SATSA Mukhapatra - Annual Technical Issue **29** : 2025 ISSN 0971-975X

Estimation of Genetic Components for Yield and its Components Using the Generation Mean Analysis in Garden Pea (*Pisum Sativum* L. spp. *Hortense*)

Kumari Shubha[1], Shri Dhar[2], Shreya Anand[3], Anirban Mukherjee[1], Sankharaj Roy[4]

(Received : December 10, 2024; Revised : January 03, 2025; Accepted : January 15, 2025)

ABSTRACT

In this study generation mean analysis (GMA) approach was used to estimate the nature and magnitude of gene action in garden pea for various yield contributing traits. Two *Fusarium* wilt resistant lines GP-55 and GP-6 and three susceptible genotypes, Arkel, Pusa Pragati and AP-3 were used in crossing. This study was conducted to understand the genetics and inheritance of yield contributing quantitative traits in resistant lines for future breeding programme. Scaling test was significant for most of the traits indicating that additive-dominance model is not enough to explain the inheritance of a trait under study. Additive gene effect (d) was significant for pod length, pods per plant, average pod weight, shelling percentage and seeds per pod whereas dominance gene effect (h) was more predominant for pod yield. Dominance × Dominance and Additive × dominance inter-allelic interactions (l) was more important than Additive × Additive type (i) for most of the traits studied which could be exploited by selecting individuals based on their performance in recurrent selection until a fixed level of additive gene effect would not attain. Duplicate type of epistasis prominent over complementary type indicated dispersion of genes in the parents.

Key words : Inheritance, Generation mean analysis, Gene effect, Additive–dominance model, Pod yield.

Introduction

Garden pea (*Pisum sativum* L. spp. *hortense*) is an annual herbaceous legume belonging to the family Papilionaceae. Its tender seeds are used as vegetables. Generally, pea is grown in winter season in the Indian plains, but it is an important summer (off-season) crop in the high hills (Rana *et al.,* 2010; Bala *et al.,* 2011). Early sown crops (mid September to mid October) fetch more profit but more vulnerable to *Fusarium* wilt due to prevailing high temperature and high moisture which are very much conducive that cause severe loss due to high favourable temperature for fungus growth that results severe mortality

[1]ICAR-Research Complex for Eastern Region Patna; [2]College of Horticulture, Thenzawl; [3] Visva-Bharati University, Bolpur Santiniketan; [4]Deptt. Of Agriculture, Govt. Of West Bengal

of plants leaving patchy appearance in the field. Yield losses due to wilt have been reported up to 95 percent along with root rot complex (Maheshwari *et al.,*1983). In addition to reduction in fresh pod yield, the disease also reduces the quality of the marketable pod. The entire popular commercial varieties are highly susceptible to *Fusarium* wilt however author(s) reported two highly resistant source of garden pea along with their inheritance pattern in 2016 (Shubha *et al.,* 2016). This study was concentrated to determine genetic component involve for yield potential of *Fusarium* wilt resistant lines.

Yield is the most essential agronomical trait; thus, it is included in almost all pea selection programmes. The definite knowledge of the nature of gene action for yield contributing traits helps in the choice of an effective breeding strategy to accelerate the pace of genetic improvement of pod yield in garden pea. Therefore, adequate choice of parental lines possessing the potential to produce a high yielding variety along with disease resistant is essential. The effect of individual gene cannot be measured and must be considered along with suitable statistical procedure to obtain genetic information (Ajay *et al.*, 2012). Generation mean analysis which was proposed by (Mather and Jinks, 1971) belongs to the quantitative biometric methods based on measurements of phenotypic performances of certain quantitative traits in basic experimental breeding generations. Considering the fact that pod yield, quality pods and resistance to *Fusarium* wilt are the most important traits and that their improvement is the most important goal in pea breeding, selection of parental components in this study was done in an attempt to fulfil these requirements. Considering these facts, this study was carried out to determine type of gene action prevailing in pea using six generation model, *i.e.* P_1, P_2, F_1, F_2, BC_1, and BC_2 in three garden pea crosses involving susceptible and resistant parents for *Fusarium* wilt.

Materials and methods :

Plant materials

The present investigation was carried out at the Research Farm of Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi during the *rabi* seasons of the year 2012-13 to 2014-15. Material used for this study consisted (Table 1) of 6 generations, Parents (P_1, P_2), F_1, F_2, BC_1, and BC_2 three cross combinations *viz.* Pusa Pragati (PP) × GP-55, Arkel × GP-6 and AP-3 × GP-55. Parents were involved in this study are selected based on their two-year *Fusarium* wilt incidence performance under field and greenhouse conditions (Shubha *et al.,* 2016) at Division of Vegetable Science, IARI, New Delhi. The progeny derived from backcrossing the F_1 to the female parent (P_1) was designated as BC_1 and those from backcrossing to the male parent (P_2) as BC_2. Each experimental unit consisted of 10 plants of each parent, 10 plants of each F_1, 60 plants of the F_2 population, 30 plants of BC_1, and 30 plants of BC_2. Non-segregating populations (parents and F_1's) were represented by fewer plants, whereas segregating populations (F_2's and backcross) were represented by more plants to balance the greater variability in error variance usually associated with segregating populations versus non-segregating populations (Hallauer and Miranda, 1988).

Crossing programme and field preparation

The programme was undertaken during 2012 at research farm of Division of Vegetable Science, IARI, New Delhi. The parental material was planted in crossing block with staggered manner to achieve possible synchronization of flowering time for different crosses. The F_1s seed and selfed seeds were individually collected and stored. Morphological traits such as plant type, leaf characteristics (*Afila* type leaves were found in GP-6 and its F_1 and F_2), pods and growth habit were used as markers to check the trueness of F_1 plants. The F_1 seeds are sown in next year. After selecting desirable plants, F_2 seeds were produced by selfing F_1 plants and backcrosses were also made by crossing F_1 plants with both parents. Thus, a complete set of six populations *viz* P_1, P_2, F_1, F_2, BC_1 and BC_2 for each cross prepared. One row of each parent and F_1, three rows of each backcross generation, six rows of each F_2 were sown in randomized complete block design with three replications during winter 2014-15. Row length was kept 3 m lengths while inter and intra row spacing was kept as 45 cm and 10 cm, respectively. The observations were recorded in each of P_1, P_2, F_1, F_2, BC_1 and BC_2 in each of the replications.

Observation recorded for Generation Mean Analysis in ten quantitative traits *viz.* plant height, node bearing first flower, days to 50% flowering, pod length, pod girth, number of pods per plant, shelling percentage, number of seeds per pod, average pod weight, pod yield per plant.

Statistical analysis

The data collected were subjected to statistical analysis using statistical software OPSTAT. The means and variances were calculated as suggested by (Hayman 1958). The presence of epistasis was detected by using A, B, C and D scaling tests as proposed by (Mather 1949; Haymen & Mather 1955). To test the adequacy of additive × dominance model, the individual scaling tests given by Mather (1949) as well as joint scaling tests by Cavalli (1952) were applied.

Results

Generation means

Mean data (Table 2) on various characters recorded on 6 generations *viz.*, P_1, P_2, F_1, F_2, BC_1 and BC_2 for three cross combinations. There were significant differences among six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) for all quantitative characters understudy involving five parents for different three cross combinations *viz.* Pusa Pragati (PP) × GP-55, Arkel × GP-6 and AP-3 × GP-55.

Traits which are related to earliness of genotypes like days to 50% flowering and node bearing first flower and plant height the F_1 and F_2 was between parental values in all three crosses. These results showed desirable negative values of heterosis indicating that alleles responsible for less value of the trait were dominant over the alleles controlling high value. These findings are very desirable for these traits as breeder selection motive is early and dwarf growth habit. However, mean value of F_2 was found to be lower than corresponding value of F_1 in all the three crosses. This might be due to more variation in F_2 progenies. Backcross generation was taken more time to flower when crossed with late parents and less time when crossed with early parents.

While, all of F_1's were lower than the better-parent value for pod length, pod girth , number of seeds/pod, number of pods/ plant, average pod weight, shelling percentage and total yield per plant. These results led to the negative heterosis values for these traits in all studied crosses which indicate that dominance direction was toward the low respective parent in these traits.

Scaling test

For days to 50% flowering, in cross PP × GP-55 scale B, C and D (Table 3) were significant, and for cross Arkel × GP-6 all the scales (A, B, C, D) were significant while in cross AP-3 × GP-55, scale B and C were significant. Node bearing first flower exhibited significance of scale A and B in cross PP × GP-55 and scale A and C in cross Arkel × GP-6 while no scale was found significant in cross AP-3 × GP-55. For plant height scale A, B and C showed significant value and only scale C showed significant value for the cross PP × GP-55 while in cross Arkel × GP-6 estimates for all four scales were found significant. In cross AP-3 ×GP-55 scale C was found significant. Pod length exhibited significance of scale B and C in cross PP × GP-55 while only scale B was significant for Arkel × GP-6. In cross AP-3 × GP-55 B, C and D were found significant. For pod girth, in cross Arkel × GP-6, scale B and D were found significant while all scales are non-significant for remaining two crosses (PP × GP-55 and AP-3 × GP-55) indicating three parameter additive/dominance model was adequate for these two crosses. For trait number of pods per plant, PP × GP-55 all four scales were significant while in cross Arkel × GP-6 scale A, B and C were found to be significant and in cross AP-3 × GP-55 scale B and D is significant. Average pod weight (g) exhibited significance of scale A and B in cross PP × GP-55 and in cross Arkel × GP-6 value for all the four scales were found to be non-significant while Scale A and C were exhibited highly significant value for cross AP-3 × GP-55. For number of seeds per pod, scale A and C showed significant value in cross PP × GP-55 other crosses Arkel × GP-6 and AP-3 × GP-55 showed significant value for scale B. Estimate value for scale, D is found significant in AP-3 × GP-55 cross only. For shelling percentage none of the scale exhibited significant value for cross PP × GP-55 and only scale B exhibited significant value in cross Arkel × GP-6 while the four scales (A, B, C and D) showed significant value for cross AP-3 × GP-55. For yield per plant (g), all the crosses showed the presence of non-allelic interaction by showing significant value of one or more scales. In cross PP × GP-55 showed significant value for scale A, B and C while scale A and D was found significant and in cross Arkel × GP-6 and scale A, C and D were significant in cross AP-3 × GP-55.

Gene action and epistasis

Nature of gene action for different traits among three crosses is presented in Table 4. In the inheritance of days to 50% flowering, additive gene action [d] showed significant value in all the three crosses (PP × GP-55, AP-3 × GP-55 and Arkel × GP-6) with negative value indicating a predominance of decreasing alleles. However, dominance gene effect [h] was highly significant in positive direction observed in cross PP × GP-55 and Arkel × GP-6 suggesting that both parents possessed heterozygous loci with dominant alleles. Among all non allelic interaction, additive × additive [i] was highly significant in two crosses *viz* PP × GP-55 and Arkel × GP-6. Additive × dominance [j] effects were highly significant in all three crosses but negative direction in cross AP-3 × GP-55. Dominance × dominance [l] effects were significant and negative in cross Arkel × GP-6. The applied model confirmed duplicate epistasis in all the three crosses as estimated value of dominance and dominance interaction was characterized by opposite sign compared to the value of the dominance effect. In the inheritance of node bearing first flower, [d] was more important in cross Arkel × GP-6 but in negative direction. Among epistasis gene action only cross PP × GP-55 exhibited significance [j] effects and non significant in other two crosses. All crosses except AP-3 × GP-55 showed duplicate type of epistasis. Plant height was governed mainly by [d] in two crosses *viz.* PP × GP-55 and AP-3 × GP-55 but in negative direction while in cross Arkel × GP-6 govern by [h] and [d] in positive direction. Among epistatic gene action [l] was observed in cross PP × GP-55 and Arkel × GP-6 however [j] was also found significant in Arkel × GP-6 and [i] in cross PP × GP-55 in negative direction. Arkel × GP-6 and AP-3 × GP-55 exhibited duplicate type of epistatis while PP × GP-55 showed complementary type of epistasis.

In the inheritance of pod length and pod girth [d] was more important for all crosses while significant [h] was also observed for pod length in cross AP-3 × GP-55 and for pod girth in cross Arkel × GP-6 but in negative direction. In epistatic gene action [l] was observed in cross PP × GP-55 and all three types of epistatic interaction were observed in cross AP-3 × GP-55 for pod length and in cross Arkel × GP-6 for pod girth while non-significant for all other crosses. Pods per plant were inherited mainly by [d] in all the crosses however magnitude of [h] was found high in cross PP × GP-55 in negative direction. Among epistatic interaction, [l] was observed in all three crosses; [j] was observed in cross PP × GP-55 and AP-3 × GP-55 and [i] was observed in PP × GP-55. Three crosses exhibited duplicate type of as estimated value of dominance × dominance interaction was characterized by opposite sign compared to the value of the dominance effect.

In the inheritance of average pod weight [h] was more important with negative value in cross PP × GP-55 and Arkel × GP-6 while in cross AP-3 × GP-55 with positive value. Epistatic gene interaction like [i] and [l] were not prominent in the inheritance of average pod weight except for Arkel × GP-6 where [j] was significant. Seeds per pod and shelling percentage were inherited mainly by [d] but [h] was also been observed in cross AP-3 × GP-55 with negative value. Among the epistatic gene interaction [i] and [j] was significant in cross Arkel × GP-6 and AP-3 × GP-55 for seeds per pod and shelling percentage and [l] was important for cross Arkel × GP-6.

Pod yield per plant was predominantly governed by [h] in cross PP × GP-55 and AP-3 × GP-55 while [d] observed in Arkel × GP-6. Significant [l] epistatic interaction was observed in all crosses but negative value in two crosses *viz* PP × GP-55 and AP-3 × GP- 55 whereas [i] type interaction was also observed in these two crosses. Three crosses exhibited duplicate type gene action.

Discussion

Scaling test (Mather. 1949), was significant for most of the traits in all the three crosses (Table 3) demonstrating additive/dominance model failed; therefore, six parameter model was used for estimation of gene effects. It also indicated that higher value interactions (inter-allelic interactions) play important role in the regulation and the expression of traits and improvement of traits studied would be more difficult as compared to the situation pertaining to more simple models of inheritance (additive-dominance model). These results are in accordance with reports of Dixit *et al..,* (2006), Sharma *et al..,* (2013) Ajay *et al..,* (2011) and Shubha *et al,* (2015), in garden pea. However, three parameter additive-dominance model was adequate for the trait like pod girth and shelling percentage in cross PP × GP-55, average pod weight in Arkel × GP-6 and node bearing first flower, pod girth in cross AP-3 × GP-55 which confirmed significant additive and dominance gene effects.

Days to 50% flowering and node bearing first flower are trait related to earliness of genotypes superior. Preponderance of positive dominance effect in cross PP × GP-55 and Arkel × GP-6 indicated that the increased expression of traits by dominance which is not desirable for earliness, similarly negative additive effect also observed in cross Arkel × GP-6. Both results suggested that the selection for early segregants should be taken up in the early generations. This finding contradicted finding of Sharma *et al.* (2013), it may be due to different set of genotypes used in both studies. Plant height is an important economic trait and desirable plant type in garden pea is the one with dwarf growth habit and does not require staking which results in saving resources both in terms of money and labour. The results revealed that additive gene effect [d] in two crosses *viz* PP × GP-55 and AP-3 × GP-55 showed highly significant value with negative value. It indicated that alleles responsible for less value of the trait were dominant over the alleles controlling high value which are very advantageous for plant height as the desirable plant type in garden pea is the dwarf growth habit.

Pod length, seed/pod and shelling percentage have a direct bearing on the total productivity of pea crop. Genic interactions for pod length, seed/pod and shelling percentage showed significance of additive component in cross PP × GP-55 and Arkel × GP-6, on the other hand, negative dominance observed for AP-3 ×GP-55 and significant [l] was observed in cross PP × GP-55 and AP-3 × GP-55 for pod length, for seed per pod in cross PP × GP-55 and Arkel × GP-6 and in cross AP-3 × GP-55 for shelling percentage. Additive variance indicates average effects of individual alleles at loci whereas dominance variance represents the summation of variance due to interaction effects between two alleles at different loci. If the trait has high additive variance, it may not follow strictly additive model. There is a possibility that traits may follow dominance model even when additive variance is high. Further, manifestation of duplicate epistasis by the crosses for pod length and seeds/pod and shelling percentage revealed that this kind of epistasis generally hinders the improvement through selection as the presence of duplicate epistasis decrease the variation in F_2 and subsequent generations (Tyagi *et al.,* 2001). Therefore, the selection should be delayed until a high level of gene fixation is attained. Dixit *et al.* 2006 also reported significant [h] for pod length and seeds/pod. In the inheritance of pod/plant, average pod weight both additive and dominance gene effect was found significant but influence of negative dominance gene effect was higher. The negative value of [h] indicated that dominance was towards the parent that has lower value of pod/plant, average pod weight than the other high value parent. Among epistatic gene interaction significant [j] and [l] was observed in cross PP × GP-55 and AP-3 × GP-55 and significant [i] and [l] was found in cross PP × GP-55 and Arkel × GP-6 respectively. Negative dominance and duplicate epistatic effect were detected in crosses which suggested dominance effects at heterozygous loci in each parent for pod/plant and average pod weight. It indicates the decreased expression of traits of dominance and selection would be effective during later generations only. Beside this paucity of more gene effects suggest that breeders would make limited and slow progress in selecting for genotype for these traits (Smith *et al.,* 2009). Pod yield was controlled by both additive and dominance gene action. It was found that dominance component was mostly higher in magnitude than additive component in cross PP × GP-55 and AP-3 × GP-55. It indicates the increased expression of traits by dominance. Among the digenic interaction effects, [i] and [l] was also found significant in same crosses, while it was observed pod yield was under the influence of [d] in cross Arkel × GP-6 and significant [l] was also observed. In this situation reciprocal recurrent selection is probably useful for the effective utilization of both additive and non-additive gene effects simultaneously. It will also lead towards an increased variability in later generations for effective selection by maintaining considerable heterozygosity.

It was observed that depending on the cross and a trait, though scaling test was significant (Table 3) for all the traits studied but non-allelic interactions were not significant (Table 4). This indicates that, such traits are governed by higher order interactions or under the control of complex genetic control or they have large environmental difference (Milus and Line 1986). It has been observed that higher order epistasis among more than two genes may play important role in genetic interactions (Hansen *et al.,* 2001; Marchini *et al.,* 2005; Purcell *et al.,* 2007; Imielinski *et al.,* 2008). Such higher order interactions have also been reported in pepper where high-order epistasis could be correlated with the aggressiveness of the isolate of *Phytophthora capsici* through influencing double crosses among different loci at meiosis (Bartual *et al.,* 1993). Wang *et al.* (2010) have proposed "N locus Epistasis" a general model for estimating higher order interactions involving any number of loci using the formula given by Mather and Jinks (1971). If n loci which form 3^n genotypes is considered, it is composed of overall mean, additive and dominance effects for each locus and epistasis of different kinds and orders among these loci. It was also reported that with the gain in [h] there will be simultaneous loss in [l] interaction (Gupta *et al.,* 1996). Therefore, opposite signs of [h] and [l] cancel each other leading to reduced heterosis (Shashikumar *et al.,* 2010).

Presence of complementary gene action for plant height and number of seed per pod in cross PP × GP-55 and average pod weight in cross AP-3 × GP-55 indicates that parents selected for crossing are diverse which is supporting Reynolds *et al.* (2009), strategy, wherein they concluded that if parents selected for crossing are complementary for traits then it is possible to realise enhanced genetic gain in breeding programme. Further, manifestation of duplicate epistasis for most of the traits indicates (Table 4) that variability in segregating generation may be reduced which hinders the selection process (Kumar & Patra, 2010), hence it is difficult to utilise them in breeding programme (Sameer *et al.,* 2009).

Shubha *et al.* (2016), reported GP-6 and GP-55 lines are highly resistant to *Fusarium* wilt and their resistance against wilt is governed by monogenic and dominant nature. Linkage drags usually come across while transferring disease resistance gene in already available high yielding but susceptible varieties. Small pod and few seeds per pods are the main constraint which associated with resistant lines. This problem could be solved by repeated backcrossing with high yielding varieties.

Conclusions

Scaling, joint scaling tests and six generation model have revealed that both intra (dominance gene action) and inter-allelic (epistasis) interaction play an important role in the inheritance of all the traits under studied. In this situation exploitation of heterosis could be followed by postponing the selection from early to later generations. Predominance of additive genetic effect for most of the traits indicates that there is difference between homozygotes at a locus with positive and negative alleles are dispersed between parents. Garden pea being a strict self-pollinated and creation of variability among genotypes is very difficult, so such an interaction effect between alleles could be exploited by selecting individuals based on their performance in recurrent selection. In any breeding programmes yield is the main criteria and it is dependent on many other quantitative traits. Hence traits like pods per plant, seeds per pod, average pod weight can be used in further breeding programmes.

Acknowledgement

The authors are thankful to Department of Science and Technology (DST) for financial assistance and Indian Agriculture Research Institute (IARI), New Delhi for infrastructural support.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Ajay, B. C., Ganesh, B. N., Ganapathy, K. N., Gowda, M. B., Prasad, P. S., Veerakumar, G. N., Venkatesha, S. C., Fiyaz, R. A. and Ramya, K. T. 2012. Genetic analysis of yield and quantitative traits in pigeonpea (*Cajanus cajan* L. Millsp.). *Euphytica* **186**: 705-714.

Bala, B., Sharma. N. and Sharma, R. K. 2011. Cost and return structure for the promising enterprise of off-season vegetables in Himachal Pradesh. *Agricultural Economics Research Review* **24** (1): 141–148.

Bartual, R., Lacasa, A., Marsal, J. and Tello, J. 1993. Epistasis in the resistance of pepper to *phytophthora* stem blight (*Phytophthora capsici* L.) and its significance in the prediction of double cross performances. *Euphytica* **72**: 149–152.

Cavalli, L. L. 1952. An analysis of linkage in quantitative inheritance. (in) *Quantitative inheritance* (Rieve, E,C,E, and Waddingon, C.H. eds). HMSO, London. pp. 144.

Dixit, G. P., Tanveer, H. and Chandra, S. 2006. Generation mean analysis for grain yield related traits in field pea (*Pisum sativum* L.). *The Indian Journal of Genetics and Plant Breeding* **66** (2): 147-148.

Gupta, A. K., Singh, I. S. and Bajpai, G. C. 1996. Generation mean analysis for flowering and maturity in four pigeonpea crosses in Pantnagar, Uttar Pradesh India. *International Chickpea and Pigeonpea Newsletter* **3**: 73–74

Hallauer, A. R. and Miranda Fo, J. B. 1988. Quantitative genetics in plant breeding. *Iowa State*.

Hanse, T. and Wagner, G. 2001. Epistasis and the mutation load: a measurement theoretical approach. *Genetics* **158**: 477.

Hayman, B. I. 1958. The separation of epistatic from additive and dominance variation in generation means. *Heredity* **12**: 371–390.

Hayman, B. I. and Mather , K. 1955. The description of genetics of interaction of continuous variation. *Biometrics* **51**: 69-82.

Imielinski, M. and Belta, C. 2008. Exploiting the pathway structure of metabolism to reveal high-order epistasis. *BMC Systems Biology* **2**: 40.

Kumar, B. and Patra, N. M. 2010. Genetic analysis of capsule and its associated economic traits in Opium poppy (*Papaver somniferum* L.). *Journal of Heredity* **101** (5): 657–660.

Maheshwari, S. K., Jhooty, J. S. and Gupta, J. S. 1983. Survey of wilt and root rot of complex of pea in Northern India and the assessment of losses. *Agricultural Science Digest*, India **3** (3&4): 139-141.

Marchini, J., Donnelly, P. and Cardon, L. 2005. Genome-wide strategies for detecting multiple loci that influence complex diseases. *Nature Genetics* **37**: 413–417.

Mather, K. 1949. Biometrical genetics. Methuen and Co Ltd., London

Mather, K. and Jinks, J. L. 1971. Biometrical genetics. Chapman and Hall ltd, London

Mather, K. and Jinks, J. L. 1971. (in) *Biometrical Genetics*, 2nd edn. Chapman and Hall, London.

Milus, E. A. and Line, R. F. 1986. Gene action for inheritance of durable, high-temperature, adult-plant resistance to stripe rust in wheat. *Phytopathology* **76:** 435–441.

Purcell, S., Neale, B., Todd-Brown, K., Thomas, L. and Ferreira, M. 2007. PLINK: a tool set for whole-genome association and population-based linkage analyses. *American Journal of Human Genetics* **81:** 559–575.

Rana, J. C., Singh, A., Sharma, Y., Pradheep, K. and Mendiratta, N. 2010. Dynamics of plant bioresources in western himalayan region of India-watershed based case experiment. *Current Science* **98** (2): 192–203.

Reynolds, M., Manes, Y., Izanloo, A. and Langridge., P. 2009. Phenotyping approaches for physiological breeding and gene discovery in wheat. *Annals of Applied Biology* **155**: 309–320.

Sameer, K. C. V., Sreelakshmi, C. H., Shivani, D. and Suresh, M. 2009. Gene effects for yield contributing characters in pigeonpea (*Cajanus cajan* L. Millsp) by generation mean analysis. *Journal of Research ANGRAU* **37** (3&4): 71–76.

Sharma, A., Kapoor, P., Katoch, V., Singh, Y. and Sharma, J. D. 2013. Development of powdery mildew resistant genotypes in garden pea (Pisum sativum L.) through generation mean analysis approach. *Indian Journal of Genetics and Plant Breeding (The)*, **73** (4): 371-377.

Shashikumar, K. T., Pitchaimuthu, M. and Rawal, R. D. 2010. Generation mean analysis of resistance to downy mildew in adult muskmelon plants. *Euphytica* **173**: 121–127.

Shubha, K., Dhar, S., Choudhary, H., Dubey, S. C. and Sharma, R. K. 2016. Identification of resistant sources and inheritance of Fusarium wilt resistance in garden pea (*Pisum sativum ssp. hortense*). *Indian Journal of Horticulture* **73** (3): 356-361.

Shubha and Dhar, S. 2015. Generation mean analysis for pod yield and its associated traits in garden pea (*Pisum sativum* L.). *Vegetable Science* **42** (2):43-46.

Smith, C. W., Braden, C. A. and Hequet, E. F. 2009. Generation mean analysis of near-long-staple fiber length in TAM 94L-25 upland cotton. *Crop Science* **49**:1638-1646.

Tyagi, M. K. and Srivastava, C.P. 2001. Analysis of gene effects in pea. *Legume Research* **24**: 71-76.

Wang, Z., Liu, T., Lin, Z., Hegarty, J., Koltun, W.A. and Wu, R. 2010. A general model for multilocus epistatic interactions in case control studies. PLoS ONE **5** (8):e11384. doi:10.1371/ journal. pone. 0011384.

Table 1 : Parent materials used in study, their description and Fusarium wilt Response

Sl. No	Genotype/ Lines	Description	*Fusarium* wilt Response
1	Arkel	Dwarf, early, wrinkled seeded high yielding variety	Susceptible
2	Pusa Pragati	Dwarf, early, wrinkled seeded high yielding variety	Susceptible
3	AP-3	Dwarf, early, wrinkled seeded high yielding variety	Susceptible
4	GP-55	Tall, late, small pod, Plant type resembles that of field peas	Resistant
5	GP-6	Dwarf, ate, Afila type leaves, two pods per bunch	Resistant

Table 2 : Mean performance of parents and their F_1 F_2, BC_1 and BC_2 of cross Arkel × GP-6 for yield and yield contributing traits

	Days to 50% flowering	Node bearing first flower	Plant height (cm)	Pod length (cm)	Pod girth (cm)	Number of pod per plant	Average pod weight(g)	Number of seeds per pod	Shelling percentage (%)	Yield per plant (g)
P_1	40.25±1.70	7.66±0.40	42.50±1.37	8.86±0.26	1.06±0.06	19.33±0.87	6.07±0.11	8.17±0.29	43.01±0.62	54.04±2.31
P_2	79.41±1.98	8.25±0.39	36.42±2.07	7.55±0.24	0.86±0.05	11.66±0.61	4.17±0.15	6.25±0.39	33.29±1.43	25.60±2.48
F_1	69.60±1.70	8.08±0.31	40.21±1.62	7.75±0.15	1.01±0.03	15.50±0.50	5.58±0.19	7.91±0.32	37.20±1.19	48.18±1.72
F_2	61.28±1.1	6.86±0.28	41.25±0.78	7.73±0.17	1.02±0.04	11.72±0.53	5.42±0.12	7.36±0.21	36.95±0.82	45.61±1.48
B_1	65.75±2.28	7.00±0.46	42.12±1.93	8.05±0.29	1.04±0.07	13.33±0.92	5.77±0.19	7.91±0.32	40.09±1.4	42.99±2.34
B_2	70.00±1.64	8.08±0.44	40.38±0.97	7.30±0.20	0.79±0.04	9.41±0.58	5.16±0.22	6.08±0.32	31.95±1.16	35.23±1.88

Table 2 : (cont.) Mean performance of parents and their F_1 F_2, BC_1 and BC_2 of cross Pusa Pragati × GP-55 for yield and yield contributing traits

	Days to 50% flowering	Node bearing first flower	Plant height (cm)	Pod length (cm)	Pod girth (cm)	Number of pod per plant	Average pod weight(g)	Number of seeds per pod	Shelling percentage (%)	Yield per plant (g)
P_1	44.08±1.05	8.28± 0.26	38.30±1.19	9.15±0.54	1.22±.05	15.16±1.11	6.24±0.15	8.66±0.36	42.24±0.76	49.85±2.22
P_2	84.61±2.26	14.33±0.54	89.50±2.47	6.89±0.21	0.83±0.05	21.16±1.90	3.31±0.15	6.91±0.34	35.76±0.87	29.17 ±0.96
F_1	77.20±2.17	9.20±0.78	87.60±2.41	8.34±0.18	1.18±0.14	17.15±1.08	6.27±0.12	8.50±0.36	38.83±0.94	51.86±0.84
F_2	65.04±1.12	9.61±0.51	71.84±3.32	7.76±0.13	1.04±0.46	14.18±0.58	5.48±0.10	7.34±0.18	38.01±0.72	47.20±1.67
B_1	63.42±2.09	9.33±0.56	52.70±2.46	8.35±0.25	1.10±0.10	14.20±1.04	5.58±0.13	7.66±0.47	39.31±1.18	41.79±0.69
B_2	79.75±1.93	10.75±0.58	83.00±2.04	6.39±0.31	0.88±0.07	9.76±0.67	5.18±0.16	6.88±0.38	37.09±1.32	37.24±1.99

Table 2. (cont.) Mean performance of parents and their F_1 F_2, BC_1 and BC_2 of cross AP-3 × GP-55 for yield and yield contributing traits

	Days to 50% flowering	Node bearing first flower	Plant height (cm)	Pod length (cm)	Pod girth (cm)	Number of pod per plant	Average pod weight(g)	Number of seeds per pod	Shelling percentage (%)	Yield per plant (g)
P_1	44.75±1.75	8.25±0.39	42.58±1.38	8.33±0.24	1.19±0.05	16.16± 1.04	5.71±0.19	7.58±0.44	44.07±0.40	49.17±1.37
P_2	84.61±2.26	14.33±0.54	89.41±2.04	6.89±0.17	0.85±0.05	22.75±0.90	3.31±0.15	6.16±0.34	35.76±0.87	29.17±0.96
F_1	66.91±2.32	11.16±1.04	87.91±1.69	7.15±0.38	0.85±0.04	17.41±0.89	6.07±0.16	7.33±0.43	41.56±1.35	42.41±2.40
F_2	64.03±2.45	10.73±0.36	80.86±2.14	8.05±0.24	0.94±0.03	13.81±0.54	4.75±0.20	7.18±0.41	39.92±0.70	38.69±1.86
B_1	56.83±2.90	9.80±0.70	67.41±4.60	8.21±0.26	1.05±0.06	14.91±1.18	5.18±0.32	7.00±0.47	38.26±2.23	36.71±2.07
B_2	72.90±3.02	12.50±0.45	85.41±4.05	6.34±0.41	0.85±0.07	11.3±1.13	4.53±0.34	6.08±0.51	35.48±2.00	31.95±2.77

Table 3 : Scaling test of the three crosses for yield contributing traits

Cross	A	B	C	D
Days to 50% flowering				
PP × GP-55	-6.55±3.63	17.73**±3.53	38.06**±4.76	-13.16**±2.57
Arkel × GP-6	-25.01**±3.85	18.01**±2.97	32.74**±4.49	-13.1**9±2.58
AP-3 × GP-55	-2.59±4.06	21.16**±6.47	22.11**±9.42	-1.76±5.06
Node bearing first flower				
PP × GP-55	-2.21**±0.93	2.76**±0.93	1.71±1.87	-0.58±0.82
Arkel × GP-6	1.75**±0.74	0.01±0.002	2.40**±1.00	-0.36±0.60
AP-3 × GP-55	-0.25±1.07	0.50±1.04	1.98±1.85	-0.86±0.78
Plant height				
PP × GP-55	22.90**±7.54	13.10**±3.78	20.00*±5.05	8.17±5.06
Arkel × GP-6	-7.53**±2.62	13.87**±3.21	26.42**±3.65	-10.04**±2.02
AP-3 × GP-55	-4.33±6.69	6.50±6.03	-15.63**±6.75	8.90±5.29
Pod length				
PP × GP-55	1.02±0.54	1.40**±0.49	1.92**±0.62	0.24±0.34
Arkel × GP-6	0.50±0.46	0.68*±0.35	0.98±0.60	0.10±0.35
AP-3 × GP-55	-0.95±0.49	1.37*±0.65	-2.68**±0.9	1.55*±0.49
Pod girth (cm)				
PP × GP-55	0.21±0.16	0.26±0.13	0.25±0.21	0.11±0.11
Arkel ×GP-6	-0.09±0.01	0.28**±0.08	-0.14±0.13	0.21**±0.08
AP-3 × GP-55	-0.60±0.10	0.006±0.11	-0.001±0.13	-0.27±0.88

Number pod per plant				
PP × GP-55	3.83*±2.74	20.41**±3.33	7.45**±3.54	8.37**±2.54
Arkel×GP-6	8.16**±1.49	8.33**±1.00	15.12**±1.84	0.69±0.63
AP-3 × GP-55	3.75±1.93	17.50*±7.99	18.48*±2.52	1.38±1.03
Average pod weight				
PP × GP-55	1.20**±0.23	-0.89*±0.27	-0.05±0.37	0.17±0.21
Arkel × GP-6	0.11±0.36	-0.55±0.36	-0.30±0.46	0.07±0.26
AP-3 × GP-55	1.41**±0.50	0.03±0.51	2.13**±0.65	-0.19±0.44
Number of seed per pod				
PP × GP-55	1.83**±0.76	1.00±0.64	2.47**±0.81	0.18±0.50
Arkel × GP-6	0.25±0.55	2.00**±0.0.58	0.81±0.83	0.72±0.44
AP-3 × GP-55	0.91±0.86	1.33*±0.65	-0.31±0.97	1.28*±0.76
Shelling percentage				
PP × GP-55	2.11±2.06	1.82±2.35	4.99±3.02	0.53±1.87
Arkel × GP-6	0.04±2.20	6.58**±2.10	2.92±1.30	1.85±1.07
AP-3 × GP-55	9.11**±3.31	6.35*±3.34	3.27*±3.15	-6.09**±2.36
Pod yield per plant				
PP × GP-55	-21.73**±5.94	2.55*±1.42	-21.56**±6.59	1.38±3.72
Arkel × GP-6	22.83*±8.49	6.28±6.33	6.46±7.14	19.00**±4.13
AP-3 × GP-55	18.18**±5.68	-7.6±4.33	38.19**±6.61	11.1*±4.37

Table 4 : Estimation of gene effects in three crosses for Days to 50% flowering, Node bearing first flower, Plant height and pod length

Cross	m	d	h	i	j	l	Epistasis
				Days to 50% flowering			
PP × GP-55	65.00**±0.79	-16.33**±2.02	31.45**±3.68	26.33**±5.14	23.33**±5.29	-14.10±9.38	Duplicate
Arkel × GP-6	61.28**±0.82	-4.25*±1.98	26.64**±5.39	26.38**±5.17	49.50**±4.38	-20.00*±9.13	Duplicate
AP-3 × GP-55	64.03**±1.73	-16.18**±2.95	-2.83±4.09	2.53±6.45	-23.85**±6.42	16.60±14.24	Duplicate
				Node bearing first flower			
PP × GP-55	9.75**± 0.32	-0.41±0.59	-0.80±1.74	1.16±1.64	5.00**±1.06	0.60±2.66	Duplicate
Arkel × GP-6	6.86**±0.20	-1.08*±0.45	2.14±1.24	2.72±2.25	-1.50±0.98	-2.39±2.06	Duplicate
AP-3 × GP-55	10.73**±0.25	2.66± 1.57	1.60± 1.74	-	-	-	-
				Plant height			
PP × GP-55	71.75**± 2.34	-30.50**± 2.26	9.70± 10.34	-16.00± 10.43	-9.8*± 4.92	52.00**±13.62	Complementary
Arkel × GP-6	30.23**± 0.56	13.74**± 1.69	14.82*± 4.29	20.08**± 4.04	21.40**± 3.82	-13.74± 7.68	Duplicate
AP-3 × GP-55	80.86**±1.51	-18.00**±4.34	4.11±10.69	-17.80±10.59	10.83± 8.8	-19.96±8.63	Duplicate
				Pod length			
PP × GP-55	7.76**±0.09	1.42**±0.28	-0.24± 0.73	-0.49± 0.69	0.37± 0.7	2.92*± 1.30	Duplicate
Arkel × GP-6	7.73**±0.17	0.75**±0.25	-0.65±0.73	-0.200±0.71	0.18±0.56	1.38±1.18	Duplicate
AP-3 × GP-55	8.05**± 0.17	1.88**± 0.34	-3.57**±1.02	-3.11**±0.98	2.32**±0.72	3.53*±1.66	Duplicate

Table 4 : (cont.) Estimation of gene effects in three crosses for pod length, Number of pod per plant, Average pod weight, Number of seed per pod, Shelling percentage, Yield per plant

Cross	m	d	h	i	j	l	Epistasis
Pod girth							
PP × GP-55	1.04**± 0.03	0.22**±0.09	-0.06±0.24	-	-	-	-
Arkel ×GP-6	1.02**± 0.02	0.25**±0.06	- 0.37*±0.17	-0.42**±0.16	0.29*±2.13	0.69*±0.28	Duplicate
AP-3×GP-55	0.94**± 0.02	0.20**± 0.06	0.11±0.18	-	-	-	-
Number of pod per plant							
PP × GP-55	16.18**±0.41	4.50*±0.85	-18.57**±2.62	-16.70**±2.57	16.58**±2.90	41.00**±4.4	Duplicate
Arkel ×GP-6	11.72**±0.37	3.91**±0.96	-1.38±2.23	-1.38±2.17	0.16±1.72	17.88**±3.61	Duplicate
AP-3×GP-55	13.81**±0.38	3.58**±1.16	-4.80±2.96	-2.76±2.79	13.75**±2.78	24.01**±5.28	Duplicate
Average pod weight							
PP × GP-55	5.48**± 0.08	0.51**± 0.21	-1.02*± 0.43	-0.37± 0.42	-2.09**± 0.33	0.66±0.93	Duplicate
Arkel ×GP-6	5.18**± 0.34	0.41**± 0.15	-1.09*± 0.57	-	-	-	-
AP-3×GP-55	4.75**± 0.14	0.65*±0.33	1.95*± 0.90	0.39± 0.89	-1.09± 0.69	1.34±1.50	Complementary
Number of seed per pod							
PP × GP-55	7.34**± 0.13	40.83*±0.42	0.72± 1.05	-0.36± 1.00	-0.833±0.92	3.19±1.90	Complementary
Arkel × GP-6	7.36**± 0.32	1.83**± 0.32	-0.73±0.93	-1.44± 088	1.75*± 0.73	3.6*± 1.53	Duplicate
AP-3 × GP-55	7.18**± 0.16	0.91**± 0.49	-2.22*± 1.19	-2.56*± 1.53	0.41± 0.98	4.81*± 2.05	Duplicate
Shelling percentage							
PP × GP-55	38.01**± 0.49	2.40*±1.57	0.20± 3.45	-	-	-	-
Arkel × GP-6	36.95**± 0.58	8.13**±1.28	-4.64±3.61	-3.7±3.47	6.54*± 2.80	10.32±6.00	Duplicate
AP-3 × GP-55	39.92**± 0.50	2.77*±2.12	-10.54**±4.85	-12.19**±4.69	-2.76±4.50	27.66*±9.06	Duplicate
Yield per plant							
PP × GP-55	47.20**± 1.18	4.55**± 0.56	10.31**± 7.78	22.96**± 7.44	2.81± 5.99	-23.26**±13.24	Duplicate
Arkel × GP-6	45.61**± 1.04	7.76**±1.87	-6.59±8.75	-6.45±8.26	12.55± 7.51	35.48*± 15.94	Duplicate
AP-3 × GP-55	38.69**± 1.31	4.76**± 1.48	12.38**± 8.92	24.54**± 8.74	6.33± 7.07	-17.89**±5.33	Duplicate