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Full Length Research Paper

Yield performance of dwarf bean (*Phaseolus vulgaris* L.) lines under Researcher Designed Farmer Managed (RDFM) system in three bean agro-ecological zones of Malawi

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An on-farm study was carried out under rain-fed condition in 2003 - 2004 and 2004 - 2005 growing seasons in five sites namely Ntchenachena and Ngong'a in Rumphi district, Chipuka in Ntchisi district, Thondwe and Matapwata in Zomba and Thyolo districts respectively representing three bean agro-ecological zones of Malawi. Seven dwarf bean entries; DC 96-95, PC 490-D8, BCMV-B2, SDDT-54-C5, APN 130, F6BC (19) and DOR 715 were evaluated for their yield stability across sites and two seasons under Researcher Designed Farmer Managed (RDFM) system. Yield stability of the entries across years varied significantly. Entries SDDT-54-C5, PC490-D8 and DOR 715 were stable across all sites and between the two seasons. DOR 715 was also high yielding entry in Thondwe and Ntchenachena sites followed by BCMV B2 though the latter was unstable. Among sites, Thondwe was the best because yields of most of the bean entries were stable at this site.

Key words: Agro-ecological zones, on-farm, *Phaseolus vulgaris* L., Researcher Designed Farmer Managed (RDFM), stability.

INTRODUCTION

Common beans (*Phaseolus vulgaris* L.) contain a high percentage of protein as compared to maize, rice and cassava. This protein is high in lysine, which is relatively deficient in maize, rice and cassava, the staple carbohydrate food crops in Malawi. When beans are consumed with these carbohydrate staples, the mixture provides a balanced diet (CIAT, 2004). In Malawi like many Eastern and Southern African countries, beans are a cheaper source of protein that is especially important in the diet of resource-poor people who live far from the lakeshore areas where fish is the main source of protein (Mekbib, 2002; CIAT, 2004). Furthermore, dry legume grain is relatively easy to store at the small-scale farm level as compared to beef, poultry or fish (Mkandawire et al., 1995).

Despite all these benefits, there are many production challenges faced by small holder bean farmers in Malawi. These include insect pests, diseases and low yield per unit area leading to inadequate supply of the crop to meet the country's demands. Insect pests damaging common beans throughout Malawi include aphids (*Aphis fabae* and *Aphis craccivora*), bean fly (*Ophiomyia spp.*), bean beetles and bean weevils. The latter is mostly common in storage (Msuku et al., 2000; Allen et al., 1996). Chiumia et al. (2003) reported that common beans are widely susceptible to diseases such as Bean Common Mosaic Virus (BCMV), Angular Leaf Spot (ALS), Common Bacterial Blight (CBB), anthracnose and halo blight. Amongst all these challenges, low and unstable yields are the most pertinent problems in common bean production in Malawi (Kadyampakeni, 2004; Mloza-Banda et al., 2003). This is because most varieties grown under

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Table 1. Description of trial sites.

Trial site	Locality	Elevation (masl)
Matapwata	15^0 57' S; 35^0 10' E	3600
Thondwe	15^0 29' S; 35^0 14' E	2500
Chipuka	13^0 30' S; 34^0 5' E	1800
Ng'onga	10^0 55' S; 33^0 57' E	3500
Ntchenachena	10^0 40' S; 34^0 5' E	4100

farmers' field conditions produce yields of less than 400 kg/ha which is far too low to meet the country's demand that is increasing every year (Mloza Banda et al., 2003).

In Malawi, bean production is grouped into three agro-ecological zones based on altitude and rainfall patterns. The first is high altitude, high rainfall bean agro-ecological zone. This zone has altitude greater than 2000 m above sea level (masl) and rainfall greater than 1500 mm per annum. Areas in this zone include Zomba, Thyolo and part of Mulanje districts among others. The second is the medium altitude, moderate rainfall bean agro-ecological zone. This zone covers most parts of central region of Malawi. Altitude ranges from 1000 to 2000 masl and rainfall between 800 and 1500 mm per annum. The third is high altitude, low rainfall bean agro-ecological zone. This has altitude of over 2000 masl and rainfall below 800 mm per annum. The areas include most of the Northern region of Malawi, (Wortmann et al., 1998).

The available bean varieties do not grow in all bean-growing areas of Malawi. CIAT (1998) reported varieties that are well suited to specific locations. Napilira, Sapatsika, Kambidzi and Mkhalira grow in highland areas (1400 masl) with prolonged rainfall averaging 1000 mm per annum while Nagaga is suitable for medium altitude plains (1200 masl) with average rainfall of 800 mm per annum. This variation in adaptation limits some farmers who would be interested to grow certain common bean varieties in a particular area but are restricted by the instability of the bean yields across different environments.

It is important that plant breeders develop bean varieties that are stable in yield levels under farmer's conditions. This should include the varieties that would be able to suit a wide range of ecological zones of Malawi but most of all; the varieties should be high yielding with minimal inputs such as inorganic fertilizers and chemicals for pests and disease control which become most limiting to production to small scale farmers of Malawi.

In trying to address low and unstable bean yields which are one of the challenges; an on-farm study was carried out under rain-fed condition in 2003 - 2004 and 2004 - 2005 growing seasons in five sites representing three bean agro-ecological zones of Malawi. The objective of this study was to evaluate on-farm yield performance of the dwarf bean lines and identify stable lines in the different bean agro-ecological zones.

MATERIALS AND METHODS

The research was conducted over two growing seasons of 2003 - 2004 and 2004 - 2005. During the first growing season, bean entries were evaluated in five different sites representing three bean agro-ecological zones of Malawi (Table 1). These were: Matapwata in Thyolo district and Thondwe in Zomba district representing high altitude and high rainfall bean agro-ecological zones; Chipuka in Ntchisi district representing medium altitude and moderate rainfall bean agro-ecological zone and Ng'onga and Ntchenachena in Rumphi district representing high altitude and low rainfall bean agro-ecological zone. During the second growing season of 2004 - 2005, three sites were used, each site representing a particular agro-ecological zone as follows: Matapwata in Thyolo representing high altitude, high rainfall agro-ecological zone, Chipuka in Ntchisi representing medium altitude, moderate rainfall agro-ecological zone and Ntchenachena in Rumphi district representing high altitude, low rainfall agro-ecological zone (Figure 1).

Bean germplasm used in the trials were BCMV B2, F6BC (19), DC 96-95, PC 490 D8 sourced from Bunda College; SDDT-54-C5, DOR 715 and APN 130 sourced from Chitedze Agricultural Research Station.

Selection of farmers and planting

In each of the five sites, five farmers were randomly selected to host on-farm trials. A primary criterion for selection was that farmers must have been growing beans for a minimum of 5 years. Selection of farmers in each site included female-headed households. Three female headed households and two male headed households conducted the trials in Matapwata, Ng'onga and Chipuka while three male headed households and two female headed households carried out the trials in Thondwe and Ntchenachena. After identification, the farmers were trained on management practices of the trials, expected outputs and impacts of their participation in the trials. Training was conducted in all the sites where the trials were located in both seasons.

During 2003 - 2004 growing season, farmers in Matapwata and Thondwe planted the bean entries on 26th and 27th November 2003 respectively. In Chipuka, farmers planted on 10th of December 2003 while in Ngong'a and Ntchenachena, planting was done on 2nd and 3rd December 2003 respectively. During 2004 - 2005 growing season, planting in Matapwata and Chipuka sites was done on 29th November 2004 while in Ntchenachena, farmers planted the bean entries on 22nd December 2004. The planting dates were determined depending on days when adequate first rains were received in each of the sites. During planting, one seed was planted along the top of the ridged row at a depth of 2 – 3 cm.

Experimental design and treatments

Bean evaluation used Researcher Designed Farmer Managed (RDFM) system. In this system, farmers in each site conducted trials that were designed and laid out by the researcher. Seven best yielding dwarf bean entries collected from advanced trials conducted at the source stations over two seasons were evaluated on-farm for their yield performance and stability across the three agro-ecological zones of Malawi.

The trials were in Randomized Complete Block Design (RCBD) with two replications at each farmer's trial area. The two replicates were arrived at due to scarcity of land as most farmers were reluctant to allocate a larger piece of land for the trials. Each replicate had seven treatments which were BCMV B2, F6BC (19), DC 96-95, PC 490 D8, SDDT-54-C5, DOR 715 and APN 130 planted in three rows each of 5m long. Each farmer was required to choose a field that measured 12 by 12 m to accommodate the trial.

Figure 1. Map of Malawi showing sites of beans trials.

Through the middle of the field, a 1 m wide path was demarcated and all around the field was a path of measuring 0.5 m wide. Twenty-one rows each measuring 5m in length were marked on either side of the center path. The distances between the row centers and planting stations in a row were 0.75 m and 10 cm respectively. Farmers were advised to weed regularly but not apply fertilizers or chemicals to the entries.

Data collection and analysis

Data collection was done at the net plot which comprised of the middle row of each treatment plot excluding 0.5 m on either side of the middle row. Data collection included 100 seed wet weight (g), 100 seed dry weight (at 10% moisture content) in grams, total yield (g) from all seeds collected from the net plot. This set of data helped to estimate yield in kilograms per hectare using standard formula:

$$\frac{DM_1\,(g)}{DM_2\,(g)}\, x\, \frac{Net\ plot\ yield\ \ (g)}{1000\,g}\, x\, \frac{10000\ m^2}{Plot\ size\ \ (m^2)}$$

Where DM_1 = dry matter after harvest; DM_2 = dry matter at 10% moisture content. The estimated data was analyzed in Genstat computer package. Pest and disease incidences (not reported) was also recorded. Rainfall data was collected throughout the trial period. During the same period of research work, government agri-

Table 2. Yield performance of dwarf entries in RDFM trials across the five locations of Malawi in 2003 - 2004 growing season (kg/ha).

Entries	Ntchenachena	Ng'onga	Chipuka	Thondwe	Matapwata	G Mean
DOR 715	577.0	1254.0	957.0	2812.0	739.0	**1267.8**
BCMV B2	541.0	462.0	773.0	1778.0	1049.0	**920.6**
APN 130	359.0	612.0	887.0	1567.0	959.0	**876.8**
SDDT-54-C5	356.0	480.0	843.0	1514.0	436.0	**725.8**
DC 96-95	599.0	466.0	306.0	1659.0	451.0	**696.2**
PC 490-D8	388.0	400.0	426.0	1580.0	667.0	**692.2**
F6BC (19)	310.0	598.0	367.0	1310.0	423.0	**601.6**
G. Mean	**449.0**	**598.0**	**633.0**	**1678.0**	**638.0**	
CV%	58	68	10	45	29	
LSD	45	58	102	202	137	
Sign.	*	***	***	*	***	

*Significant at 5%, **significant at 1%, ***significant at 0.1%.

cultural extension workers assisted in data collection on each and every farmer's field.

The stability test was done using Additive Main effect and Multiplicative Interaction (AMMI) model (Gauch, 1993). This model is more efficient in determining the most stable and high yielding genotypes in multi-environment trials compared to other methods. The model uses the analysis of variance (ANOVA) approach to study the main effects of genotypes and environments. It also uses an Interaction Principal Component Analysis (IPCA) for the residual multiplication interaction between genotypes and environments (Egesi and Asiedu, 2002).

Genotypes with IPCA scores near zero show little interaction across environments depicting stable characteristics (Carbonell et al., 2004). Genotypes and environments combinations with IPCA scores of the same sign produce positive specific interaction effects, whereas combinations of opposite signs have negative specific interactions. Genotypes appearing to the right side of vertical ordinates for grand mean yield are high yielding while those to the left are low yielding hence below average performance (Egesi and Asiedu, 2002; Manrique and Hermann, 2000; Abidin et al., 2005).

RESULTS AND DISCUSSION

The analysis of variance showed that beans performed differently within sites and across agro-ecological zones. A bean entry could produce the highest yields in one zone and become among the lowest in yields in another. In other cases, differences occurred within the same agro-ecological zone but different sites. For example, DC 96-95 had the highest yields in Ntchenachena but was rather poor in Ng'onga area, yet the two areas are in the same zone. It also yielded poorly in Chipuka and Matapwata (Table 2). This bean line behaviour may not be of preferable yield traits because according to Mekbib, (2002), farmers prefer bean varieties that are consistent in yield performance across locations and seasons but may be recommended for site specific adaptation since it is also another aspect in breeding which help to overcome interaction of genotype and environment (Casquero et al., 2006). DOR 715 was the most consistent in yield across sites. It was the highest yielding in Ng'onga and only line that attained 1 tonne in the site. It was also highest in Ntchisi and Thondwe and second and third highest in Ntchenachena and Matap-wata respectively which rates it as a dwarf bean entry that was adaptive across the zones in its performance

Best yields were attained in Thondwe as all the entries attained over 1300 kg/ha in yield. DOR 715 was the highest yielding entry in the area with 2821 kg/ha. This was followed by BCMV B2 with 1778 kg/ha and DC 96-95 with 1659 kg/ha while BCMV B2 was the only entry in Matapwata that yielded more than 1049 kg/ha. It is important to note that these results were obtained under farmers' management where other bean varieties under similar management usually produce yields of less than 400 kg/ha (Mloza-Banda et al., 2003). The yield differences in the trial indicate a clear environmental effect that affected the bean lines in these sites. As reported by Casquero et al. (2006), the best genotype for one environment may not always be the best for another. However, it is important to note that one bean line DOR 715 was high yielding among the rest of the bean lines in three sites representing all zones which might give it a possibility of having adaptive traits across the agro-ecological zones.

When similar trial was repeated in 2004 - 2005 growing season, the yield of the bean entries dropped drastically in all the sites of the trials. Unlike in the previous year where most entries attained over 1000 kg/ha of yield, none of the tested sites provided consistent yield levels. In two of the three sites that were tested, there were no significant differences obtained among entries (Table 3). The sites included Ntchenachena in Rumphi and Matap-wata in Thyolo district.

The results meant that yield performance of all entries in these sites were the same. One of the possible factors that may have contributed to this low and non significance results is inadequate rainfall. During 2004 - 05

Table 3. Yield performance of dwarf entries in RDFM trials across the three sites of Malawi in 2004 - 2005 growing season (kg/ha).

Entries	Ntchenachena	Chipuka	Matapwata	G. Mean
SDDT-54-C5	170.3	485.0	554.0	**403.1**
BCMV B2	160.6	482.0	553.0	**398.5**
F6BC (19)	199.9	522.0	387.0	**369.6**
DOR 715	187.9	524.0	394.0	**368.6**
DC 96-95	167.6	470.0	389.0	**342.2**
PC 490-D8	151.7	441.0	381.0	**325.0**
APN 130	146.8	388.0	275.0	**269.9**
G. Mean	**169.3**	**473.1**	**419.0**	
CV%	48.3	50.8	72.3	
LSD	76.8	107.4	360.8	
Sign.	NS	*	NS	

*Significant at 5%, **significant at 1%, ***significant at 0.1%, NS = not significant.

Table 4. Mean monthly rainfall collected during 2003 - 2004 and 2004 - 2005 growing seasons in five and three trial sites respectively.

Month	Ntchenachena		Ngonga		Chipuka		Thondwe		Matapwata	
	2003-04	2004-5	2003-04	2004-05*	2003-04	2004-05	2003-04	2004-05*	2003-04	2004-05
October	39.0	0.0	0.0		0.0	0.0	0.0		37.0	6.0
November	9.9	0.0	0.0		11.4	149.2	130.8		177.1	80.2
December	138.9	51.9	197.6		168.5	350.6	297.9		66.6	469.3
January	199.1	200.3	52.3		168.6	98.6	190.8		160.6	36.0
February	267.6	180.1	108.1		184.4	75.9	200.2		127.8	27.1
March	215.6	238.7	135.8		149.8	61.0	150.6		111.9	56.5
April	0.0	16.0	0.0		70.9	0.0	199.4		138.2	57.5
May	9.4	11.2	0.0		0.0	0.0	154.7		231.0	59.2
June	9.4	5.4	0.0		47.0	13.0	45.0		65.0	39.0
July	0.0	0.0	0.0		0.0	0.0	56.0		49.3	0.0
August	0.0	0.0	0.0		0.0	0.0	23.0		15.1	0.0
September	1.9	0.0	2.4		0.0	0.0	12.0		7.6	0.0
Total	**890.7**	**703.6**	**496.2**		**800.6**	**748.3**	**1460.4**		**1187.2**	**831.4**

* Trials were not conducted during this growing season hence no data was collected

growing season, all these areas received low rainfall totaling to 703.6, 748.3 and 831.4 mm/annum for Ntchenachena, Chipuka and Matapwata respectively compared to 890.7, 800.6 and 1187.2 mm/annum in the previous growing season. The critical area most affected was Matapwata in Thyolo where dry spell was experienced when the bean entries were flowering during the months of January and February while in Chipuka the rains were very low during flowering and pod filling in February and March (Table 4).

Schneider et al. (1997) reported that lack of water interferes with the normal metabolism of the plant during flowering time and pod-fill as these are the stages when water stress causes greatest yield reduction. Moderate to high drought stress can reduce biomass, number of seeds and pods, days to maturity, harvest index and most of all seed yield in common beans (Acosta-Gallegos and Adams, 1991; Rosales-Serna et al., 2000). Some entries could still be capable of producing better yields under water deficient environments due to genotypic differences (Abebe et al., 1998; Henry and Singh, 2002), however it appeared that none of the entries in this trial produced these features during second season. However, overall performance in the second season showed that all entries in Matapwata yielded above Ntchenachena though some entries in Chipuka produced similar yields to Matapwata (Table 3) which may indicate that this area could be a suitable site for dwarf bean production given a year of good rainfall. Significant difference among entries was however recorded in Chipuka site in Ntchisi district with APN 130 that yielded 388 kg/ha as the only significantly lowest yielding entry in the site compared to

Table 5. AMMI analysis of variance for yield of dwarf entries under RDFM trials.

Source of Variation	Degrees of freedom (df)	Sums of Squares (SS)	Mean squares (MS)	Explained %
Total	335	109062087	325558	
Treatments	55	84561003	1537473***	
Genotypes	6	5790905	965151***	6.8
Environments	7	66678615	9525516***	78.8
Block	16	2785379	174086	
G&E Interactions	42	12091483	287892***	14.3
IPCA 1	12	7389551	615796***	61.1
IPCA 2	10	2645159	264516***	21.9
Residuals	20	2056773	102839	17.0
Error	264	21715705	82256	

*Significant at 5%, **significant at 1%, ***significant at 0.1%.

the rest of the entries. The entry was equally low (though statistically insignificant with other entries) in Matapwata and Ntchenachena yielding 275 and 146.8 kg/ha respectively.

AMMI Analysis of variance for yield of dwarf entries in the trials was carried out to determine whether there was interaction between genotypes and environments. It was shown that there were very high significant differences ($P < 0.001$) between treatments, genotypes, environment as well as interactions between environment and genotypes (Table 5).

Genotypes, environments and interactions between genotype and environment accounted for 6.8, 78.8 and 14.3% of the treatment sum of squares respectively. The large percentage of environmental sums of squares indicates that most of the variations in yields were due to environmental influence. First Interaction Principal Component (IPCA 1) accounted for larger percentage (61.1%) for sums of squares for yield compared to 21.9% of IPCA 2 (Table 5). According to Egesi and Asiedu (2002), this means that the model validation procedure identifies that the 17% of the treatment sum of squares as allocated to the residual term was not of predictive value and it also means that genotypic performance for the bean entries was affected by environmental differences among locations where the trials were conducted. It was therefore necessary to identify the genotypes that were dependent on environmental interaction and specific environments that were contributing to the differences in yield performances.

Dwarf entry SDDT-54-C5 (G4) was very stable across seasons and locations as suggested by its IPCA scores that were very close to zero (Figure 2). G2 (PC 490-D8) was another stable entry in the trial across seasons and environments while G7 (DOR 715) was a very high yielding and stable line compared to PC 490-D8 that was in the same stability range but the latter being low yielding.

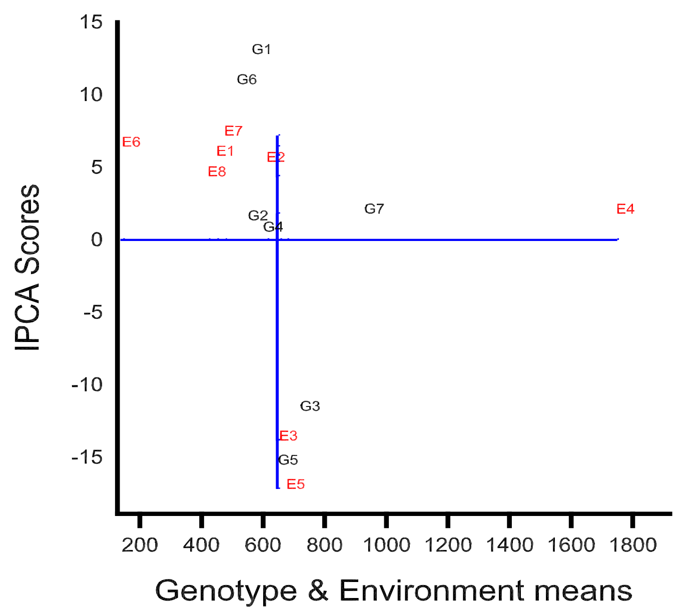

Figure 2. Bi-plot of dwarf genotype and environment IPCA 1 under RDFM versus means yield (kg/ha) of seven genotypes and eight environments. Genotype: G1 = DC 96-95, G2 = PC 490-D8, G3 = BCMVB2, G4 = SDDT-54-C5, G5 = APN 130, G6 = F6BC (19), G7 = DOR 715. Environment: E1 = Ntchenachena 2003 - 04, E2 = Ngong'a, E3 = Chipuka 2003 - 04, E4 = Thondwe, E5 = Matapwata 2003 - 04, E6 = Ntchenachena 2004 - 05, E7 = Chipuka 2004 - 05, E8 = Matapwata 2004 – 05.

Genotypes G1 (DC 96-95) and G5 (APN 130) were very unstable entries in the trials though the latter was slightly above average as depicted by the high IPCA scores both negative and positive direction from the zero line of stability. These entries can not, therefore, be recommended as those with consistent yield both across locations as well as seasons since stable entries are located close to zero line of IPCA scores (Abidin et al., 2005; Carbonell et al., 2004).

Environment E4 (Thondwe) was a best suitable environment for the bean entries in the trials as it was a stable and high yielding location (Figure 2) while Matapwata was the most unstable location for bean trials with low yields in 2004 - 2005 season (E8) though yielded above average in 2003 - 2004. This could be attributed to the inadequate rains that were received in the location during the period that resulted in poor bean yields.

Conclusion

The trial identified some bean entries that were high yielding and stable across sites and agronomic seasons of on-farm trials despite changes in environmental characteristics such as rainfall and temperature over the two growing seasons. Entries SDDT-54-C5, PC490-D8 and DOR 715 were stable in all locations and across seasons. DOR 715 was also high yielding entries in other sites such as Thondwe and Ntchenachena during 2003-2004 growing season. AMMI also identified BCMV B2 as another high yielding entry though it was unstable. These high yielding entries may be recommended for further evaluation that may lead to their release for production by farmers in Malawi. Among environments, Thondwe was best suitable for the bean entries for the trials as it was stable and high yielding in 2003 - 2004 growing season.

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