

Full Length Research Paper

# Performance of parental genotypes and inheritance of Angular Leaf Spot (*Phaeosariopsis griseola*) resistance in the common bean (*Phaseolus vulgaris*)

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Two studies, one on performance of six common bean parental genotypes and another on inheritance of resistance to *Phaeosariopsis griseola* (*Pg*) in the common bean were carried out in Malawi. Common bean entries namely; Chimbamba, Nasaka, RC 15, CAL 143 and Mexico 54 were evaluated on station in the 2004/2005 growing season at Bunda, Dedza, Ng'onga and Ntchenachena sites. The second study started by generating F<sub>1</sub>s and then F<sub>2</sub> and F<sub>3</sub> seeds in greenhouse at Bunda College. CAL 143 and Mexico 54 were sources of *Pg* resistance genes while Chimbamba, Nasaka and RC 15 were susceptible recipient parents. Following green house trials, *Pg* resistance was evaluated on station in the same sites. CAL 143 was highest yielding but unstable across sites. RC 15 was stable and gave the highest yield at the dry-spell-stricken Ng'onga whereas Mexico 54 was superior at Ntchenachena but highly unstable across sites. Yield was strongly correlated to number of effective pods per plant in all genotypes. The inheritance study showed that resistance to *Pg* in the common bean is controlled by one gene using both CAL 143 and Mexico 54 as resistant parents.

**Key words:** AMMI, GxE interaction, on-station, yield stability, inheritance.

## INTRODUCTION

The importance of the common bean can not be overemphasized. Apart from providing the subsistence needs such as food to many people in the world (CIAT, 2004; Osorio-Diaz et al., 2003; Parra et al., 2004), beans are also sold in local markets and urban areas to provide cash to farmers and traders (Mwale et al., 2008). Beans also have a good export market, hence providing opportunities to earn foreign currency (CIAT, 1981; Mauyo et al., 2007). They are the leading grain legume crop taking up 30% of the total pulse production and grown on more than 14 million hectares world wide (Singh, 2001). Of the five domesticated species of *Phaseolus*, the common bean (*P. vulgaris*) is the most widely grown, occupying

more than 85% of production area sown to all *Phaseolus* species in the world (Singh, 2001). It is produced primarily in tropical low-income countries which account for over three quarters of the annual world production.

Bean production in Malawi is far below demand. Data adapted from Mloza-Banda (2000) indicated that bean production in all Agricultural Development Divisions (ADDs) does not meet consumption requirements. The main bean producing areas in Malawi are Kasungu, Dowa, Lilongwe, Ntchisi, Dedza and Ntcheu in the central region; Chitipa North, Rumphu East and West and South west Mzimba in the northern region and Mangochi, Machinga, Chiradzulo, Thyolo, Mulanje and Phalombe in the southern region (Edje, 1980; Msuku et al., 2000).

Despite the importance of the common bean (*P. vulgaris* L.) there are so many biotic and abiotic production constraints which include poor agronomic practices, soil infertility, lack of improved cultivars, moisture stress,

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**Table 1.** Description of locality and elevation in metres above sea level (masl) of the trial sites.

Trial site	Locality	Average temperature	Soil type	Elevation (masl)
Ntchenachena	10° 40' S 34° 5' E	22.4°C	Clay loam	4100
Ng'onga	10° 55' S 33° 57' E	25.0°C	Sandy clay loam	3500
Bunda	14° 12' S 33° 46' E	21.7°C	Sandy clay loam	1200
Dedza	14° 20' S 34° 18' E	20.9°C	Clay loam	1500

temperature extremes, weed competition and damage caused by pests and diseases, have led to low yield (Schwartz and Pastor-Corrales, 1989; Allen et al., 1996; Wortmann et al., 1998; Beebe and Pastor-Corrales, 1991; Banjo et al., 2003; Mahuku et al., 2003). The diseases which are considered to be of economic importance in Malawi are angular leaf spot (ALS) (*Phaeosariopsis griseola*), common bacterial blight (CBB) (*Xanthomonas campestris* pv *phaseoli*), halo blight (HB) (*Pseudomonas syringae* pv *phaseolicola*) and Bean common mosaic virus (BCMV) (Msuku et al., 2000; Malawi Bean Improvement Project, 1996).

The interaction between the environment and genotypes determine the phenotypic expression of the genotype and are responsible for the temporal and spatial instability of crop yields hence considered a hindrance to crop improvement in the target region (Annicchiarico, 2002; Kang, 1998). The major interaction can be expected when there is either wide variation between genotypes for morphophysiological characters conferring resistance to one or more stresses or wide variation between environments for incidence of the same stresses. The objectives of this study were therefore to determine yield performance and adaptability of six parental genotypes to four bean growing sites in Malawi; to determine the influence of yield components (plant height, number of nodes per plant, number of pods per plant and number of seeds per pod) on grain yield of the genotypes and to determine the nature of inheritance of resistance to ALS.

## MATERIALS AND METHODS

Two studies, one on performance of six common bean parental genotypes and another on inheritance of resistance to Angular Leaf Spot (*Phaeosariopsis griseola* (*Pg*)) in the common bean were carried from 2003 to 2005.

In the first study, six common bean genotypes, Chimbamba, Nasaka, RC 15, CAL 143 (sourced from Bunda Bean/Cowpea Collaborative Research Support Program), Mexico 54 and VAX 6, (sourced from Chitedze Research Station) were evaluated on station in the 2004/2005 growing season at Bunda in Lilongwe district (Central Malawi), Dedza in Dedza district (Central Malawi), Ng'onga and Ntchenachena in Rumphi district (Northern Malawi). Matapwata in Thyolo district (Southern Malawi) was abandoned because beans were adversely affected by prolonged drought, which led to the loss of the genotypes (Table 1).

A randomized complete block design (RCBD) with three replicates was used. Grain yield data was analyzed using General statistics (Genstat) computer package and both genotypes and sites were fixed factors. When the interaction between sites and

genotypes was significant further analysis was done using Additive Main Effects and Multiplicative Interaction (AMMI) model to determine adaptive response of specific genotypes to specific locations (Annicchiarico, 2002; Egesi and Asiedu, 2002). Determination of the strength of the relationship between grain yield and other measured variables was done using SPSS software version 9.0

The second study started by generating F<sub>1</sub>s using Partial Diallel Design and advancing them to F<sub>2</sub> and F<sub>3</sub> in greenhouses at Bunda College and Bvumbwe Research Station from November, 2003 to October, 2004. CAL 143 and Mexico 54 were sources of *Pg* resistance genes while Chimbamba, Nasaka and RC 15 were susceptible recipient parents. Following the green house study, *Pg* resistance was evaluated on station at Ntchenachena, Ng'onga, Bunda and Dedza sites in 2004/2005 growing season. The evaluation was based on natural occurrence of the pathogen in the trial plots. Previous studies have identified races 30-0, 31-0, 30-5 and 63-7 as some of the races prevalent in Malawi (Aggarwal et al., 2004). Trials were planted on 7<sup>th</sup>, 13<sup>th</sup>, 15<sup>th</sup> and 29<sup>th</sup> of December, 2004 at Dedza, Bunda, Ng'onga and Ntchenachena respectively. Forty kilograms of nitrogen per hectare (kgN/ha) was applied at trifoliolate stage in all the sites and weeding was done on regular basis. Individual plant canopies were evaluated for pests and diseases using a CIAT scale of 1 to 9 (CIAT, 1987). Plants were scored twice for disease incidences during the entire growing period thus at flowering and pod filling stages. The fitness of the observed disease score ratios to the expected was analyzed using SPSS package version 9.0. Pest incidences were controlled by occasional spraying of Dimethoate pesticide. Rainfall data (in millimeters) was collected from each site using rain gauges mounted at each of the station's premises at an average distance of fifty metres from the trial fields.

## RESULTS AND DISCUSSION

### Performance and adaptability of common bean genotypes

Analysis of variance for Additive Main Effect and Multiplicative Interaction (AMMI) model showed significant differences amongst treatments, genotypes (G), sites (E) and interactions between genotypes and sites (GxE) ( $P > 0.001$ ) (Tables 2 and 3). Genotypes, sites and GxE accounted for 5.8, 62.7 and 31.6% of the sum of squares treatment respectively (Table 2). The large sum of squares for sites was due to large differences among site means causing most of the variation in the yield. The larger sum of squares for GxE than genotypes (six times larger) indicated the substantial differences in genotypic response across sites. When the analysis was split into Interaction Principle Component Axes (IPCA), both IPCA-1 and IPCA-2 showed significant different mean yields ( $P < 0.001$ ) and captured 67.2 and 30.1% of the sum of

**Table 2.** AMMI analysis of variance for yield (kg ha<sup>-1</sup>) of six common bean genotypes across the four sites.

Source of variation	Degrees of freedom (df)	Sum of squares (SS)	Mean squares (MS)	Explained percentage (%)
Treatments	23	48,709,712	2,117,814***	
Genotype (G)	5	2,819,660	563,932**	5.8
Site (E)	3	30,521,328	10,173,776***	62.7
GE	15	15,368,724	1,024,582***	31.6
IPCA-1	7	10,329,580	1,475,654***	67.2
IPCA-2	5	4,625,145	925,029***	30.1
Residuals	3	414,000	138,000	2.7
Error	40	6,070,138	151,753	

\*Significant at 0.05, \*\* significant at 0.01, \*\*\* significant at 0.001.

**Table 3.** Mean yield (kg ha<sup>-1</sup>) of six genotypes in each site, across four sites and the site mean.

Site	Genotype						Site mean
	Chimbamba	Nasaka	RC 15	CAL 143	Mexico 54	VAX 6	
Bunda	627	821	998	1058	654	824	830 <sup>r</sup>
Dedza	921	1330	808	2550	112	1087	1135 <sup>s</sup>
Ng'onga	461	928	1610	711	26	946	780 <sup>r</sup>
Ntchenachena	2310	2084	2168	2188	3339	2226	2386 <sup>t</sup>
Mean	1080 <sup>ab</sup>	1291 <sup>ab</sup>	1396 <sup>bc</sup>	1627 <sup>c</sup>	1033 <sup>a</sup>	1271 <sup>ab</sup>	1283

Genotypes P < 0.01 SE: 110.9 LSD: 315.7

Site P < 0.001 SE: 90.6 LSD: 257.8

GxE P < 0.001 SE: 221.8 LSD: 631.4

Means with the same superscripts are not significantly different.

squares for interaction (Table 2).

Ntchenachena produced the highest mean yield (2386 kg/ha) seconded by Dedza (1135 kg/ha) whereas Ng'onga had the least yield (780 kg/ha) (Table 3). Since management practices were the same in all the sites, the observed yield differences might be due the differences in the prevailing environmental conditions for each site (Casquero et al., 2006).

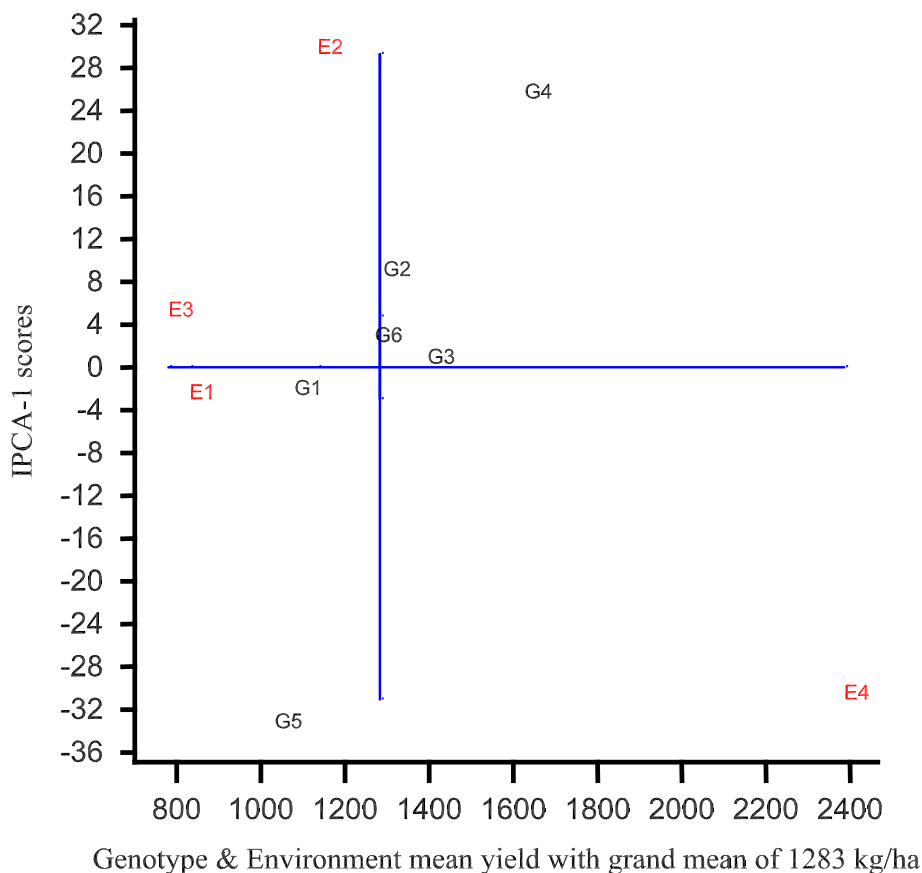
Performance of genotypes at Bunda did not vary widely. RC 15 and CAL 143 were however outstanding with mean yields of 1058 and 998 kg/ha respectively whereas Chimbamba (627 kg/ha) and Mexico 54 (654 kg/ha) performed below the site mean (830 kg/ha). Large yield variations among the genotypes were observed in Dedza with CAL 143 yielding the highest (2550 kg/ha) and Mexico 54 yielding the least (112 kg/ha). The other genotypes clustered around the site mean. RC 15 showed best performance (1610 kg/ha) in the drought stricken Ng'onga; which had the lowest total rainfall of 482.3 mm, while Mexico 54 was the least (26 kg/ha). On the other hand, Mexico 54 had an outstanding performance in Ntchenachena (3339 kg/ha) while the other genotypes clustered around the site mean of 2386 kg/ha (Table 3).

In a biplot of interaction principal component axis-1 (IPCA-1) against mean yield, genotypes or sites on the same parallel line, relative to the ordinate, had similar

yield and those to the right meant they yielded more than those to the left (Figure 1). Among the sites, Ntchenachena (E4) was the most favourable and gave the highest grain yield whereas Bunda (E1) and Ng'onga (E2) and Dedza (E3) performed below average. Sites which exhibited relatively stable but low yields (Bunda and Ng'onga) were affected by drought suggesting the influence drought conditions on performance and stability of grain yield of the genotypes. Yield reduction due to erratic rains and dry spell was also reported by White and Singh (1991), Rosales-Serna et al. (2000) and Mwale et al. (2008).

Among the genotypes, CAL 143 (G4) and Mexico 54 (G5) produced the highest and least grain yield average respectively and were both very unstable suggesting high interaction with the sites (Figures 1 and 2). CAL 143 showed positive GxE effect at Dedza and Ng'onga whereas Mexico 54 had positive GxE effect at Ntchenachena and Bunda. Chimbamba (G1), RC 15 (G3) VAX 6 (G6) had little interaction with the sites suggesting relatively stable performance across the sites. Among the stable genotypes, RC 15 was high yielding and hence might be an ideal genotype to be recommended in fluctuating environmental conditions (Mwale et al., 2008). Nasaka performed slightly above average yield and was unstable.

Performance of genotypes is influenced by prevailing biotic and abiotic stresses. Resistance to biotic stresses



**Figure 1.** Biplot of interaction principal component axis-1 (IPCA-1) against mean yield ( $\text{kg ha}^{-1}$ ) of six genotypes and four sites. Sites: E1 = Bunda; E2 = Dedza; E3 = Ng'onga; E4 = Ntchenachena. Genotypes: G1 = Chimbamba; G2 = Nasaka; G3 = RC 15; G4 = CAL 143; G5 = Mexico 54 and G6 = Vax 6.

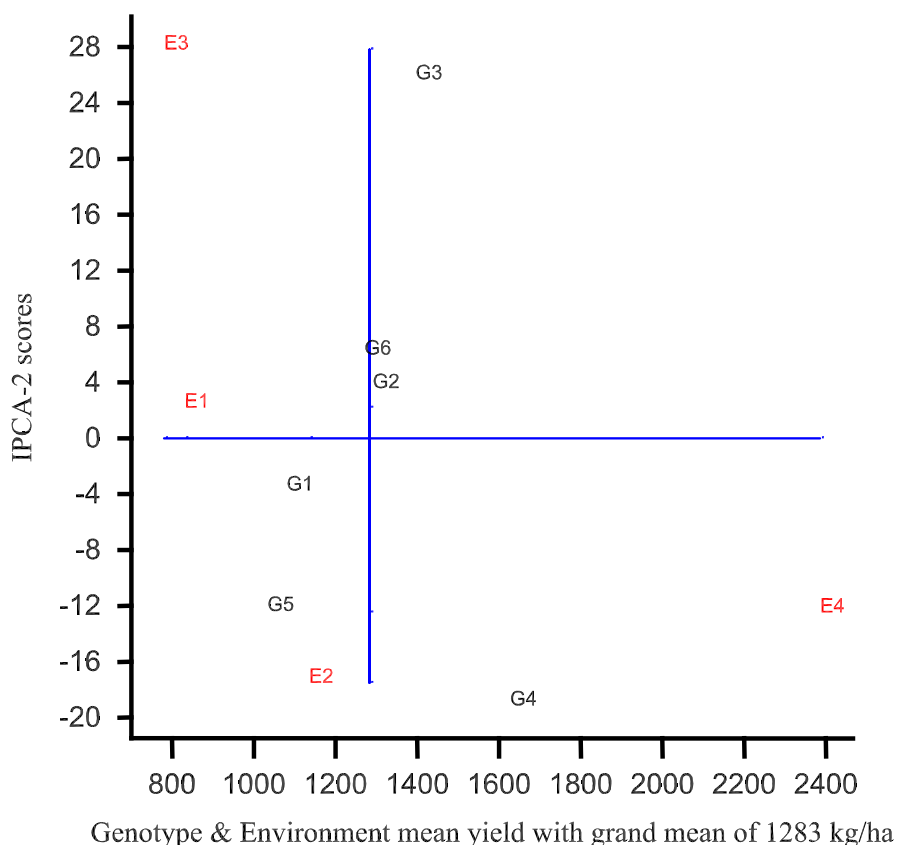
in addition to tolerance to common abiotic factors in the sites would ensure good genotype performance. In this study, the yields for Bunda and Ng'onga were low but not significantly different. Both sites experienced dry spell conditions during month of January 2005 when monthly rainfall was as low as 68.5 and 55.9 mm per month respectively (Table 4) and this was probably the contributing factor for low yield. Dry spell in this month affected both vegetative and reproductive growth differently in different genotypes. The rapid onset of dry spell might have interrupted both photosynthesis and tissue expansion and consequently led to low yield at Bunda and Ng'onga.

Interrupted photosynthetic activities reduce gas exchange due to stomatal closure as has been observed by White and Singh (1991). In beans, full closure may be reached in a few minutes after an application of a stress (White and Singh, 1991). RC 15, however seemed to have drought tolerant or escape mechanisms as manifested by its highest yield at Ng'onga. If the possibility of the presence of the gene responsible for drought tolerant or escape be further investigated and confirmed, RC 15 could be used as a source drought tolerant/escape genes

in breeding for drought stress. Bunda trials were also attacked by insect pest *Oothena bennigseni* at the early stages which caused extensive leaf damage. This attack was the additional contributing factors to low yield at the site apart from dry spell.

On the contrary, Ntchenachena and Dedza had enough and reliable rainfall distribution throughout the bean growing period (Table 4) and hence this led to high site mean yields of 2386.0 and 1135 kg/ha respectively. The mean seed yields for Ntchenachena and Dedza were significantly different from each other and from the mean yields for Bunda and Ng'onga ( $P > 0.001$ ). The yield for Dedza was significantly lower than that of Ntchenachena due to aphids (*Aphis fabae*) infestation and cutworm attack in Dedza which drastically reduced plant stand. Apart from excessive sap sucking, the aphids excreted sugary honey dew which coated the plant surfaces hence reducing photosynthetic efficiency of leaves, restricting growth and consequently reducing yield. Dimethoate application and occasional heavy rainfall, however, averted the infestation.

The results suggested that environmental conditions



**Figure 2.** Biplot of interaction principal component axis-2 (IPCA-2) against mean yield ( $\text{kg ha}^{-1}$ ) of six genotypes and four sites. Sites: E1 = Bunda; E2 = Dedza; E3 = Ng'onga; E4 = Ntchenachena. Genotypes: G1 = Chimbamba; G2 = Nasaka; G3 = RC 15; G4 = CAL 143; G5 = Mexico 54 and G6 = Vax 6.

**Table 4.** Rainfall (mm/month) collected from the four trial sites in Malawi during 2004/2005 growing season

Month	Ntchenachena (2004 – 2005)	Ng'onga (2004 – 2005)	Bunda (2004 – 2005)	Dedza (2004 – 2005)
September	0.0	0.0	0.0	0.0
October	0.0	0.0	3.2	20.0
November	0.0	0.0	137.5	101.3
December	519.1	167.9	198.0	303.1
January	200.3	55.9	68.5	200.5
February	180.1	118.7	138.8	157.6
March	238.7	139.8	81.8	19.7
April	16.0	0.0	0.0	7.2
May	11.2	0.0	0.0	2.1
June	5.4	0.0	0.0	0.0
July	0.0	0.0	0.0	0.0
August	0.0	0.0	0.0	0.0
Total	1170.8	482.3	627.8	811.5

such as rainfall, pests and disease attack affect yield potential of bean genotypes hence the environmental conditions for specific sites should be well characterized in order to aid in recommending bean production to those

sites. According to this study, sites with similar environmental conditions as that of Ntchenachena would be ideal for bean production. The results also indicate that different genotypes interacted differently with the sites in

**Table 5.** Correlation coefficients between grain yield and pod load of the six common bean genotypes in four test sites in Malawi.

Yield component	Genotype	Site			
		Bunda	Dedza	Ng'onga	Ntchenachena
Pod load (Effective pods/plant)	Chimbamba	0.37***	0.94***	0.74***	0.93***
	Nasaka	0.54***	0.81***	0.88***	0.75***
	RC 15	0.45***	0.76***	0.85***	0.90***
	CAL 143	0.59***	0.69***	0.79***	0.75***
	Mexico 54	0.24	0.95***	0.87***	0.90***
	Vax 6	0.53***	0.73***	0.78***	0.78***
	Site mean	0.70***	0.78***	0.78***	0.86***

\* \*\* and \*\*\* mean significant at 0.05, 0.01 and 0.001 probability level, respectively.

which they are grown and hence affecting performance and stability across different sites. The interaction can either be positive or negative and these are important in breeding programs aimed at recommending genotypes to specific or a range of contrasting and fluctuating environments. Mwale et al. (2008) also reported that genotypes can vary in their performance when grown from one environment to another and that it is also possible to have genotypes that can grow consistently across environments.

### Relationships between yield and yield components

Correlation analysis showed that plant height, number of nodes per plant, seed size, pods per plant, number of effective pods per plant, pod length and number of seeds per pod, were positively correlated to grain yield in all sites. This meant that an increase of either of the yield components might lead to increased grain yield. Effective number of pods per plant (pod load) was the only parameter consistently correlated to grain yield across sites.

The high association between number of effective pods per plant and grain yield at Bunda, Dedza, Ng'onga and Ntchenachena, correlation coefficients ranging from 0.24 to 0.59, 0.69 to 0.95, 0.74 to 0.88 and 0.75 to 0.98, respectively implied that selection for pod load might improve yield (Table 5). This observation is important to breeders interested in improving bean yield by selecting for yield components that are highly correlated to seed yield. Selection for pod load may not necessarily have a positive effect on other yield components thus posing a challenge on its use in improving grain yield. Most researches have shown compensation where selection for one yield component causes a reduction in other yield components leaving yield unchanged. The other parameter which needs investigation, if pod load is to be reliably used in indirect selection for higher yield, is its heritability as compared to grain yield itself. Nonetheless, the finding sets a milestone in the design of management practices of bean genotypes that can be directed towards

maximization of pod load and other yield components in order to have significant yield increase in both farmers' fields and research sites. High pod load was a function of more fertilized flowers accumulating adequate photosynthase to form seeds and this was influenced by the prevailing environmental conditions. Deposition of photosynthate into the storage sink in form of seed was a function of adequate supply from photosynthesizing organs and this depended on the prevailing environmental conditions which included moisture supply. Moisture stress during reproductive period led to low pod load (Table 6) and poor pod filling which resulted in shriveled seed and hence low grain yield.

Further investigations on the effect of drought on reproductive period and pod load in different genotypes revealed that drought reduced both reproductive period and pod load (Table 6).

This explained the differences in yielding capability among the genotypes in Ng'onga and Ntchenachena. Mexico 54 maintained its reproductive stage for 84 days in Ntchenachena and had produced 20pods/plant on average and was the highest yielding. On the contrary, it remained in reproductive stage for only 45 days with pod load of 6 at Ng'onga and produced the least seed yield. It was also observed that most of the flowers were aborting at Ng'onga which might be due to the drought.

### Inheritance of angular leaf spot (*Phaeoisariopsis griseola*) resistance in the common bean (*Phaseolus vulgaris*)

The observed number of plants resistant and susceptible to *P. griseola* (*Pg*) in the three populations, derived from CAL 143 as a source of resistance, were not significantly different from the expected Mendelian ratios for one gene conferring resistance to *Pg* except in the F<sub>3</sub> from RC 15 x CAL 143 (Table 7). This is the first time that the inheritance of resistance for CAL 143 (Mesoamerican) has been determined in Malawi. The Chi-square values for additivity for both F<sub>2</sub> ( $X^2 = 0.367$ ;  $P = 0.832$ ) and F<sub>3</sub> ( $X^2$

**Table 6.** The relationships between reproductive period and pod load in bean in the two contrasting sites in Malawi.

Genotype	Reproductive period (days)		Pod load (Effective pods/plant)	
	Ng'onga	Ntchenachena	Ng'onga	Ntchenachena
Chimbamba	34 ± 2	68 ± 4	5 ± 1	16 ± 2
Nasaka	30 ± 1	40 ± 2	5 ± 1	7 ± 1
RC 15	29 ± 2	40 ± 1	6 ± 1	10 ± 4
CAL 143	32 ± 1	46 ± 2	5 ± 1	10 ± 1
Mexico 54	45 ± 2	84 ± 10	6 ± 3	20 ± 1
Vax 6	30 ± 2	57 ± 2	10 ± 3	16 ± 3
Mean	34 ± 6	56 ± 17	6 ± 2	13 ± 5

P-values: Site (E) = 0.002, Site (E) = 0.020, Genotypes (G) < 0.000, Genotypes (G) = 0.002, G x E < 0.000, G x E = 0.002.

**Table 7.** Frequency distributions of plants, and segregation of F<sub>2</sub> and F<sub>3</sub> progenies for reaction to *P. griseola* in the common bean using CAL 143 as a source of resistance.

Parent/Crosses	Frequency distribution of plants on a 1 - 9 scale									Observed # of plants		Expected Ratio of R:S	X <sup>2</sup>	P
	1	2	3	4	5	6	7	8	9	R	S			
Chimbamba(P <sub>1</sub> )	6	8	6	3	2	2	1	5	3					
CAL 143 (P <sub>4</sub> )	13	10	7	7	1	0	0	0	0					
F <sub>2</sub> (P <sub>1</sub> *P <sub>4</sub> )	10	5	10	1	3	2	1	0	0	25	7	3:1	0.167	0.683
F <sub>3</sub> (P <sub>1</sub> *P <sub>4</sub> )	1	5	8	7	4	7	4	2	0	21	17	5:3	0.841	0.359
Nasaka (P <sub>2</sub> )	1	0	0	7	11	9	10	2	0					
CAL 143 (P <sub>4</sub> )	36	5	2	1	0	0	0	0	0					
F <sub>2</sub> (P <sub>2</sub> *P <sub>4</sub> )	16	7	5	3	4	6	2	0	0	31	12	3:1	0.186	0.666
F <sub>3</sub> (P <sub>2</sub> *P <sub>4</sub> )	14	5	4	3	5	6	1	2	0	26	14	5:3	0.107	0.744
RC 15 (P <sub>3</sub> )	0	0	0	3	11	12	11	3	0					
CAL 143 (P <sub>4</sub> )	47	1	0	0	0	0	0	0	0					
F <sub>2</sub> (P <sub>3</sub> *P <sub>4</sub> )	23	6	3	3	6	2	1	1	0	35	10	3:1	0.192	0.661
F <sub>3</sub> (P <sub>3</sub> *P <sub>4</sub> )	25	5	4	5	3	1	0	0	0	34	9	5:3	5.005	0.025
∑(P <sub>1</sub> , P <sub>2</sub> and P <sub>3</sub> )	7	8	6	13	24	23	22	10	3					
∑(P <sub>4s</sub> )	96	16	9	8	1	0	0	0	0					
∑F <sub>2</sub> across crosses	49	18	18	7	12	11	5	2	0	92	28	3:1	0.178	0.673
∑F <sub>3</sub> across crosses	40	15	16	15	12	14	5	4	0	71	50	5:3	0.746	0.388
Chi-square value for additivity in F <sub>2</sub>													0.367	0.832
Chi-square value for additivity in F <sub>3</sub>													5.207	0.074
Pooled Chi-square value (total) in F <sub>2</sub>													0.545	0.909
Pooled Chi-square value (total) in F <sub>3</sub>													5.953	0.114

= 5.207; P = 0.074) populations were less than the tabulated Chi-square values meaning that the data from crosses with different female/recipient parents were homogeneous and hence could be pooled without affecting the segregation pattern. Pooled Chi-square values for F<sub>2</sub> (X<sup>2</sup> = 0.545; P = 0.909) and F<sub>3</sub> (X<sup>2</sup> = 5.953; P = 0.114) confirmed the presence of one dominant gene with two alleles conferring resistance to *Pg*. Caixeta et al. (2005) identified monogenic inheritance using Cornell 49-242 (Mesoamerican bean) as a source of resistance. Namayanja et al. (2006) also detected monogenic

inheritance using BAT 332 (Mesoamerican) as sources of inheritance and allelism test indicated that the resistance to pathotype 63-39 was controlled by the same resistance locus. However, results by Mahuku et al. (2009), who used G5686 (Andean bean) as a source of resistance, identified three dominant and complimentary genes conferring resistance to *Pg* pathotype 31-0.

When Mexico 54 (Mesoamerican bean) was used as a source of resistance, Chi-square additivity test in both F<sub>2</sub> and F<sub>3</sub> segregating progenies were non-significant (X<sup>2</sup> = 1.909, P > 0.25, d.f. = 2 in F<sub>2</sub> and X<sup>2</sup> = 2.67, P > 0.10, d.f.

**Table 8.** Frequency distributions of the number of plants, and segregation of plants in F<sub>2</sub> and F<sub>3</sub> progenies for reaction to *P. griseola* in the common bean using Mexico 54 as a source of resistance.

Parent/Crosses	Frequency distribution of plants on a 1 - 9 scale									Observed # of plants		Expected Ratio of R:S	X <sup>2</sup>	P
	1	2	3	4	5	6	7	8	9	R	S			
Chimbamba(P <sub>1</sub> )	0	2	3	12	9	4	1	1	0					
Mexico 54 (P <sub>4</sub> )	13	12	6	4	0	0	0	0	0					
F <sub>2</sub> (P <sub>1</sub> x P <sub>4</sub> )	12	9	7	1	2	3	1	0	0	28	7	3:1	0.467	0.495
F <sub>3</sub> (P <sub>1</sub> x P <sub>4</sub> )	16	6	3	3	5	3	1	1	0	25	13	5:3	0.175	0.675
Nasaka (P <sub>2</sub> )	0	0	1	2	7	6	3	3	1					
Mexico 54 (P <sub>4</sub> )	12	8	9	8	2	0	0	0	0					
F <sub>2</sub> (P <sub>2</sub> x P <sub>4</sub> )	10	6	5	3	3	3	1	0	0	21	10	3:1	0.871	0.351
F <sub>3</sub> (P <sub>2</sub> x P <sub>4</sub> )	7	7	9	1	3	5	1	2	0	23	12	5:3	0.154	0.694
RC 15 (P <sub>3</sub> )	0	1	1	3	11	8	5	6	0					
Mexico 54 (P <sub>4</sub> )	23	10	0	0	0	0	0	0	0					
F <sub>2</sub> (P <sub>3</sub> *P <sub>4</sub> )	18	6	6	1	1	1	2	2	0	30	7	3:1	0.730	0.393
F <sub>3</sub> (P <sub>3</sub> *P <sub>4</sub> )	18	9	4	1	2	2	1	1	0	31	7	5:3	5.902	0.015
∑(P <sub>1</sub> , P <sub>2</sub> and P <sub>3</sub> )	0	3	5	17	27	18	9	10	1					
∑(P <sub>4</sub> s)	48	30	15	12	2	0	0	0	0					
∑F <sub>2</sub> across crosses	40	21	18	5	6	7	4	2	0	79	24	3:1	0.159	0.690
∑F <sub>3</sub> across crosses	41	22	16	5	10	10	3	4	0	79	32	5:3	3.561	0.059
Chi-square value for additivity in F <sub>2</sub>													1.909	0.385
Chi-square value for additivity in F <sub>3</sub>													2.67	0.263
Pooled Chi-square value (total) in F <sub>2</sub>													2.068	0.558
Pooled Chi-square value (total) in F <sub>3</sub>													6.231	0.101

= 2 in F<sub>3</sub>) indicating homogeneity of the data from segregating plants from different recipient parents (Table 8). Using the summation of the X<sup>2</sup> of the segregating plants from crosses involving Chimbamba, Nasaka and RC 15 showed that the observed ratios agreed with the Mendelian 3:1 ratio (X<sup>2</sup> = 2.068, P > 0.50, d.f. = 3), based on a scale of 1 - 3 as resistant and 4 - 9 as susceptible.

Analysis of F<sub>2</sub> plants from respective recipient parents showed stronger agreements to a 3:1 ratio in Chimbamba x Mexico 54 cross seconded by RC 15 x Mexico 54 and then thirdly Nasaka x Mexico 54 (Table 8). Bimodal distribution of the segregating plants was confirmed by plotting the percentage distribution of plants against the scores. The graphical distribution, however, categorized the plants with scores from 1 - 4 as resistant and 5 - 9 as susceptible. Chi-square analysis based on these categories, nevertheless, still supported the presence of one major gene controlling resistance to *P. griseola* (*Pg*). Confirmation of the existence of one major gene controlling resistance to *Pg* was also done in F<sub>3</sub> individual plants. The segregation of F<sub>3</sub> plants supported the existence of one major gene controlling resistance to *Pg* (X<sup>2</sup> = 6.231, P = 0.10, d.f. = 3). Although X<sup>2</sup> additivity in F<sub>3</sub> suggested that data from individual recipient parents was homogeneous (X<sup>2</sup><sub>a</sub> = 2.67, P > 0.25). Similar result was reported by Namayanja et al. (2006) using the same source of resistance. The authors crossed Mexico 54 and

BAT 332 to both Andean and Mesoamerican background in order to determine stability of the resistance gene in the two cultivars.

Studies conducted by CIAT (2002) on the mode of inheritance to *Pg* in Mexico 54 also found a single dominant gene controlling resistance, hence, supporting the findings in this study. Mahuku et al. (2003), on the other hand, reported that there is a single recessive gene in Mexico 54 controlling resistance to *Pg* in *Pg* differential genotypes and complex inheritance in identified resistance sources.

The F<sub>3</sub> segregation ratio in RC 15 x Mexico 54 was noted to be significantly different from the expected 5:3 segregation ratio. This might be responsible for the weak relationships in the pooled Chi-square despite having strong agreement with the expected ratios in crosses involving Chimbamba x Mexico 54 and Nasaka x Mexico 54 (Tables 8).

## Conclusions

Performance of the six parental genotypes showed different patterns within and across the sites. CAL 143 was found to be highest yielding but unstable across sites. RC 15 was stable but gave the highest yield at the drought stricken Ng'onga whereas Mexico 54 was



superior at Ntchenachena but highly unstable across sites. Nasaka and Vax 6 performed slightly above the overall sites mean and were unstable and moderately stable respectively. Chimbamba performed below the overall sites mean and was relatively stable across sites. Yield was strongly correlated to number of effective pods per plant in all genotypes evaluated at all sites.

Resistance to *Pg* in the common bean is controlled by a single gene using CAL 143 and Mexico 54 as sources of resistance. Breeding for resistance to *Pg* should be possible since inheritance was simply controlled.

An allelic test would indicate whether the two parents possess the same gene or not. Since CAL 143 is Andean and Mexico 54 is Mesoamerican, they would probably contain different genes. Should that be the case, then gene pyramiding would be a proper strategy to enhance durability of resistance to *Pg*.

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