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RESEARCH ARTICLE

Assessment of Gene Effects for Yield and Yield Attributing Traits in Mungbean (*Vigna radiata* (L.) Wilczek)

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ABSTRACT

The study was carried out to evaluate the inheritance pattern of eight quantitative traits in two crosses of mungbean *viz.,* CO 7 × V2709 and CO 8 × V2709 using the generations, P_1, P_2, F_1, F_2 and F_3. The traits included plant height, days to first flowering, days to fifty per cent flowering, number of pods per plant, pod length, number of seeds per pod, hundred seed weight and single plant yield. Generation mean analysis revealed the inadequacy of the simple additive-dominance model in explaining all the traits. The crosses, CO 7 × V2709 and CO 8 × V2709 exhibited complementary epistasis for two or more of the following traits, plant height, days to first flowering, days to fifty per cent flowering, number of pods per plant and hundred seed weight. These crosses could be exploited through pedigree breeding. However, the continuous directional selection should be employed to develop complementary gene interactions in the remaining traits in the above mentioned two crosses.

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INTRODUCTION

Mungbean serves as an excellent source of high quality protein with an ideal essential amino acid profile. Globally, mungbean is cultivated around 7.3 million hectares with a production of about 5.3 million tonnes (Nair *et al* 2022). It is principally important for its protein (24-26%), carbohydrates (51%), minerals (4%) and vitamins (3%) (Nair *et al*., 2013; and Karthikeyan *et al*., 2014). India being the largest producer contributes nearly 65 percent of the world acreage and 54 per cent of the world production (Baraki *et al.,* 2020). The high protein content, short duration, nitrogen fixing ability of mungbean catches attention towards cereal based cropping systems. It is a highly demanded plant-based protein source for many consumers because of its easy cooking and high digestibility nature (Sehrawat *et al.,* 2020). However, the production and productivity of the crop is remaining far from satisfactory. The choice of appropriate breeding procedure depends on the type of gene action involved in the expression of the characters. Gene action is measured in terms of components of genetic variance *viz.,* additive, dominance and epistatic variance. Generation mean analysis, is a higher-order statistic, is a simple but useful technique for characterizing gene effects for polygenic characters (Hayman, 1958) and determines the presence and absence of non-allelic interactions. The greatest merit of generation mean analysis is that it helps in detection of epistasis, and estimates of additive and dominance components of variation for yield components and also helps in the estimation of epistatic gene effects *viz.,* additive × additive (i),

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dominance × dominance (l) and additive × dominance (j). Knowledge about the inheritance pattern of different quantitative traits would be helpful for determining the selection criteria in improving yield in mungbean. Earlier many researchers reported the gene action for yield attributing traits in mungbean (Devendra *et al.,* 2010; Pathak *et al.,* 2015; Singh *et al.,* 2016; Sinha *et al.,* 2020 and Lenka *et al.,*2022). With this background knowledge, the present study was undertaken to study the nature of gene action for yield attributing traits and also to identify the appropriate breeding methods to be adopted for considerable trait expression.

MATERIALS AND METHODS

The crossing was conducted using the cultivars *viz*., CO 7, CO 8 and V2709 during June to September 2018 at ARS, Bhavanisagar. The F_1 and F_2 generations of the following crosses CO 7 × V2709 and CO 8 × V2709 were raised in November 2018 to February 2019 and March to June 2019 respectively. Seeds of each plant in F_2 were collected individually, and the selected progenies were forwarded to F_3 generation during July to October 2019. Various generations *viz.,* P_1, P_2, F_1, F_2 and F_3 of both the crosses were raised adopting a spacing of 30 x 10 cm in 4 m rows during December 2019 to March 2020. Thirty plants were studied in each of the parental populations and in the F_1 generation, whereas 200 plants in F_2 and 150 plants in F_3 generations were evaluated. The observations were recorded on each of the plants, for plant height (cm), days to first flowering, days to fifty per cent flowering, number of pods per plant, pod length (cm), number of seeds per pod, hundred seed weight (g) and single plant yield (g) and mean were calculated for each generation. The variances and corresponding standard error of the means were computed from the deviations of the individual values from the pooled mean for each of the generations in each cross. The predominance of simple additive-dominance model was identified by using Joint scaling test (Cavalli, 1952). The generation means were analysed using five parameter model by the method suggested by Hayman (1958). The data were analyzed employing TNAUSTAT statistical package (Manivannan, 2014).

RESULTS AND DISCUSSION

Generation mean analysis not only provides information regarding nature and magnitude of gene effects but also about the non-allelic interactions operating in the inheritance of quantitative traits. In the present study, the generation mean analysis involving five parameter model was employed to partition the genetic variance into additive, dominance and epistasis, which helps in formulating an effective, and sound breeding programme. The comparative mean performance of F_1, F_2 and F_3 generations of two crosses *viz.,* CO 7 × V2709 and CO 8 × V2709 are given in Table 1. Eight traits recorded from the parental and segregating generations were analysed to assess the gene action involved for the inheritance of the traits. Scaling test (Cavalli, 1952) for C and D, indicated the inadequacy of the simple additive-dominance model in explaining all the traits from the two crosses studied except for plant height in CO 7 × V2709.

Plant height

In case of CO 7 × V2709 (56.81 cm) and CO 8 × V2709 (44.36 cm) the mean of P_2 (39.36 cm) was lower than that of the corresponding parent P_1 (Table 1). The F_1 mean of CO 8 × V2709 (45.06 cm) was higher than the corresponding parental means, whereas the F_1 mean (50.43 cm) of CO 7 × V2709 was intermediate between the parents (CO 7 and V2709). The F_2 mean of CO 7 × V2709 and CO 8 × V2709 were 48.48 cm and 39.26 cm respectively, which were lower than F_1 and found to be intermediate between their respective parents. The F_3 mean (46.74 cm) of CO 7 × V2709 was intermediate between the parents but lower than the corresponding F_1 and F_2 mean. The F_3 mean (40.04 cm) of CO 8 × V2709 was intermediate between the parents as well as lower than F_1 and higher than F_2 of the cross. The scaling test revealed that either or both C and D scales were significant in the cross, CO 8 × V2709 (Table 2). Therefore, it revealed the inadequacy of the simple additive-dominance model in this cross. Hence, the model was extended to study the additive, dominance and epistatic effects. In the cross CO 7 × V2709, absence of epistasis indicated the involvement of additive gene (d) effects alone for plant height. The additive (d) gene effect for plant height was also described by Devendra *et al.* (2010). Both additive × additive (i) and dominance × dominance (l) interaction were reported by Singh *et al.* (2016). The two crosses (CO 7 × V2709, CO 8 × V2709) exhibited positive and significant mid parental effect (m) and exhibited significant positive additive gene effect (d). CO 7 × V2709, exhibited opposite and CO 8 × V2709 exhibited same signs of dominance (h) and dominance × dominance (l) suggesting that epistasis

Table1. Mean and standard errors of various generations involved in generation mean analysis

Traits	Crosses	P_1	P_2	F_1	F_2	F_3
PH	C1	56.81±0.40	39.36±0.24	50.43±0.69	48.48±0.87	46.74±0.86
	C2	44.36±0.34	39.36±0.24	45.06±0.42	39.26±0.50	40.04±0.80
DFF	C1	32.33±0.24	32.60±0.24	30.40±0.24	31.69±0.07	31.10±0.09
	C2	28.40±0.24	32.60±0.24	27.40±0.24	30.31±0.09	30.53±0.10
DFPF	C1	36.40±0.24	36.60±0.24	35.60±0.24	36.52±0.08	36.02±0.09
	C2	33.40±0.24	36.60±0.24	32.40±0.24	34.66±0.11	34.88±0.12
PPP	C1	46.20±0.86	25.80±0.73	50.80±2.35	38.55±0.92	41.53±1.07
	C2	41.00±0.89	25.80±0.73	47.00±1.95	34.35±0.75	37.25±0.94
PL	C1	8.31±0.04	7.10±0.03	8.66±0.09	8.58±0.06	8.63±0.08
	C2	6.99±0.01	7.10±0.03	7.48±0.11	7.43±0.04	7.46±0.04
SPP	C1	10.40±0.24	9.40±0.24	11.40±0.24	11.09±0.10	11.24±0.08
	C2	12.20±0.20	9.40±0.24	12.40±0.24	11.69±0.09	12.03±0.09
HSW	C1	4.15±0.04	3.80±0.01	4.33±0.01	4.00±0.16	4.08±0.19
	C2	3.78±0.01	3.80±0.01	3.91±0.02	3.76±0.01	3.83±0.01
SPY	C1	16.18±0.26	7.44±0.07	20.30±1.09	13.13±0.44	14.93±0.51
	C2	15.01±0.13	7.44±0.07	17.59±0.46	11.44±0.38	13.35±0.46

PH – Plant height; DFF – Days to first flowering; DFPF – Days to fifty percent flowering; PPP – Number of pods per plant; PL – Pod length; SPP – Number of seeds per pod; HSW –Hundred seed weight; SPY – Single plant yield; P_1 – Parent 1; ; P_2 – Parent 2; F_1 – First filial generation; F_2 – Second filial generation; F_3 – Third filial generationl; C1 - CO 7 × V2709; C2 - CO 8 × V2709

was complementary and duplicate type respectively. Both complementary and duplicate type of epistasis was documented by Devendra *et al.* (2010), whereas duplicate type of epistasis was documented earlier by Pathak *et al.* (2015). Use of reciprocal recurrent selection has been suggested to improve the characters when both additive and non-additive gene effects are involved.

Days to first flowering

The mean of P_1 was 32 days and 28 days in the cross CO 7 × V2709 and CO 8 × V2709 respectively and was also lower than the corresponding P_2 (33 days) (Table 1). The F_1 mean was intermediate between both the parents in two crosses (CO 7 × V2709 (30 days) and CO 8 × V2709 (27 days)). The F_2 mean of two crosses *viz.,* CO 7 × V2709 (32 days) and CO 8 × V2709 (30 days) were intermediate between the respective parents but higher than their F_1. The F_3 mean (31 days) of CO 7 × V2709 was lower than both the parents and F_2, whereas higher than F_1. The F_3 mean (31 days) of CO 8 × V2709 was intermediate between the parents and higher than F_1 and F_2 of the cross. In analyzing five genetic parameters both the crosses recorded significant and positive mid parent effect (m) (Table 2). The cross CO 7 × V2709 exhibited significant dominance (h) gene action, whereas in the cross CO 8 × V2709, additive (d) and dominance (h) gene effects were significant and the magnitude of the additive (d) gene action was greater than dominance (h) gene action. This indicated the importance of both additive and dominant type of gene action in the inheritance of days to first flowering. The higher magnitude of additive × additive (i) interaction as compared to dominance × dominance (l) interaction in two crosses (CO7 × V2709, CO 8 × V2709) suggested the predominant role of additive × additive (i) epistasis in the interaction of these two crosses. Both additive × additive (i) and dominance × dominance (l) interactions were reported by Singh *et al.* (2016). Same signs of dominance (h) and dominance × dominance (l) in CO 8 × V2709 suggested complementary type of epistasis.

Table 2. Scaling test and estimates of genetic parameters for morphological traits in mungbean

Traits	Crosses	Scaling test		Genetic Parameters				
		C	D	m	d	h	i	l
PH	C1	-3.12±3.76	-6.15±3.87	48.48*±0.87	8.73*±0.23	5.93*±2.91	21.03±2.76	-4.04±8.50
	C2	-16.82*±2.22	-2.09±3.39	39.26*±0.50	2.50*±0.21	1.79±2.38	3.59±2.02	19.63*±5.98
DFF	C1	0.77±0.67	-4.19*±0.51	31.69*±0.07	-	0.72*±0.32	2.92*±0.43	-6.62*±0.99
	C2	5.44*±0.69	0.51±0.56	30.31*±0.09	-2.10*±0.17	-2.53*±0.36	-3.63*±0.45	-6.58*±1.09
DFPF	C1	1.87*±2.77	-1.96*±0.51	36.52*±0.08	-0.10±0.17	0.71*±0.32	1.41*±0.43	-5.10*±1.01
	C2	3.84*±0.74	0.19±0.64	34.66*±0.11	-1.60*±0.17	-2.08*±0.43	-2.68*±0.50	-4.87*±1.26
PPP	C1	-19.41*±6.08	17.04*±4.78	38.55*±0.92	10.20*±0.57	0.21±3.73	5.81±3.64	48.61*±11.21
	C2	-23.38*±5.06	13.50*±4.20	34.35*±0.75	7.60*±0.58	0.70±3.19	2.30±3.12	49.18*±9.39
PL	C1	1.60*±0.31	1.94*±0.36	8.58*±0.06	0.61*±0.02	-0.07±0.26	0.19*±0.23	0.44±0.71
	C2	0.67*±0.28	0.87*±0.20	7.43*±0.04	-0.05*±0.01	-0.03±0.16	-0.58*±0.16	0.26±0.51
SPP	C1	1.78*±0.71	2.96*±0.52	11.09*±0.10	0.50*±0.17	-0.18±034	-0.68±0.45	1.59±1.11
	C2	0.36±0.69	3.15*±0.52	11.69*±0.09	1.40*±0.16	-0.44±0.35	0.76±0.43	3.72*±1.11
HSW	C1	-0.59*±0.08	0.35*±0.09	4.00*±0.02	0.18*±0.02	0.02±0.06	0.02±0.07	1.25*±0.17
	C2	-0.34*±0.06	0.21*±0.06	3.76*±0.01	-0.01±0.01	-0.08±0.04	-0.22*±0.04	0.73*±0.12
SPY	C1	-11.69*±2.82	9.83*±2.23	13.13*±0.44	4.37*±0.14	-0.02±1.77	0.24±1.68	28.69*±5.32
	C2	-11.89*±1.77	8.08*±2.00	11.44*±0.3	3.79*±0.07	-1.00±1.47	0.20±1.32	26.63*±4.08

*Significant at 5% level

C and D – Scales; m- Mean; d – Additive; h – Dominance; i - Additive × Additive; j - Additive × Dominance; l - Dominance × Dominance

PH – Plant height; DFF – Days to first flowering; DFPF – Days to fifty percent flowering; PPP – Number of pods per plant; PL – Pod length; SPP – Number of seeds per pod; HSW –Hundred seed weight; SPY – Single plant yield; C1 - CO 7 × V2709; C2 - CO 8 × V2709

On contrary, the cross (CO 7 × V2709) showed opposite signs of 'h' and 'l' suggested that duplicate type of epistasis could also play a role in expression of days to first flowering. Duplicate type of epistasis for days to first flowering was also reported by Singh *et al.* (2016).

Days to fifty per cent flowering

The mean of P_1 in two crosses *viz.,* CO 7 × V2709 (36 days) and CO 8 × V2709 (33 days) were lower than their corresponding P_2 (37 days) (Table 1). The F_1 mean 36 days of CO 7 × V2709 was the same as P_1 and lower than P_2. The F_1 mean of the cross CO 8 × V2709 (32 days) were lower than their respective parents. The F_2 mean (37 days) CO 7 × V2709 were inclined towards the respective P_2 (37 days). The F_2 mean (35 days) of CO 8 × V2709 was intermediate between P_1 (33 days) and P_2 (37 days) and higher than F_1. The F_3 mean (36 days) of CO 7 × V2709 was similar to P_1 and F_1 whereas lower than P_2 and F_2. The F_3 mean of CO 8 × V2709 (35 days) were similar to their corresponding F_2. The mid-parental value (m) was significant and positive in all the four cross combinations (Table 2). The additive (d) and dominance (h) gene effects were significant in CO 8 × V2709, and the magnitude of additive (d) gene action was greater than dominance (h) gene action, whereas the cross CO 7 × V2709 exhibited significant dominance (h) gene action. This portrayed the importance of both additive and dominant type of gene action in the inheritance of days to fifty per cent flowering. Both additive (d) and dominance (h) gene effects were detailed by Singh *et al.* (2016). The higher magnitude of additive × additive (i) interaction as compared to dominance × dominance (l) interaction in two crosses (CO7 × V2709, CO 8 × V2709) suggested the predominant role of additive × additive (i) epistasis interaction in these two crosses. Both additive × additive (i) and dominance × dominance (l) interaction were detailed by Singh *et al.* (2016). Same sign of dominance (h) and dominance × dominance (l) in CO 8 × V2709 suggested complementary type of epistasis. On contrary, CO 7 × V2709 showed opposite signs of 'h' and 'l' suggested that duplicate type of epistasis could also play a role in expression of days to fifty per cent flowering. Similar type of inheritance for days to fifty per cent flowering was detailed earlier by Pathak *et al.* (2015).

Number of pods per plant

The mean of P_1 (46.20 and 41.00) in two crosses *viz.,* CO 7 × V2709 and CO 8 × V2709 were lower than their corresponding P_2 mean (25.80 and 25.80) (Table 1). The mean of F_1 (50.80 and 47.00) in two crosses was higher than their respective parents. The mean of F_2 (38.55 and 34.35) in two was intermediate between their respective parents but lower than their F_1. The F_3 mean of CO 7 × V2709 (41.53) and CO 8 × V2709 (37.25) were inclined towards their P_1, higher than P_2 and F_2 and lower than F_1. Significant positive mid parent effect (m) was observed in both the crosses (Table 2). Only additive (d) gene action was positive and significant in two crosses suggesting that simple selection following pedigree method would be effective for this trait. Similar results of additive (d) gene action were stated by Devendra *et al.* (2010) and Singh *et al.* (2016). Among the components of epistasis, dominance × dominance (l) interaction was significant in two crosses suggesting the predominant role of non-additive type of epistasis for this trait. The dominance × dominance (l) interaction in number of pods per plants was also observed by Devendra *et al.* (2010) and Singh *et al.* (2016). Perhaps, reciprocal recurrent selection would be a better strategy to exploit dominance and dominance based genetic control for genetic enhancement of number of pods per plant. Same signs of (h) and (l) in CO 7 × V2709 and CO 8 × V2709 suggested complementary type of epistasis. It recommended effective execution of simple selection method of breeding procedure that could be followed for the improvement of number of pods per plant. Singh *et al.* (2016) stated duplicate epistasis while Devendra *et al.* (2010) reported both complementary and duplicate epistasis in the inheritance of number of pods per plant.

Pod length

The P_1 mean (8.31 cm) of CO 7 × V2709 was higher than P_2 (7.10 cm), whereas the mean of P_1 (6.99 cm) of CO 8 × V2709 were lower than their corresponding P_2 (7.10 cm) (Table 1). The F_1 mean (8.66 cm and 7.48 cm) of CO 7 × V2709 and CO 8 × V2709 crosses were higher than their respective parents. The F_2 mean (8.58 cm and 7.43 cm) and F_3 mean (8.63 cm and 7.46 cm) of CO 7 × V2709 and CO 8 × V2709 was higher than their respective parents and lower than F_1. However, the F_3 mean of CO 7 × V2709 and CO 8 × V2709 was higher than their F_2 mean. The mid-parental value (m) was significant and positive in both the cross combinations (Table 2). Additive (d) gene action was significant in two crosses (CO 7 × V2709, CO 8 × V2709). The additive (d) effect for pod length was also reported by

Devendra *et al.* (2010), whereas both additive (d) and dominance (h) effect was stated by Singh *et al.* (2016). The interaction component (i) was significant in CO 7 × V2709 and CO 8 × V2709 representing the additive type of epistasis in these two crosses. This was akin to the findings of Devendra *et al.* (2010) and Singh *et al.* (2016) with additive × additive (i) interaction effect. The higher magnitude of dominance × dominance (l) interaction as compared to additive × additive (i) interactions suggested the predominant role of non-additive type of epistasis for this trait. The opposite signs of dominance (h) and dominance × dominance (l) suggested that epistasis was predominantly duplicate type as described by Devendra *et al.* (2010).

Number of seeds per pod

The P_1 mean (10.40 and 12.20) of CO 7 × V2709 and CO 8 × V2709 was higher than P_2 (9.40) (Table 1). The mean of F_1 (11.40 and 12.40) in two crosses was higher than their respective parents. The F_2 mean (11.09) of CO 7 × V2709 was higher than the parents and lower than F_1 whereas, the F_2 mean (11.69) of CO 8 × V2709 was intermediate between the respective parents and lower than $F_{1.}$ The F_3 mean of CO 7 × V2709 (11.24) was higher than the parents and F_2 and lower than $F_{1.}$ The F_3 mean of CO 8 × V2802BG (12.03) was intermediate between the respective parents, lower than F_1 and higher than $F_{2.}$ Significant and positive mid-parent effect (m) was observed in both the crosses (Table 2). The additive (d) gene effect was significant in two crosses indicating the importance of additive type of gene action in controlling pod length in CO 7 × V2709 and CO 8 × V2709. Significant additive (d) gene effect for number of seeds per pod was also stated by Singh *et al.* (2016) and Devendra *et al.* (2010). CO 8 × V2709 exhibited significant dominance × dominance (l) interaction. Both additive × additive (i) and dominance × dominance (l) interaction were reported by Devendra *et al.* (2010), whereas additive × additive (i) interaction alone by Singh *et al.* (2016). The opposite signs of dominance (h) and dominance × dominance (l) suggested that epistasis was predominantly of duplicate type. Devendra *et al.* (2010) reported both duplicate and complementary type of epistasis for the inheritance of number of seeds per pod.

Hundred seed weight

The P_1 mean (4.15 g) of CO 7 × V2709 was higher than P_2 mean (3.80 g) whereas, P_1 (3.78 g) of CO 8 × V2709 was lower than their corresponding P_2 (3.80 g) (Table 1). The F_1 mean of CO 7 × V2709 (4.33 g) and CO 8 × V2709 (3.91 g) was higher than the respective parents. The F_2 mean of CO 7 × V2709 (4.00 g) was intermediate between the respective parents and lower than $F_{1.}$ The F_2 mean (3.76 g) of CO 8 × V2709 was lower than parents and $F_{1.}$ The F_3 mean of CO 7 × V2709 (4.08 g) was intermediate between the respective parents, lower than F_1 and higher than $F_{2.}$ The F_3 mean of CO 8 × V2709 (3.83 g) was higher than parents and $F_{2,}$ whereas lower than $F_{1.}$ Significant and positive mid-parent effect (m) was noticed in both the crosses (CO 7 × V2709, CO 8 × V2709) (Table 2). The additive (d) gene effect was significant in CO 7 × V2709 indicating the importance of additive type of gene action in controlling hundred seed weight. Such a parallel finding for additive (d) gene effects were reported by Devendra *et al.* (2010). CO 7 × V2709 exhibited significant dominance × dominance (l) effect. CO 8 × V2709 exhibited both additive × additive (i) as well as dominance × dominance (l) interaction effect with higher magnitude of dominance × dominance (l) interaction, revealing the predominant role of non-additive type of epistasis. Both additive × additive (i) and dominance × dominance (l) interaction in hundred seed weight were stated by Devendra *et al.* (2010). The opposite signs of dominance (h) and dominance × dominance (l) suggested that epistasis was predominantly of duplicate type in CO 7 × V2709. Same signs of 'h' and 'l' in CO 8 × V2709 exhibited complementary type of epistasis. Pathak *et al.* (2015) stated duplicate type of epistasis, whereas Devendra *et al.* (2010) reported both duplicate and complementary type of epistasis in the inheritance of hundred seed weight.

Single plant yield

The mean of P_1 (16.18 g and 15.01 g) in two crosses *viz.,* CO 7 × V2709 and CO 8 × V2709 was were higher than their corresponding P_2 (7.44 g and 7.44 g) (Table 1). The mean of F_1 (20.30 g and 17.59 g) in two crosses was higher than their respective parents. The F_2 mean (13.13 g and 11.44 g) of CO 7 × V2709 and CO 8 × V2802BG was intermediate between their respective parents and lower than $F_{1.}$ The F_3 mean of CO 7 × V2709 (14.93 g) and CO 8 × V2709 (13.35 g) was inclined towards their $P_{1,}$ higher than P_2 and F_2 and also lower than $F_{1.}$ Significant and positive value for mid-parent effect (m) and additive component (d) was noticed in both the crosses

(Table 2). Single plant yield (g). The dominance (h) gene effect was significant in the cross CO 7 × V2709, whereas both additive (d) and dominance (h) gene effects were significant in the cross CO 8 × V2709 with higher magnitude of additive (d) effect. Both dominance (h) and additive (d) gene effect for single plant was showed by Devendra *et al.* (2010), whereas dominance (h) effect alone by Singh *et al.* (2016). Both additive × additive (i) and dominance × dominance (l) interactions were significant in two crosses (CO 7 × V2709, CO 8 × V2709) with higher magnitude for additive × additive (i) interaction. Devendra *et al.* (2010) and Singh *et al.* (2016) also reported both additive × additive (i) and dominance × dominance (l) interaction for single plant yield.

From the above discussion, it could be concluded that there was a major contribution of the additive and additive × additive gene action for the expression of pod length; additive and dominance × dominance type of gene interaction for the expression of plant height, number of pods per plant, number of seeds per pod, hundred seed weight and single plant yield; dominance and additive × additive type of gene effects played major role in expression of days to first flowering and days to fifty per cent flowering.

Though, generation mean analysis is valuable for detection and estimation of the additive, dominance and epistatic gene effects, it does have some limitations. In the presence of linkage, the estimates of additive × additive and dominance × dominance gene effects are biased to an unknown extent (Mather and Jinks, 1982). Inferences based on the magnitude of additive effects are not advisable, because the distribution of positive and negative gene effects in the parents may result in different degrees of cancellation of effects in the expression of the generation means. For the same reason, the magnitudes of additive gene effects do not necessarily reflect the magnitude of additive variance.

However, dominance (h) and dominance × dominance (l) are independent of the degree of gene distribution due to which the combined estimates of dominance could be considered to be the best representative of sign and magnitude of individual dominance (h) and dominance × dominance (l), respectively. So, practically these are the only components which can safely be used to determine the type of epistasis that may have influence on the observed performance of generations (Mather and Jinks, 1982). For the same reason, emphasis has been given to the traits which are governed by such gene effects for suggesting appropriate breeding method that could be followed to achieve higher expression of such traits.

CONCLUSION

The characters governed by additive gene action (d) and additive × additive gene interaction (i) effects are fixable. The crosses which are governed by complementary epistasis are also of worth in exploitation. Such crosses have the potentiality to produce transgressive segregants on the positive side. Bulk method of breeding followed by simple selection in later segregating generations will be a meaningful breeding strategy to be followed in such crosses for the improvement of the traits under consideration. Based on the criteria mentioned above, both crosses (CO 7 × V2709, CO 8 × V2709) could be exploited through pedigree breeding for the improvement of plant height, days to first flowering, days to fifty percent flowering, number of pods per plant and hundred seed weight. On the other hand, the continuous directional selection should be made to develop complementary gene interactions in plant height, days to first flowering, days to fifty percent flowering, number of pods per plant and hundred seed weight in the above mentioned two crosses.The desirable crosses suitable for particular trait improvement through pedigree breeding is selected based on the presence of complementary epistasis. The cross CO 8 × V2709 is suitable for selection based on plant height, days to first flowering, days to 50 per cent flowering and number of pods per plant. The cross CO 7 × V2709 is useful for developing high yielding varieties with more number of pods per plant and with greater hundred seed weight.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflicts of interest in the publication of this content

Authors' contributions

NS and SMS contributed equally to this work. NS, DM, SJH, and SMS, conceived and designed the methods and experiments. NS, SMS and DM managed the fieldwork. NS, SMS, and AK conducted the phenotype screening. SMS, MD, and AK performed data analysis. MD, DM, SJH and NS provided suggestions on experiments. SMS, NS and SJH drafted the manuscript. All authors contributed to the article and approved the submitted version.

Compliance with ethical standards

Ethical issues: *None*

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