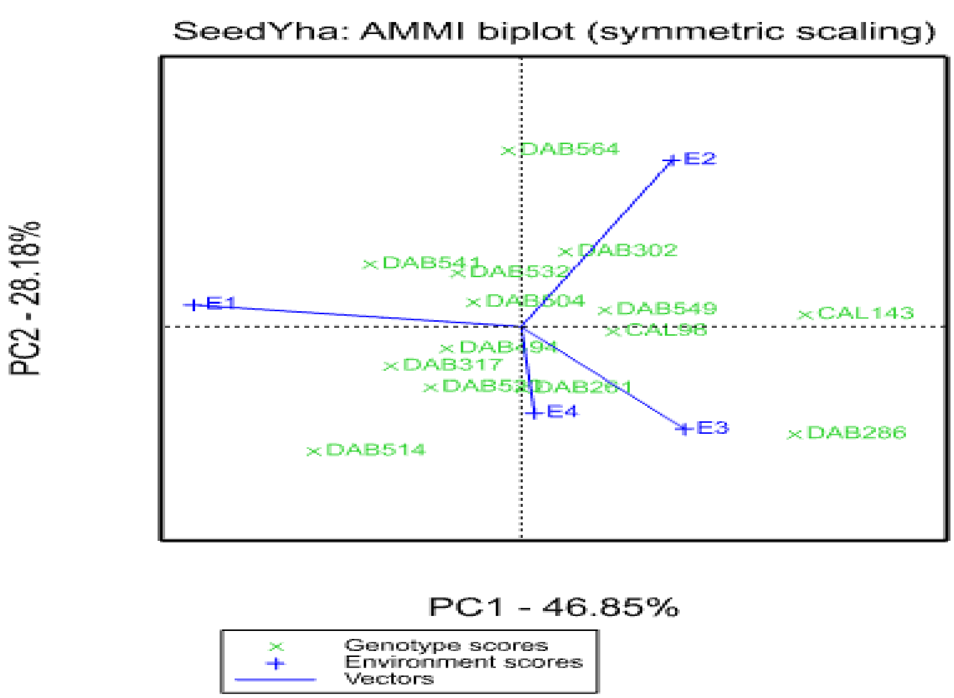

Figure 2. Biplot for the two main axes of interaction (IPCA1 *vs* IPCA2) of grain yield by 14 common bean genotypes and selected environments, E1 = Pandamatenga 2014-2015, E2 = Pandamatenga 2015-16, E3 = Sebele 2014-2015, E4 = Sebele 2015-2016.

Table 4. Mean yield (kg/ha), IPCA, AMMI, Cultivar Superiority index, Finlay & Wilkinson and their ranks for the 14 common bean varieties grown in four environments from 2014-2016.

Cultivar	Yield kg/ha	IPCA1	Rank	Wricke's Ecovalence	Rank	Cultivar Superiority	Rank	Finlay & Wilkinson	Rank
CAL143	349.9	11.207	14	60053	13	24087	13	0.262	2
CAL96	448.7	3.631	9	6329	3	3750	1	0.726	3
DAB261	316.6	0.040	1	5964	2	21036	12	0.805	4
DAB286	395.6	10.787	13	77983	14	18474	10	-0.148	1
DAB302	379.7	1.738	3	12777	6	10954	5	1.109	7
DAB317	379.9	-5.139	10	13423	7	10323	4	1.241	11
DAB494	397.3	-2.930	6	5031	1	7118	2	1.133	8
DAB504	354.9	-1.891	4	9869	4	14083	9	1.185	10
DAB514	384.6	-8.180	12	49251	11	13410	8	1.177	9
DAB520	375.4	-3.580	8	16869	8	12757	6	1.064	6
DAB532	358.1	-2.502	5	11392	5	13101	7	1.339	12
DAB541	404.1	-5.959	11	30260	9	9952	3	1.641	14
DAB549	313.3	3.300	7	53314	12	29682	14	0.861	5
DAB564	341.7	-0.522	2	47678	10	20769	11	1.594	13

Stability coefficient ranking position of each genotype is in the previous column, running downward from 1 as the best.

soil type and low topography, result in poor drainage and may not allow farmers to grow crops at the right planting time, and this may reduce the crop yield (Fitt, 2012).

The second biplot, was produced using genotype and environmental scores of the first two AMMI components to determine the interaction pattern of the 14 common bean genotypes tested in four environments (Figure 2). In this case, genotypes DAB504, DAB494, DAB549, and CAL96 are considered stable based on their closeness to the plot origin, however genotypes with higher yields than the mean such as DAB494 and CAL96 are considered the most stable (Figure 2), which is in accordance to Figure 1. While those genotypes far from the origin such as DAB286, CAL143, DAB564, and DAB514 are considered the most unstable ones. Similarly, environment E4 is considered the most stable, but it has an acute angle with E3 which indicates a positive correlation between the two environments. Environment E1 and E2 are far from the origin hence higher contribution to genotype and environment interaction (GEI). The sites where specific genotypes are adapted to, are clearly defined, genotype DAB286 is specifically adapted to E3, while genotype DAB564 is specifically adapted to environment, and this is revealed by close association between the genotypes and environment (Figure 2).

For the presentation of quantitative measure of stability, parameters of IPCA values, Wricke's ecovalence, cultivar superiority index and Finlay-Wilkinson are shown in Table 4. Lower IPCAs values close to zero indicate more stable genotypes, which in this case are the best ranked as 1st (DAB261), 2nd (DAB564), 3rd (DAB302), 4th (DAB504), 5th (DAB532) and 6th (DAB494), and the genotypes with higher IPCA values and most unstable were CAL143 and DAB286 (Table 4). Wricke's ecovalence (Wi^2), is using genotype × environment interaction (GEI) for each genotype as a stability measure, where genotypes with lower Wi^2 is considered more stable. The lower value (5031) was recorded for genotype DAB494, followed 5964 for DAB261 and 6329 for CAL96. The results revealed that even though the ecovalence value for genotype DAB261 was low, it had the lowest mean yield compared with the overall mean yield (Table 4). The highest ecovalence 77983 was recorded for the last ranked genotype DAB286. However, this genotype had a relatively higher yield compared to the average mean and is specifically adapted to environment E3 (Figure 2). Cultivar superiority measure and ranks of the 14 genotypes for seed yield are shown in Table 4. For cultivar performance measure, the lower values (P_i), the less the distance to the genotype with maximum yield, therefore the genotype is considered the best. Pi shows superiority in the wide adaptation of the genotype. According to the cultivar superiority analysis, the genotype with low values are considered more stable and these are CAL96 (3750), ranked first, followed by DAB494 (7118) and DAB541 at 9952 (Table 4). The most unstable ranked 14th was DAB549 at 29682, which is specifically adapted to environment E2 (Figure 2).

According to the Finlay-Wilkinson (1963), joint regressions (bi), genotypes with regression coefficients close to 1 are considered of average stability; those with values increasing above 1 are below the average stability; while those with values below 0 are considered above average stability. Genotypes with regression values (bi) below 0 are ranked first is DAB286 with (-0.148), CAL143 (0.262), CAL96 (0.726) and DAB261 (0.805), but when looking at the consistence of the genotypes in terms of yield performance, it was only CAL96 that produced above average yields across all sites, which shows it performs well in all the environments (Table 4). General adaptability attributes especially in areas with limited rainfall from season to season in the semi-arid environment of Botswana could be a useful trait. On the other hand, variety DAB541 which has a regression value significantly higher than 1 (1.64) is considered specifically adapted as it had the highest yield in the most favourable environment of E1, it also consistently produced above average yield in environments E2 and E3 (Table 3). The stability coefficient of Wricke's ecovalence, Finlay-Wilkinson and Cultivar superiority index consistently identified genotypes CAL96 and DAB494 among the top three best adapted and best performing varieties. However, some differences in the rankings by stability coefficients were noticed, for example DAB541 was ranked 11th by IPCA scores, 9th by Wricke's ecovalence, 3rd by cultivar superiority index, and 14th by and Finlay and Wilkinson.

Conclusion

It has been shown that it is possible to produce common beans in the semi-arid environment of Botswana, though at relatively lower yield. The biplots analysis, AMMI analysis, Wricke's ecovalence, Cultivar superiority index and Finlay and Wilkinson were able to identify, stable and adaptable genotypes such DAB494, CAL96, and DAB541. The best performing lines were CAL96, DAB541, and DAB494 with overall average yields of 448.7, 404.1 and 397.3 kg/ha, respectively. Further studies on other agronomic aspects of the crop in the country could improve the management and production of common bean. Further testing of genotypes under favourable environments across the country could yield reasonable higher yields. Any areas with similar agro-ecologies to Pandamatenga and Sebele in the country could potentially be used for the production of common bean and this could possibly reduce the importation of the crop in the country.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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