Full Length Research Paper

Diallel analysis of Snap bean (*Phaseolus vulgaris* l.) varieties for important traits

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The breeding programmes of many crops use diallel analyses because of the genetic information they offer to breeders. Six morphological and agronomic traits of Snap bean (*Phaseolus vulgaris* L.) were studied to investigate their gene action, and to estimate the general combining abilities (GCA) and specific combining abilities (SCA) of parents and crosses. Three snap bean varieties - Amy, Monel and Morlane and two dry bean varieties - GLP 20 and GLPX 92 were used as parents in a complete diallel cross. The experiment was laid out in a randomized complete block design in a greenhouse. Significant (p < 0.01) additive and dominance effects were observed for days to flowering, plant height at flowering, number of pods per plant, pod weight per plant, pod length and pod diameter. Additive gene effects were predominant for all traits apart from pod weight. Significant (p < 0.01) maternal and non-maternal reciprocal effects were detected on plant height and days to flowering. Estimates of GCA, SCA and reciprocal effects suggested that Amy, Morlane and GLP 20 were generally the best combiners for incorporation into snap bean breeding programmes. This basic information is valuable for snap bean breeding programmes.

Key words: Diallel analysis, snap bean, additive, dominance, GCA, SCA.

INTRODUCTION

The breeding programmes of many crops use diallel analyses because they offer breeders genetic information on quantitative traits (Viana et al., 2001). Knowledge of the genetic control of characters and the role of non-allelic interaction is essential to the breeder when deciding on the selection method and breeding procedure to follow (Esmail, 2007). From diallel analysis, plant breeders are able to gather information on heterosis and the effects due to reciprocal, maternal, general combining ability (GCA) and the specific combining ability (SCA) of parents in crosses (Yanchuk, 1996; Glover et al., 2005). Diallel mating systems have provided genetic understanding for a chosen set of parents (Murray et al., 2003) and have been used to study various traits in many crops. This has been demonstrated for cassava (*Manihot esculenta* Crantz), chickpea (*Cicer arietinum* L), common bean (*Phaseolus vulgaris* L.), maize (*Zea mays* L.) and soya bean (*Glycine max* L.) among others (Derera et al.,

2007; Dhliwayo et al., 2005; Franco et al., 2002; Gwata et al., 2005; Jaramillo et al., 2005; Kumar et al., 2001).

Snap bean (*P. vulgaris* L.), also known as French bean, is an important export crop for Kenya. One of the challenges facing snap bean breeders is the difficulty of incorporating novel traits without breaking up the desired complex of pod traits (Myers and Baggett, 1999). In addition, inheritance studies of these pod and other agronomic traits of snap bean are scarce and in some cases contradictory. For example, Carvalho et al. (1999) found that, dominance effects were involved in the genetic control of number of days to flowering; while Silva et al. (2004) showed that additive effects were predominant. Basically, such information is important during planning and execution of any breeding programme (Viana et al., 1999).

Several methods have been proposed for diallel analyses (Jinks and Hayman, 1953; Hayman, 1954; Dickinson and Jinks, 1956; Griffing, 1956; Gardner and Eberhart, 1966). Among these methodologies, Hayman's (1954) approach has been used to determine gene action on different traits. Apart from additive and dominance gene effects, this method is efficient in detecting epistasis.

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It also estimates the genetic component and the limit of selection that may be obtained from assessed parents (Cruz, 2001). Determination of the GCA and SCA effects of a trait is also an important method of estimating additive and non-additive gene action (Griffing, 1956).

Examining the GCA of each parent helps in developing superior genotypes, while the SCA effect estimates the performance of hybrids (Cruz and Regazzi, 1994). There-fore, an analysis based on a large number of progenies from diverse parents is essential for formulating an efficient strategy for varietal improvement. Such an analysis enables broad inferences to be drawn about the nature of gene effects and the combining abilities of different varieties. The purpose of the present study was to assess the genetic control of some important traits in snap beans so that they can be improved scientifically. The study also determined the combining abilities of five parents in order to assess their potential for use in breeding programmes.

MATERIALS AND METHODS

Three snap bean varieties (Amy, Monel and Morlane) and two dry bean varieties (GLP 20 and GLPX 92) were used in this study. The two dry bean varieties were included in order to evaluate their potential in snap bean improvement. Amy, the main Kenyan export variety, produces white flowers, slender round pods, which are of medium length, and white seeds. Monel, which was once well established in Kenya as a snap bean for canning, is widely adapted and produces purple flowers, medium to long, plump pods and black seeds. Morlane, which is suitable for canning, has pink flowers, slender long pods and red-brown coloured seeds. GLP 20 produces pink flowers and is resistant to anthracnose (*Colletotrichum lindemuthianum*), rust (*Uromyces appendiculatus*) and bean common mosaic (BCM). Its pod shape resembles that of the snap bean. GLPX 92 is a pinto bean which is drought tolerant and resistant to halo blight (*Pseudomonas savastanoi* pv. *Phaseolicola*). It has an indeterminate growth habit and produces white flowers.

A complete diallel was obtained giving 25 combinations consisting of five parents (n), 10 F_1s [n (n-1)/2] and 10 reciprocals. Forty seeds of each combination were pre-germinated in Petri dishes and then transplanted into 20 cm diameter plastic pots containing about 3 kg medium substrate made up of farm soil, petro-plinthite, farmyard manure and sand in the ratio of 2:1:1:1. Each pot received nitrogen (N) and phosphorus (P) at an equivalent rate of 65 and 72 kg per ha. The pots were watered until the media reached field capacity. In order to control pests, the crop was sprayed weekly from seedling emergence to flowering with dimethoate at a comparable rate of 340 g a.i per ha. Strings were tied next to the indeterminate genotypes to provide support. The experiment was laid out in a randomized complete block design (RCBD) with four replications in a greenhouse in Chepkoilel, Kenya (0°32'N, 35° 17'E). The experimental unit consisted of a row of ten 20 cm diameter plastic pots. The rows were approximately 30 cm apart and the distance between the centres of the pots was 10 cm.

Data were collected on days to flowering – the time when 50% of the plants in a row had produced flowers. The height of the plant when the first flower opened was measured. The height was determined as the length of the stem from the base of the plant to the topmost flower bud. At the time of harvesting, pods were sampled and measured from the end of the petiole to the tip of the pod. Pod diameter was measured by passing the pods through

holes in a bean ruler manufactured by Royal Sluis. The average number of pods per plant was computed by dividing the total number of pods by the number of plants. In addition, the average weight of pods per plant was determined by dividing the total weight of the pods by the number of plants. Harvesting was done twelve times, at two-day intervals, when the green pods were ready for picking.

An analysis of variance, using the following general linear model, tested for the genotypic differences:

$$Y_{ijk} = \mu + \beta_i + \alpha_j + \varepsilon_{ijk}.$$

Where; Y_{ijk} = observations; μ = mean of experiment; β_i = effect of ith replicate; α_j = effect due to jth genotype in the ith replicate and ε_{ijk} = experimental error

The genotypic mean squares were significant, justifying Griffing's (1956) and Hayman's (1954) analyses (Singh and Chaudhary, 1985). Hayman's (1954) approach was used in partitioning the components of variation into a (the additive effect), b (the dominance effect, which is further sub-divided into b_1, b_2 and b_3), c (the maternal effect) and d (the reciprocal differences other than c). Griffing's (1956) approach, method 1 model 1 (fixed effects), was used to analyse the combining abilities The simple additive-dominance model was tested by plotting the covariance values of family means in female arrays with respective non-recurrent parents (Wr), against variance values of female arrays (Vr). The regression coefficient of Wr-Vr line subtracted from 1 (B-1) should not be significant (p > 0.05) if the data fit the additive-dominance model (Singh and Chaudhary, 1985). GenStat 10th edition 2007 (VSN International) was used for all the analyses.

RESULTS

Gene action

The analysis of variance revealed significant (p < 0.001) variation among the 25 genotypes for the traits investigated (Table 1). The hybrid GLPX 92 × GLP 20 had the shortest days to flowering – a mean of 5.8% days less than the mean of its parents (Table 2). There was a significant difference between Amy × GLPX 92 with its reciprocal for days to flowering.The tallest hybrid was GLPX 92 × Morlane and was significantly different from all the other entries apart from its reciprocal. For the number of pods per plant, the hybrid Amy × Monel reached 35.56% mid-parent heterosis. Amy × GLPX 92 demonstrated the highest pod weight per plant and it differed significantly from all other crosses involving Amy as the female parent. The longest pods, which were significantly differ-rent from all genotypes, were produced by a Morlane parent. The mean performances revealed that the F_1s had greater mean values than the parents for plant height at flowering, number of pods per plant, pod weight per plant and pod length. The F_1 means were lower than the parental means for days to flowering and pod diameter (Table 2).

The mean squares (MS) of GCA and SCA were significant (p < 0.001) for the traits studied and this shows the importance of both additive and dominance effects (Table 3). To weigh the relative importance of GCA and

Table 1. Means squares showing genotypic differences for days to flowering, plant height, number of pods per plant, pod weight per plant, pod length and pod diameter derived from 5 × 5 diallel cross.

Source of variation	d.f	Mean squares					
		Days to flowering	Plant height at flowering (cm)	Number of pods per plant	Pod weight per plant (g)	Pod length (cm)	Pod diameter (mm)
Replications	3	0.62	286.27	16.93	151.05	0.16	0.37
Genotypes	24	9.44***	1706.98***	87.71***	245.18***	22.80***	4.86***
Residual	72	1.09	24.83	9.36	59.91	0.34	0.28
CV %		2.50	7.40	13.20	13.30	4.60	7.50

*** Significant at $p < 0.001$.

Table 2. Genotypic means of days to flowering, plant height, number of pods per plant, pod weight, pod length and pod diameter of parents and hybrids derived from a 5 × 5 diallel cross.

Line combination	Days to 50% flowering	Height at flowering (cm)	Number of pods per plant	Pod weight per plant (g)	Pod length (cm)	Pod diameter (mm)
Amy × Amy	43.75	33.50	31.15	51.12	12.27	6.25
Amy × Monel	42.25	45.00	32.40	60.90	12.65	7.25
Amy × GLPX 92	40.00	80.50	27.47	74.75	11.00	8.50
Amy × GLP 20	42.00	42.25	28.12	58.27	12.55	7.75
Amy × Morlane	43.00	55.50	24.80	54.72	13.65	6.50
Monel × Amy	42.50	54.75	27.22	59.20	11.87	7.00
Monel × Monel	44.00	61.50	16.65	44.17	13.22	7.25
Monel × GLPX 92	43.50	93.25	23.42	50.40	9.72	8.25
Monel × GLP 20	42.25	57.50	22.62	68.77	13.80	8.25
Monel × Morlane	43.25	70.25	18.97	60.20	15.80	7.50
GLPX 92 × Amy	42.00	86.00	26.97	66.38	10.52	5.50
GLPX 92 × Monel	42.50	96.75	24.52	58.55	10.10	5.50
GLPX 92 × GLPX 92	39.25	86.25	17.37	43.70	8.00	6.75
GLPX 92 × GLP 20	38.50	85.00	23.70	56.25	10.15	6.00
GLPX 92 × Morlane	40.00	106.50	19.80	54.57	11.35	5.70
GLP 20 × Amy	41.25	45.25	29.92	65.52	12.37	7.50
GLP 20 × Monel	42.25	57.25	21.30	67.45	14.05	8.25
GLP 20 × GLPX 92	39.50	86.50	24.95	59.95	10.15	5.70
GLP 20 × GLP 20	42.50	46.75	21.27	56.77	12.35	8.50
GLP 20 × Morlane	41.25	55.75	21.95	66.80	16.00	8.50
Morlane × Amy	42.25	54.00	22.52	52.20	13.87	6.75
Morlane × Monel	43.00	62.50	19.67	60.60	16.30	7.75
Morlane × GLPX 92	39.75	103.00	19.75	52.52	11.50	6.00
Morlane × GLP 20	42.00	51.00	19.55	66.95	16.40	9.00
Morlane × Morlane	43.75	63.50	13.25	48.65	17.32	7.25
Grand mean	41.85	67.20	23.17	58.38	12.68	6.93
Parental mean	42.65	58.30	19.94	48.88	12.63	7.20
Hybrid mean	41.65	69.42	23.98	60.74	12.69	6.86
LSD (0.05)	1.47	7.02	4.31	10.91	0.82	0.73
CV %	2.50	7.40	13.20	13.30	4.60	7.50

SCA in the expression of the different traits, the proportions of GCA and SCA variances were calculated.

The GCA variance was higher than the SCA variance component for all traits other than pod weight. The

Table 3. GCA, SCA and reciprocal mean squares for days to flowering, plant height, number of pods per plant, pod weight, pod length and pod diameter derived from a 5 × 5 diallel cross.

Source of variation	d.f	Mean squares					
		Days to flowering	Plant height at flowering (cm)	Number of pods per plant	Pod weight per plant (g)	Pod length (cm)	Pod diameter (mm)
GCA	4	9.37***	2166.50***	101.99***	65.64***	31.23***	5.22***
SCA	10	1.52***	145.30***	9.52***	109.94***	1.11***	0.80*
Reciprocal	10	0.39	12.30*	2.31	0.73	0.08	0.03
Residual	72	0.27	6.20	2.34	1.00	1.00	0.88

* Significant at $p < 0.05$; *** Significant at $p < 0.001$.

preponderance of GCA variance demonstrates the role of additive gene effects while the predominance of SCA denotes the higher influence of non-additive gene effects. Significant ($p < 0.05$) reciprocal effects were observed in plant height at flowering.

Hayman's analysis of variance (Table 4) was in agreement with Griffing's apart from days to flowering where Hayman's analysis showed significant ($p < 0.01$) reciprocal effects. Additive and dominance MS were significant ($p < 0.01$) for all traits. The overall mean dominance deviation, b_1, was significant ($p < 0.05$) for plant height at flowering, number of pods per plant, pod weight per plant and pod diameter. The b_2 component was significant ($p < 0.01$) for days to flowering, plant height at flowering, pod length and pod diameter. The significance ($p < 0.05$) of the b_3 item was observed in all traits other than number of pods per plant. Maternal reciprocal effects were significant for plant height at flowering and non–maternal reciprocal effects were significant for days to flowering. One way of testing Hayman's hypothesis of the absence of non-allelic interactions is through regression coefficients. The re-gression coefficients of all observed traits subtracted from 1 (B-1) were not significant ($p > 0.05$) (data not shown). This signifies the absence of non-allelic or epistasis interactions.

Combining abilities

The estimates of the GCA effects showed that two varieties had positive significant values while two had negative significant values for days to flowering (Table 5). GLPX 92 had the highest negative significant value for this trait. GLPX 92 was the best combiner for plant height at flowering, while Amy was the worst combiner for that trait. Nevertheless, Amy showed the highest significant GCA value for number of pods per plant, while GLPX 20 was the best combiner for pod weight per plant. Morlane had the highest GCA value for pod length, while GLPX 92 was the best combiner for pod diameter. However, the latter variety had flat pods and thus its pod diameter was determined by calculating its circumference.

The SCA estimates show that Amy × Monel, GLPX 92

× GLP 20 and GLPX 92 × Morlane were good crosses to reduce days to flowering (Table 5). Negative significant reciprocal values were observed for GLPX 92 × Amy, although a positive SCA value was observed for Amy × GLPX 92 for days to flowering. For plant height, the highest positive significant SCA value was achieved by GLPX 92 × Morlane. There were negative significant reciprocal effects from Monel × Amy for this trait. Also, the SCA value for the same cross was negative and thus the cross is not desired for increase in plant height. Only two crosses showed significant SCA values for the number of pods per plant, while three hybrids showed significant SCA values for pod weight per plant. The cross Amy × GLPX 92 had the highest significant and positive SCA values for pod weight and, surprisingly, pod length, for which the parents showed negative significant GCA effects. Other significant SCA values for pod length were observed in GLP 20 × Morlane, Monel × Morlane and Monel × GLP 20. The cross GLPX 92 × GLP 20 exhibited the lowest SCA value for pod diameter.

DISCUSSION

The present study provides a good understanding of the performance of five bean varieties in a diallel mating design. The significant variations among the genotypes indicate considerable genetic diversity among the parents and their respective crosses; this is appropriate for further biometrical assessments of the traits under consideration (El-Bramawy and Shaban, 2007). The significant GCA mean squares for all traits indicated variability of GCA among the parents and this suggests that genetic gain is achievable through selection over the segregant population. The significant GCA and SCA mean square for all traits showed the importance of both additive and dominance gene effects. Hayman's additive-dominance model fitted the data; the slope of the regression line did not deviate significantly from one. If parental genes have interactions with other genes, the data points belonging to the parents will be far from the regression line so the slope will be less than one.

The results of this study are both similar to and contradict previous studies of snap bean. For example,

Table 4. Mean squares of Hayman's analysis for days to flowering, plant height, number of pods per plant, pod weight, pod length and pod diameter obtained from a 5 × 5 diallel cross.

Genetic parameter	d.f	Mean squares					
		Days to flowering	Plant height at flowering (cm)	Number of pods per plant	Pod weight per plant (g)	Pod length (cm)	Pod diameter (mm)
Additive	4	37.46***	8666.14***	407.95***	262.56***	124.91***	20.88***
Dominance	10	6.09***	581.09***	38.08***	439.76***	4.45***	3.18**
b_1	1	16.00	1980.25***	261.63**	2251.97**	0.05	1.82*
b_2	4	3.02***	834.3***	12.08	32.70	2.54**	5.79***
b_3	5	6.57**	98.7*	14.18	402.96**	6.86**	1.38**
Maternal	4	0.34	99.18*	10.33	21.78	0.68	0.32
Reciprocal	6	2.40**	15.87	8.52	58.22	0.06	0.01

* Significant at $p < 0.05$; ** Significant at $p < 0.01$; *** Significant at $p < 0.01$.

the predominance of additive gene effects for number of days to flowering has been reported (Barelli et al., 1999; Silva et al., 2004) which is similar to these findings. The role of dominance gene effects for plant height was reported by Rodrigues et al. (1998) while this study indicates that additive gene effects play a major role. For number of pods per plant, the results of Barelli et al. (1999) are similar to this study while Silva et al. (2004) contradicts the findings. Such variations in the results may arise from differences in the genetic backgrounds of the varieties used in the various studies.

Evidence that both additive and non-additive gene effects are involved in the genetic control of the traits investigated implies that both gene effects should be considered when developing breeding schemes for the selection of superior lines. Consequently, both parents need not necessarily have high GCA during breeding because the dominance gene effects could also be exploited to enhance these traits. In contrast, the predominance of the additive gene effects suggests that the best progeny might be derived from crosses with genotypes having the greatest positive GCA. The snap bean is a self-pollinating crop, and autogamous plants are homozygous and thus they do not make use of the dominance effects of genes at individual loci (Moreno-Gonzalel and Cubero, 1993). Usually, varieties of autogamous plants are pure lines or multi-lines whose seed are commercially produced by self-pollination, even though a few exceptions, like wheat, tobacco, cotton and tomato can produce commercial hybrids. Therefore, crosses involving genotypes with greater estimates of general combining ability should be potentially superior for the selection of lines in advanced generations (Franco et al., 2001).

The predominance of SCA variance on pod weight per plant denotes that selection for pod yield may not be made in early breeding generations (Wu et al., 2000). Studies reveal that the additive gene effects were important for grain yield in maize (Betran et al., 2003; Derera et al., 2007) and the dominance gene effects were predominant for root yield in cassava (Jaramillo et

al., 2005). If dominance effects are important for a trait, the most appropriate selection methods are those that take advantage of heterosis and the general and specific combining abilities (Moreno-Gonzalel and Cubero, 1993). The significance of component b_1 indicates that the dominance effect was non-directional. A significant b_2 item illustrates an uneven distribution of dominant genes among the parents, reflecting that parents carry different numbers of dominant alleles (Kersey and Pooni, 1996). The b_3 component confirmed the presence of specific dominance or combining ability in some crosses. Significant non-maternal and maternal reciprocal effects were observed in days to flowering and plant height at flowering, respectively. Reciprocal differences for days to flowering and silking dates have been reported in other crops (Jinks, 1954; Khehra and Bhalla, 1976). Generally, the choice of female parent is critical in a breeding programme. Moreover, it recommended that crosses portraying reciprocal effects should not be mixed with direct crosses (Khan et al., 1991; Pavasia et al., 1999).

Snap bean breeders prefer to reduce the number of days to flowering and thus increase the number of harvests per growth cycle. Monel exhibited the largest GCA for days to flowering, while the lowest was GLPX 92. GLPX 92 is indeterminate in growth type. One dominant gene controls the indeterminate character (Koinange et al., 1996) which is uncommon in current snap bean varieties. Indeterminate climbing snap bean varieties will allow harvesting over a long period and thus increase the total yield. Because of that, the variety can be exploited for varietal improvement for different combinations, especially dry beans. GLP 20 had the largest GCA value for pod weight per plant. Consequently, incorporating GLP 20 in snap bean could improve yield and resistance to anthracnose, bean rust and BCM – an additional series of desirable traits. However, to improve its pod quality, other parents have to be incorporated in the programme. The quality of snap bean pods depends on pod length and diameter. Long slender pods are preferred to short bobby beans and, as a result, alleles that increase pod length are of great

Table 5. Estimates of GCA, SCA and reciprocal effects for days to flowering, plant height, number of pods per plant, pod weight, pod length and pod diameter obtained from a 5 × 5 diallel cross.

Genotype	Traits					
	Days to 50% flowering	Height at flowering (cm)	Number of pods per plant	Pod weight per plant (g)	Pod length (cm)	Pod diameter (mm)
GCA effects						
Amy	0.43*	-14.17*	5.00*	1.04	-0.37*	-0.31
Monel	1.10*	-1.17	-0.83	-0.93	0.39*	0.19*
GLPX 92	-1.42*	23.80*	-0.64	-2.3	-2.63*	-1.05*
GLP 20	-0.45*	-9.80*	0.29	3.98*	0.34*	0.87*
Morlane	0.35	1.35	-3.82*	-1.79	2.27*	0.30*
SE[a] of g(ı)	0.15	0.70	0.43	1.09	0.08	0.07
SCA effects						
Amy × Monel	-1.00*	-1.97	2.47*	1.56	-0.44*	0.30
Amy × GLPX 92	0.15	6.42*	-0.31	13.44*	1.09*	-0.07
Amy × GLP 20	-0.20	0.52	0.56	-1.50	-0.18	0.13
Amy × Morlane	0.00	0.37	-0.69	-4.17	-0.81*	-0.30
Monel × GLPX 92	1.47*	5.17*	2.27*	-0.67	-0.53*	-0.70*
Monel × GLP 20	-0.25	1.15	-0.67	6.70*	0.51*	0.26
Monel × Morlane	-0.17	-1.00	0.80	4.75	0.70*	0.21
GLPX 92 × GLP 20	-0.97*	4.55*	1.50	-1.95	-0.24	-0.87*
GLPX 92 × Morlane	-0.90*	12.40*	1.06	-0.74	-0.90*	-0.30
GLP 20 × Morlane	-0.12	-5.37*	1.10	6.32*	0.91*	0.66*
SE[a] of s(ji)	0.30	1.45	0.89	2.26	0.17	0.15
Reciprocal effects						
Monel × Amy	-0.12	-4.87*	2.59	0.85	0.39	0.13
GLPX 92 × Amy	-1.00*	-2.75	0.25	4.19	0.24	0.00
GLP 20 × Amy	0.37	-1.50	-0.90	-3.62	0.09	0.13
Morlane × Amy	0.37	0.75	1.14	1.26	-0.11	-0.13
GLPX 92 × Monel	0.50	-1.75	-0.55	-4.07	-0.19	-0.13
GLP 20 × Monel	0.00	0.12	0.66	0.66	-0.12	0.00
Morlane × Monel	0.12	3.87	-0.35	-0.20	-0.25	-0.13
GLP 20 × GLPX 92	-0.50	-0.75	-0.62	-1.85	0.00	0.13
Morlane × GLPX 92	0.13	1.75	0.02	1.02	-0.07	-0.13
Morlane × GLP 20	-0.37	2.37	1.20	-0.70	-0.2	-0.25
SE[a] of r(ji)	0.37	1.76	1.08	2.74	0.21	0.18

[a] standard error, * Significant at $p < 0.05$ (Students t-test)

importance (Silva et al., 2004). Morlane is a relatively new variety and had the largest GCA value for pod length. Hence the variety can be valuable when breeding for increased pod length.

SCA values provide important information about the performance of the hybrid relative to its parents. The SCA effect alone has limited value in the choice of parents in breeding programmes for self-pollinated crops like bean (Cruz and Regazzi, 1994). The SCA effect should be used in combination with other parameters, such as the hybrid mean value of a trait and the GCA of the respective parents. Thus, hybrid combinations with high means, favourable SCA estimates and involving at least one of the parents with high GCA, would tend to increase the concentration of favourable alleles. Moreover, it was

observed that parents having low GCA might show good potential in varietal combinations. For example, GLPX 92 had low GCA value for pod weight while its cross with Amy had the highest and significant SCA. Similar phenomenon of some parents has been noted in studies of upland cotton (*Gossypium hirsutum*) (Azhar and Rana, 1993; Ilyas et al., 2007).

Conclusion

Evidence that both additive and non-additive gene effects are involved in the investigated traits, should be considered when developing new breeding schemes to select superior lines. Maternal reciprocal effects were

significant for plant height at flowering and non-maternal reciprocal effects were significant for days to flowering, suggesting that the choice of parents is critical for these traits. In this study, there was no epistasis and so the data fitted the additive-dominance model. The best general combiners were GLP 20 for pod weight, Morlane, for pod length, and Amy for pod diameter. These varieties can be incorporated into snap bean breeding programmes.

ACKNOWLEDGEMENTS

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