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GENETIC BASIS OF HETEROSIS AND INBREEDING DEPRESSION ACROSS GENERATIONS IN VEGETABLE COWPEA (*VIGNA UNGUICULATA* L. WALP)

Dhrumi N. Dalsaniya[1]*, S.D. Solanki[1], B.R. Virdiya[1] and K.N. Prajapati[2]

[1]Department of Genetics and Plant Breeding, C.P. College of Agriculture, Sardarkrushinagar (Dantiwada Agricultural University, Sardarkrushinagar) - 385 506, Gujarat, India.

[2]Center for Vegetable Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar - 385 506, Gujarat, India

*Corresponding author E-mail : dndalsani1999@gmail.com

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ABSTRACT

Since cowpeas are autogamous, recombinant and heterosis breeding is important for generating variability and for combining several desired features, such as long, lush green pod with a high potential yield. The information on heterosis is utilized to identify crosses that can result in superior transgressive segregants in the segregating generation. The present investigation was accomplished in summer, 2024 at Center for Vegetable Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar to study heterosis and inbreeding depression of eleven different quantitative characters of vegetable cowpea in five crosses *viz*., Pusa Sukomal × Pusa Phalguni, Pusa Phalguni × GC 3, Pusa Phalguni × GC 4, GC 3 × Kashi Kanchan and GC 4 × GDVC 2 through generation mean analysis (each having P_1, P_2, F_1, F_2, BC_1 and BC_2 generations) in a Compact Family Block Design (CFBD) with three replications. For traits like number of branches per plant, pod length, pod girth, number of pod per plant, pod weight, number of pod per cluster, green pod yield per plant and fresh pod crude protein content all five cross show positive relative heterosis in desired direction some had significant while some crosses had non-significant value. For green pod yield per plant, both relative heterosis and heterobeltiosis observed positive and significant in Pusa Phalguni × GC 4. While cross GC 4 × GDVC 2 and Pusa Phalguni × GC 3 showed significant relative heterosis for green pod yield per plant and these crosses were also positive and significant for yield contributing traits *viz*., number of branches per plant, number of pod per plant and pod weight. Cross between Pusa Phalguni × GC 4 showed significant relative and better parent heterosis for days to picking, number of branches per plant, number of pod per plant and green pod yield per plant. These crosses demonstrate considerable potential for crop improvement, as they exhibited superior *per se* performance coupled with significant heterosis for most yield and yield-contributing traits. The results highlight promising opportunities for identification of elite progenies from F_1 hybrids. In most of the cross significant inbreeding depression was observed for pod girth, number of pod per cluster, green pod yield per plant and fresh pod crude protein content indicated major role of non-additive gene actions in the inheritance of this characters.

Key words : Inbreeding depression, Heterobeltiosis, Relative heterosis, Fresh pod crude protein content.

Introduction

Vegetable cowpea [*Vigna unguiculata* (L.) Walp.] is a diploid species (2n= 2x =22) belongs to family *Fabaceae* and domesticated in Africa. It is cultivated for the collection of immature pods, ripe seeds, leaves, richness in proteins, vitamins (thiamine, riboflavin), photo chemicals (phenolic acids, anthocyanins) and minerals (potassium, phosphorus iron, calcium) (Ceyhan *et al*., 2014; Abdulazeez *et al*., 2019).

Vegetable cowpea is a nutritious, underutilized legume with potential to combat protein malnutrition. It thrives in warm, drought-prone and sandy soils, showing remarkable adaptability to arid and semi-arid tropics (Abebe and Alemayehu, 2022). Cowpea is often referred as vegetable meat due to its high grain protein content with superior biological value on a dry weight basis. Apart from this, its dense vegetative growth provides effective ground cover, thereby reducing soil erosion (Singhal *et al.*, 2015). It's root nodules are able to fix atmospheric nitrogen and reducing input needs and making it highly suitable for resource-poor farmers and in intercropping systems. Its pod can be eaten as vegetable and whole plant is used as forage for animals due to its palatability and relatively free of metabolites or other toxicants (Mndzebele *et al.*, 2020).

Cowpea is a nutritive vegetable and its tender marketable pod contain 83.3 per cent moisture, 3.5 per cent protein, 2.0 per cent fiber, 8.1 per cent carbohydrates, 0.09 per cent mineral matter, 0.5 per cent niacin and 14.0 mg vitamin-C per 100 gm of edible pod (Gopalkrishnan, 2007). Cowpea is consumed at both the green shell and dry grain stages. It serves as an excellent source of dietary fiber, protein and phytosterols.

Since cowpeas are autogamous, recombinant and heterosis breeding is the best method for combining several desired features, such as long, lush green pod with a high potential yield. The availability of trustworthy data regarding the type and extent of gene effects in the population is crucial for selecting the best plant breeding technique to increase yield potential (Aghora *et al.*, 2024). The widespread use of generation mean analysis in plant breeding and genetics remains strong, as it aids in evaluating gene action and parental performance in hybrid combinations and assessing the potential of crosses for either heterosis exploitation or pedigree selection (Dvojkovic *et al.*, 2010).

Heterosis defined as the superiority of a F_1 hybrid over both the parents in terms of yield and some other characters (Shull, 1948). The information on heterosis is utilized to identify crosses that can result in superior transgressive segregants in the segregating generation (Shirisha *et al.*, 2022). Estimation of heterosis over better parent may be useful in identifying true heterotic cross combination and these crosses show superiority over best variety of area. Heterosis breeding has proved to be a potential method of increasing yield in most of the self fertilized crops (Surin *et al.*, 2018). On the other hand, inbreeding depression means reduction or loss in vigour, fertility and yield. The knowledge of heterosis accompanied with inbreeding depression is essential for maximum exploitation of heterosis in subsequent generations through appropriate breeding methodology.

Materials and Methods

The present investigation was accomplished in summer 2024 at Center for Vegetable Research, Sardarkrushinagar, Dantiwada Agricultural University, Sardarkrushinagar to study the heterosis and inbreeding depression of eleven different quantitative characters of vegetable cowpea in five crosses *viz.*, Pusa Sukomal × Pusa Phalguni, Pusa Phalguni × GC 3, Pusa Phalguni × GC 4, GC 3 × Kashi Kanchan and GC 4 × GDVC 2 through generation mean analysis (each having P_1, P_2, F_1, F_2, BC_1 and BC_2 generations) in a Compact Family Block Design (CFBD) with three replications. Parental lines of cowpea were planted during summer 2023 for producing F_1 hybrids. Backcrossing of F_1 with their respective parents and selfing of F_1 was done in *kharif*, 2023 to get F_2.

In each experimental unit, observations were taken for various quantitative characters i.e., five plants in each P_1, P_2 and F_1 generation, ten plants in each BC_1 and BC_2 and twenty plants in F_2 generation (in the ratio of 1:1:2:4 for P; F_1; BC; F_2). The plants were randomly selected for record observations.

Heterosis was estimated as per cent increase or decrease in the mean value of F_1 hybrid over the mid-parent, *i.e.*, relative heterosis (Briggle, 1963), over the better parent, *i.e.*, heterobeltiosis (Fonseca and Patterson, 1968).

$$\text{Relative heterosis}\ (\%) = \frac{\overline{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis}\ (\%) = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

Where,

$\overline{F}_1$ = Mean performance of the F_1 hybrid

$\overline{MP}$ = Mean value of the parents (P_1 and P_2) of a hybrid

$\overline{BP}$ = Mean value of better parent

The standard errors and calculated 't' value for test of significance for heterosis and heterobeltiosis were calculated as under:

Standard errors

$\text{S.E.}\left(\overline{F}_1 - \overline{MP}\right)$ (Standard error for relative heterosis)

$$= \sqrt{\frac{3Me}{2r}}$$

$\text{S.E.}\left(\overline{F}_1 - \overline{BP}\right)$ (Standard error for heterobeltiosis) =

$$= \sqrt{\frac{2Me}{r}}$$

Where,

Me = Error mean square

r = Number of replications

Test of significance

The test of significance for heterosis and heterobeltiosis was carried out by comparing the calculated values of ‘t’ with the tabulated values ‘t’ at 5 per cent and 1 per cent levels of significance.

$$t = \frac{\overline{F_1} - \overline{MP}}{S.E.\left(\overline{F_1} - \overline{MP}\right)} \text{ (For relative heterosis)}$$

$$t = \frac{\overline{F_1} - \overline{BP}}{S.E.\left(\overline{F_1} - \overline{BP}\right)} \text{ (For heterobeltiosis)}$$

Estimation of Inbreeding Depression

Inbreeding depression was computed by using the following formulae:

$$\text{Inbreeding depression } (\%) = \frac{\overline{F_1} - \overline{F_2}}{\overline{F_1}} \times 100$$

The standard error and ‘t’ value for the test of significance for inbreeding depression were estimated as under:

$$S.E.\left(\overline{F_1} - \overline{F_2}\right) = \sqrt{\frac{\left[V(F_1)(n_1 - 1)\right] + \left[V(F_2)(n_2 - 1)\right]}{n_1 + n_2 - 2}}$$

$$t = \frac{= \overline{F_1} - \overline{F_2}}{S.E.\left(\overline{F_1} - \overline{F_2}\right)}$$

Where,

$\overline{F_1}$ = Mean value of the F_1 hybrid

$\overline{F_2}$ = Mean value of the F_2 generation

$V(F_1)$ = Variance of the F_1 generation

$V(F_2)$ = Variance of the F_2 generation

n_1 = Number of observations in the F_1 generation

n_2 = Number of observations in the F_2 generation

The significance of the inbreeding depression was tested by comparing the calculated ‘t’ value with the table ‘t’ value at 5 per cent (1.96) and 1 per cent (2.58) levels of significance.

Results and Discussion

Heterosis especially heterobeltiosis plays a crucial role in shaping future breeding strategies and in pinpointing promising cross combinations.

Inbreeding depression refers to a decrease in fitness and vigour due to continuous inbreeding and decreased heterozygosity. It results due to fixation of unfavourable recessive genes in F_2, while in case of heterosis, undesirable recessive genes of one parent are suppressed by favourable dominant genes of another parent.

The combined estimates of heterosis and inbreeding depression help determine the nature of gene action controlling quantitative characters. A high level of heterosis in F_1 hybrid followed by noticeable inbreeding depression in F_2 suggests the involvement of non-additive gene action (dominance and epistasis). When the performance of F_1 and F_2 generations is similar, it indicates additive gene action. Likewise, negative heterosis in F_1 followed by no inbreedign depression in F_2 also points to additive effects.

The extent of heterotic effects *i.e.*, relative heterosis (RH) and heterobeltiosis (HB) as well as inbreeding depression (ID) were estimated for all the eleven quantitative characters in five crosses of vegetable cowpea are presented in Tables 1 and 2. The results for each character are presented and discussed in the following paragraphs.

Days to flowering

For days to flowering data embodied in Table 1 of relative heterosis showed significant negative value for Pusa Sukomal × Pusa Phalguni (-2.61%) and Pusa Phalguni × GC 4 (-1.85%), which is desirable for early flowering while all other crosses exhibited positive relative heterosis.

The perusal of heterobeltiosis showed non-significant positive heterosis in Pusa Sukomal × Pusa Phalguni (0.81%) and Pusa Phalguni × GC 4 (4.72%), while Pusa Phalguni × GC 3 (6.75%), GC 3 × Kashi Kanchan (8.37%) and GC 4 × GDVC 2 (10.35%) showed significant and undesirable positive heterosis for this trait. Inbreeding depression was negative and desirable in Pusa Phalguni × GC 4 (-6.29%) followed by GC 3 × Kashi Kanchan (-2.64%), Pusa Sukomal × Pusa Phalguni (-2.18%), GC 4 × GDVC 2 (-2.01%) and Pusa Phalguni × GC 3 (-0.10%). The results of present study are also akin with finding of Trambadia *et al*. (2006).

Days to first picking

For days to first picking, the parent with fewer days was regarded as the better parentand significantly

Table 1 : Relative heterosis (RH %), heterobeltiosis (HB %) and inbreeding depression (ID %) for various characters in five crosses of vegetable cowpea.

Particulars	Days to first flowering		Days to first picking		Number of branches per plant		Plant height		Pod length		Pod girth	
Cross I (Pusa Sukomal × Pusa Phalguni)												
RH %	-2.61	±0.89	-3.40*	±0.84	2.99	±0.39	-3.06	±0.90	1.22	±0.71	5.89**	±0.55
HB%	0.81	±0.98	-0.12	±1.02	-8.51	±0.48	-1.57	±0.88	-21.73**	±0.76	-4.16	±0.60
ID%	-2.18	±0.78	-5.16**	±0.78	-10.47	±0.38	-4.47*	±0.89	-6.20*	±0.71	8.87**	±0.53
Cross II (Pusa Phalguni × GC 3)												
RH %	3.34*	±0.76	-5.29**	±0.97	20.00**	±0.40	-0.59	±0.96	8.16**	±0.42	9.94**	±0.77
HB%	6.75**	±1.00	-4.38*	±1.07	18.68*	±0.47	7.88**	±1.12	2.07	±0.52	7.10	±0.93
ID%	-0.10	±0.67	-13.37**	±0.89	13.19*	±0.39	-8.22**	±0.88	0.81	±0.40	10.20**	±0.71
Cross III (Pusa Phalguni × GC 4)												
RH %	-1.85	±1.04	-5.73**	±0.94	23.17**	±0.36	16.80**	±1.23	17.90**	±0.64	7.77*	±0.78
HB%	4.72	±1.11	-4.66*	±1.11	9.78	±0.43	30.16**	±1.60	8.99	±0.69	-0.84	±0.90
ID%	-6.29 **	±0.96	-7.58**	±0.84	20.05**	±0.31	11.97**	±1.08	15.94**	±0.66	5.83*	±0.75
Cross IV (GC 3 × Kashi Kanchan)												
RH %	2.08	±0.88	-3.98*	±1.13	26.26**	±0.33	8.34**	±1.29	8.89	±0.90	5.82	±0.71
HB%	8.37**	±1.15	0.00	±1.40	22.83**	±0.36	9.79**	±1.44	-10.33**	±1.05	-3.23	±0.85
ID%	-2.64	±0.76	-7.48**	±1.01	18.36**	±0.33	5.60**	±1.23	1.31	±0.91	5.94*	±0.67
Cross V (GC 4 × GDVC 2)												
RH %	7.61**	±0.88	2.08	±1.15	30.77*	±0.48	3.31	±1.27	12.03**	±0.45	2.45	±0.65
HB%	10.35**	±1.06	4.63	±1.44	25.93*	±0.54	10.59**	±1.33	7.12	±0.52	-4.57	±0.81
ID%	-2.01	±0.78	-3.74*	±1.04	-7.84	±0.46	4.79*	±1.18	5.26	±0.43	-2.06	±0.63

* and ** = 5% and 1% level of significance, respectively.

negative heterosis was considered desirable. The estimates of relative heterosis ranged from -5.73% in Pusa Phalguni × GC 4 to 2.08% in GC 4 × GDVC 2. All crosses, except GC 4 × GDVC 2 (2.08%), exhibited significant and desirable negative heterosis for this trait. With respect to heterobeltiosis, the estimates varied from -4.66% (Pusa Phalguni × GC 4) to 4.63% (GC 4 × GDVC 2). Significant and desirable negative heterobeltiosis was recorded in Pusa Phalguni × GC 3 (-4.38%) and Pusa Phalguni × GC 4 (-4.66%), which is ideal for days to first picking. while Pusa Sukomal × Pusa Phalguni (-0.12%) and GC 3 × Kashi Kanchan (0.00%) showed negative and non-significant heterobeltiosis. In contrast, GC 4 × GDVC 2 (4.63%) manifested a positive and undesirable value.

All five crosses exhibited significant and negative inbreeding depression, with estimates ranging from -13.37% (Pusa Phalguni × GC 3) to -3.74% (GC 4 × GDVC 2), indicating the inferiority of early segregating generations for this character. These results are in close agreement with the earlier findings of Venkatachalam *et al*. (2002), Pal *et al*. (2007), Talape *et al*. (2020) and Shinde *et al*. (2021).

Number of branches per plant

For number of branches per plant, all crosses recorded significant positive relative heterosis, except Pusa Sukomal × Pusa Phalguni, which is desirable for this trait.

With respect to heterobeltiosis, significant positive values were observed in GC 4 × GDVC 2 (25.93%), GC 3 × Kashi Kanchan (22.83%)and Pusa Phalguni × GC 3 (18.68%), indicating superiority over the better parent. Pusa Phalguni × GC 4 (9.78%) showed non-significant positive heterobeltiosis, whereas Pusa Sukomal × Pusa Phalguni (-8.51%) exhibited significant negative heterobeltiosis, which is undesirable for this character.

As shown in Table 1, the highest positive inbreeding depression was recorded in Pusa Phalguni × GC 4 (20.05%), followed by GC 3 × Kashi Kanchan (18.36%) and Pusa Phalguni × GC 3 (13.19%), indicating a considerable reduction in performance due to inbreeding. On the other hand, Pusa Sukomal × Pusa Phalguni (-10.47%) and GC 4 × GDVC 2 (-7.84%) exhibited negative inbreeding depression, suggesting greater stability and less reduction in performance of this trait in advanced generations. These findings are in close agreement with

Table 2 : Relative Heterosis (RH %), heterobeltiosis (HB %) and inbreeding depression (ID %) for various characters in five crosses of vegetable cowpea.

Particulars	Number of pod per plant		Pod weight		Number of pod per cluster		Green pod yield per plant		Fresh pod crude protein content	
Cross I (Pusa Sukomal × Pusa Phalguni)										
RH %	14.74*	±2.19	19.00**	±1.38	34.58**	±0.42	10.56	±9.24	6.94**	±0.484
HB%	-2.10	±2.42	13.99**	±1.53	12.50	±0.50	9.60	±10.91	3.01	±0.52
ID%	-4.86	±2.29	2.56	±1.50	13.19	±0.41	8.78	±8.25	6.15**	±0.48
Cross II (Pusa Phalguni × GC 3)										
RH %	26.06**	±1.99	29.25**	±2.24	26.40*	±0.42	15.35*	±7.67	1.46	±0.78
HB%	18.83**	±2.16	21.32**	±2.26	9.72	±0.47	9.45	±8.34	-0.51	±0.96
ID%	24.47**	±2.17	4.03	±2.23	9.81	±0.42	5.06	±6.94	13.30**	±0.66
Cross III (Pusa Phalguni × GC 4)										
RH %	18.96**	±2.27	11.14**	±1.32	12.00	±0.38	15.43**	±6.63	2.31	±0.78
HB%	18..44**	±2.49	7.42	±1.44	-1.41	±0.42	13.68*	±7.63	-0.63	±0.83
ID%	-3.53	±2.25	-3.57	±1.45	3.93	±0.36	6.32	±6.53	3.17	±0.73
Cross IV (GC 3 × Kashi Kanchan)										
RH %	-21.95**	±2.14	1.46	±1.87	28.30**	±0.31	2.09	±7.68	5.83**	±0.43
HB%	-25.62**	±2.77	-7.89	±2.24	7.24	±0.36	-2.73	±9.51	3.83	±0.60
ID%	-35.98**	±1.73	-3.11	±1.93	-4.04	±0.33	-9.57	±7.64	6.46**	±0.42
Cross V (GC 4 × GDVC 2)										
RH %	23.92**	±1.85	16.62**	±1.44	16.28	±0.40	14.29*	±8.42	7.26*	±0.75
HB%	19.28**	±2.27	14.93**	±1.54	1.35	±0.44	9.19	±9.50	4.75	±0.91
ID%	8.41*	±2.06	2.99	±1.58	8.33	±0.39	3.71	±8.46	2.82	±0.73

* and ** = 5% and 1% level of significance, respectively.

earlier reports by Patil and Gosavi (2007), Patel *et al*. (2009), Pathak *et al*. (2017) and Shinde *et al*. (2021).

Plant height

As the dwarf plant height is desirable, vigour in plant height may lead to the unfavourable source to sink ratios and below optimum yield. Significant positive relative heterosis (%) was found for cross *viz.*, Pusa Phalguni × GC 4 (16.80%) and GC 3 × Kashi Kanchan (8.34%), which was not desirable.

For plant height, Pusa Sukomal × Pusa Phalguni (-3.06%) and Pusa Phalguni × GC 3 (-0.59%) recorded negative but non-significant relative heterosis, which was due to the lower plant height of F_1 as compared to the mid-parent. The estimates of heterobeltiosis were calculated using the dwarf parent as the superior standard. Significant positive heterobeltiosis was observed in all the crosses except Pusa Sukomal × Pusa Phalguni (-1.57%), which was undesirable for this trait.

With respect to inbreeding depression, significant desirable positive values were observed in Pusa Phalguni × GC 4 (11.97%), GC 3 × Kashi Kanchan (5.60%) and GC 4 × GDVC 2 (4.79%), while significant negative inbreeding depression was recorded in Pusa Sukomal × Pusa Phalguni (-4.47%) and Pusa Phalguni × GC3 (-8.22%). These results are in close agreement with the earlier findings of Kadam *et al*. (2013), Talape *et al*. (2020) and Shinde *et al*. (2021).

Pod length (cm)

For pod length, significant positive relative heterosis was recorded in Pusa Phalguni × GC 4 (17.90%), GC 4 × GDVC 2 (12.03%) and Pusa Phalguni × GC 3 (8.16%), while non-significant but positive values were noted in GC 3 × Kashi Kanchan (8.89%) and Pusa Sukomal × Pusa Phalguni (1.22%). Positive but non-significant heterobeltiosis was observed in Pusa Phalguni × GC 4 (8.99%), GC 4 × GDVC 2 (7.12%) and Pusa Phalguni × GC 3 (2.07%), whereas significant negative heterobeltiosis was recorded in Pusa Sukomal × Pusa Phalguni (-21.73%) and GC 3 × Kashi Kanchan (-10.33%), which was undesirable.

Inbreeding depression was significant and positive in Pusa Phalguni × GC 4 (15.94%), significant and negative in Pusa Sukomal × Pusa Phalguni (-6.20%) and non-significant in the remaining crosses. Similar findings on positive heterosis for pod length in cowpea have been reported by Trambadia *et al*. (2006), Meena *et al*. (2008), Patel *et al*. (2009), Rashwan *et al*. (2010) and Pathak *et al*. (2017).

Pod girth (nm)

For pod girth significant and desirable relative heterosis was recorded in Pusa Phalguni × GC 3 (9.94%), followed by Pusa Phalguni × GC 4 (7.77%) and Pusa Sukomal × Pusa Phalguni (5.89%). GC 3 × Kashi Kanchan (5.82%) and GC 4 × GDVC 2 (2.45%) showed positive but non-significant relative heterosis. Since all crosses expressed positive relative heterosis, the trait showed favorable improvement potential.

The highest positive value of heterobeltiosis was observed in Pusa Phalguni × GC 3 (7.10%), while GC 4 × GDVC 2 (-4.57%), Pusa Sukomal × Pusa Phalguni (-4.16%), GC 3 × Kashi Kanchan (-3.23%) and Pusa Phalguni × GC 4 (-0.84%) recorded negative and undesirable heterobeltiosis.

The highest positive and significant inbreeding depression was found in Pusa Phalguni × GC 3 (10.20%), followed by Pusa Sukomal × Pusa Phalguni (8.87%), GC 3 × Kashi Kanchan (5.94%) and Pusa Phalguni × GC 4 (5.83%), whereas only GC 4 × GDVC 2 (-2.06%) recorded negative inbreeding depression, suggesting additive effect and better stability for this trait under inbreeding.

Number of pod per plant

Number of pod per plant is important yield-contributing character that positively influences the green pod yield per plant. Significant and positive relative heterosis in cross Pusa Phalguni × GC 3 (26.06%), followed by GC 4 × GDVC 2 (23.92%), Pusa Phalguni × GC 4 (18.96%) and Pusa Sukomal × Pusa Phalguni (14.74%), while GC 3 × Kashi Kanchan (-21.95%) showed undesirable negative but significant relative heterosis. Significant and positive heterobeltiosis was observed in GC 4 × GDVC 2 (19.28%), Pusa Phalguni × GC 3 (18.83%) and Pusa Phalguni × GC 4 (18.44%), indicating superiority over the better parent, whereas GC 3 × Kashi Kanchan (-25.62%) recorded a significant reduction. Inbreeding depression was significant and positive in Pusa Phalguni × GC 3 (24.47%) and GC 4 × GDVC 2 (8.41%) indicating reduced stability in later generations, while negative values were observed in Pusa Sukomal × Pusa Phalguni (-4.86%), Pusa Phalguni × GC 4 (-3.53%) and GC 3 × Kashi Kanchan (-35.98%) were favorable for maintaining performance under inbreeding (Fig. 1).

These results are in accordance with the results of Venkatachalam *et al*. (2002), Trambadia *et al*. (2006), Patil and Gosavi (2007), Meena *et al*. (2008), Patel *et al*. (2009), Ushakumari *et al*. (2010), Gupta *et al*. (2020), Shinde *et al*. (2021) and Lovely and Kumar (2024).

Pod weight (g)

Pod weight is one of the important yield-contributing traits that positively influences the green pod yield per plant. An experimental data presented in Table 2 indicated positive significant relative heterosis for all crosses except GC 3 × Kashi Kanchan. The highest was recorded in Pusa Phalguni × GC 3 (29.25%), followed by Pusa Sukomal × Pusa Phalguni (19.00%), GC 4 × GDVC 2 (16.62%) and Pusa Phalguni × GC 4 (11.14%) reflecting a desirable increase in pod weight across all hybrids.

Significant positive heterobeltiosis was recorded in Pusa Phalguni × GC 3 (21.32%), Pusa Sukomal × Pusa Phalguni (13.99%) and GC 4 × GDVC 2 (14.93%), suggesting superiority over the better parent for pod weight. while Pusa Phalguni × GC 4 (7.42%) showed non-significant and GC 3 × Kashi Kanchan (-7.89%) showed undesirable negative heterobeltiosis.

Inbreeding depression was highest in Pusa Phalguni × GC 3 (4.03%), followed by Pusa Sukomal × Pusa Phalguni (2.56%) and GC 4 × GDVC 2 (2.99%), whereas negative values in Pusa Phalguni × GC 4 (-3.57%) and GC 3 × Kashi Kanchan (-3.11%) suggested better stability under inbreeding in segregaing generations.

Similar result was reported by Rashwan *et al*. (2010), Kadam *et al*. (2013) and Varan *et al*. (2015).

Number of pod per cluster

The hybrids showing positive heterosis for number of pod per cluster directly contribute to yield improvement. Hence, this trait is considered highly desirable. Relative heterosis for number of pod per cluster was significant and positive in Pusa Sukomal × Pusa Phalguni (34.58%), Pusa Phalguni × GC 3 (26.40%) and GC 3 × Kashi Kanchan (28.30%), with the highest value recorded in Pusa Sukomal × Pusa Phalguni. Moderate heterosis was also observed in GC 4 × GDVC 2 (16.28%) and Pusa Phalguni × GC 4 (12.00%).

Heterobeltiosis was desirable and positive in Pusa Sukomal × Pusa Phalguni (12.50%), followed by Pusa Phalguni × GC 3 (9.72%) and GC 3 × Kashi Kanchan (7.24%), while GC 4 × GDVC 2 (1.35%) was positive but non-significant and Pusa Phalguni × GC 4 (-1.41%) showed negative heterobeltiosis, which is undesirable for this trait.

Inbreeding depression was highest in Pusa Sukomal × Pusa Phalguni (13.19%), followed by Pusa Phalguni × GC 3 (9.81%), GC 4 × GDVC 2 (8.33%) and Pusa

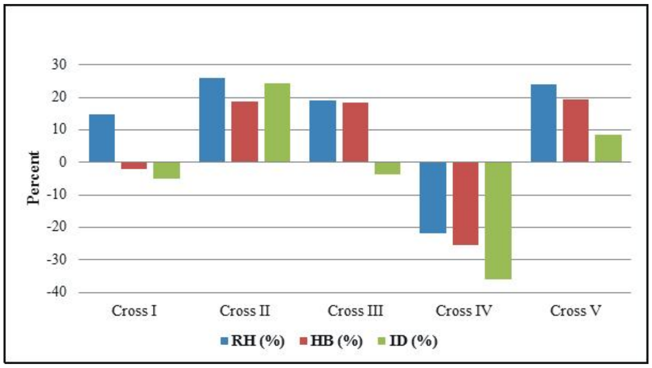

Fig. 1 : Graphical representation of percent relative heterosis (RH), heterobeltosis (BP) and inbreeding depression (ID) for number of pod per plant in all the five crosses.

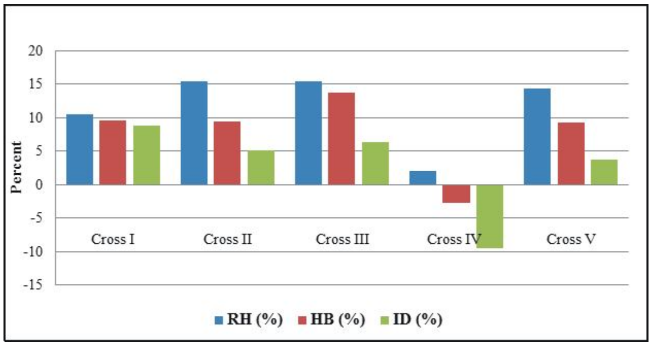

Fig. 2 : Graphical representation of percent relative heterosis (RH), heterobeltosis (BP) and inbreeding depression (ID) for green pod yield per plant in all the five crosses.

Phalguni × GC 4 (3.93%) all showing positive and undesirable effects, whereas GC 3 × Kashi Kanchan (-4.04%) expressed a desirable negative value, indicating greater stability under inbreeding conditions.

These results were in accordance with Meena *et al*. (2008), Ushakumari *et al*. (2010) and Yadav *et al*. (2010).

Green pod yield per plant(g)

As the green pod yield per plant is a complex quantitative character it is a cumulative outcome of several yield-contributing components. The results tabulated in Table 2 indicated significant positive relative heterosis for three crosses, namely Pusa Phalguni × GC 4 (15.43%), Pusa Phalguni × GC 3 (15.35%) and GC 4 × GDVC 2 (14.29%), while non-significant but positive relative heterosis was observed in Pusa Sukomal × Pusa Phalguni (10.56%) and GC 3 × Kashi Kanchan (2.09%).

All the crosses except GC 3 × Kashi Kanchan (-2.73%) exhibited positive heterobeltiosis for green pod yield per plant. The highest heterobeltiosis was observed in Pusa Phalguni × GC 4 (13.68%), followed by Pusa Sukomal × Pusa Phalguni (9.60%), Pusa Phalguni × GC 3 (9.45%) and GC 4 × GDVC 2 (9.19%), indicating superiority of the hybrids over their respective better parents.

The inbreeding depression for green pod yield per plant was found to be positive in all crosses except GC 3 × Kashi Kanchan. The positive inbreeding depression was recorded in Pusa Sukomal × Pusa Phalguni (8.78%), followed by Pusa Phalguni × GC 4 (6.32%), Pusa Phalguni × GC 3 (5.06%) and GC 4 × GDVC 2 (3.71%). Cross between GC 3 × Kashi Kanchan (-9.57%), showed negative value for inbreeding depression, indicating stability and better retention of yield in segregating generations (Fig. 2). Desirable and positive relative heterosis and heterobeltiosis for green pod yield per plant followed by considerable inbreeding depression indicated major role of non-additive gene actions in the inheritance of this character.

These results were in accordance with those reported earlier by Meena *et al*. (2008), Yadav *et al*. (2010), Kadam *et al*. (2013), Wankhade *et al*. (2018) and Gupta *et al*. (2020).

Fresh pod crude protein content (%)

All crosses exhibited positive relative heterosis for fresh pod crude protein content, with the highest value in GC 4 × GDVC 2 (7.26%), followed by Pusa Sukomal × Pusa Phalguni (6.94%), GC 3 × Kashi Kanchan (5.83%), Pusa Phalguni × GC 4 (2.31%) and Pusa Phalguni × GC 3 (1.46%), which is desirable for improving crude protein content in fresh pod.

Heterobeltiosis was maximum in GC 4 × GDVC 2 (4.75%), followed by GC 3 × Kashi Kanchan (3.83%) and Pusa Sukomal × Pusa Phalguni (3.01%), whereas cross Pusa Phalguni × GC 3 (-0.51%) and Pusa Phalguni × GC 4 (-0.63%) showed negative heterobeltiosis, which is undesirable for this trait.

Inbreeding depression ranged from 2.82% in GC 4 × GDVC 2 to 13.30% in Pusa Phalguni × GC 3, with positive and significant values in Pusa Phalguni × GC 3 (13.30%), GC 3 × Kashi Kanchan (6.46%) and Pusa Sukomal × Pusa Phalguni (6.15%), which is undesirable for this trait, as it indicates a reduction in crude protein content in segregating generations.

These findings indicate that while positive heterosis was generally observed for crude protein content, the presence of inbreeding depression in most crosses suggests the need for maintaining hybrid vigor through appropriate breeding strategies. These results were in accordance with Pathak *et al*. (2017) and Gupta *et al*. (2020).

Conclusion

Significant heterosis over mid-parent and better parent in desirable direction for days to first picking was observed in cross Pusa Phalguni × GC 3 and Pusa Phalguni × GC 4. For plant height only Pusa Sukomal × Pusa Phalguni cross showed negative and desirable relative heterosis and heterobeltiosis.

For green pod yield per plant, both relative heterosis and heterobeltiosis observed significant in Pusa Phalguni × GC 4. While GC 4 × GDVC 2 and Pusa Phalguni × GC 3 showed significant relative heterosis for green pod yield per plant. The cross Pusa Phalguni × GC 3 and GC 4 × GDVC 2 were also positive and significant for yield contributing traits *viz*., number of branch per plant, number of pod per plant and pod weight.

The best heterotic cross was Pusa Phalguni × GC 4 as it shown significant relative and better parent heterosis for days to picking, number of branch per plant, number of pod per plant and green pod yield per plant. Significant and positive relative heterosis observed for fresh pod crude protein content in Pusa Sukomal × Pusa Phalguni, GC 3 × Kashi Kanchan and GC 4 × GDVC 2.

In most of the cross significant inbreeding depression was observed for pod girth, number of pod per cluster, green pod yield per plant and fresh pod crude protien content. In GC 3 × Kashi Kanchan cross inbreding depression was negative for number of pod per plant, pod weight, number of pod per cluster and green pod yield per plant which indicating presence of superior recombinant in segregating generations due to fixation of favorable alleles in F_2 generation.

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