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Estimation of genetic parameters through additive-dominance model in lentil

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Abstract

The objective of the present study was to estimate the genetic parameters and hybrid vigor of yield and yield contributing traits in lentil through additive-dominance model. Mean $\hat{m}$ found to be significant in all cases which indicating polygenic nature of the traits. Parameters [d] and [h] significant in few cases indicating that both additive and dominant gene effects played an important role in the inheritance of the respective traits. In all crosses and for all characters, mid-parent and high-parent heterosis were not significant except the cross $P_5 \times P_6$. Potence was non-significant in most cases which indicated that differences don't exist between F_1 and F_2 generations. It was revealed from the joint scaling test that for most characters in different crosses χ^2 values were not significant. Non-significant χ^2 test indicated the adequacy of additive-dominance model and hence those traits carry only additive and dominant genes which can be used in breeding programs to improve lentil varieties.

Keywords: Additive-dominance model; Heterosis; Lentil; Potence

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Introduction

Lentil (*Lens culinaris* Medic.) is a winter season crop and mostly is planted after rice on a roughly prepared seed bed with one or two ploughing. This crop is cultivated as a sole or mixed crop with mustard (*Brassica campestris* L.). Like many leguminous crops, lentils play a key role in crop rotation due to their ability to fix nitrogen. It's lens-shaped edible seed which is one of the most ancient of cultivated foods, has a great importance as compared to other dry seeds for the low water content and impervious seed coats which enhance its value for storage purposes and increase their longevity. There are many varieties of lentil grown and eaten throughout the world, but the three most common types used in cooking are brown, red, and green. Lentil is a highly nutritious and sustainable food source which contains proteins, fiber, and other micronutrients such as iron and vitamin B. Lentils are often mixed with grains, such as rice, which results in a complete protein dish. For the above reasons, this plant is popular in the vegetarian population of the world.

Looking to the importance and production of this crop, greater attention is needed for its improvement. In this regard, efforts should be made to develop high yielding varieties through breeding programs. Lentil is a self-pollinated species and very little cross pollination has been observed in this plant. The breeding methods common for self-pollinated crops, viz. pure-line selection, pedigree method, bulk method, and back cross method are all followed by lentil breeders and sometimes some modifications are done with these. Mutagenesis has also been used to improve existing cultivars for specific traits. Information regarding genetic nature of yield and yield contributing traits is necessary for developing high yielding varieties. Breeding methods are dictated by the gene action and linkage of different quantitative traits. Plant breeders are interested in estimating gene effects in order to formulate the most advantageous breeding procedures for improving the genetic material (Bond *et al*. 1994; Abdalla *et al*. 1999). A biometrical method is always helpful to plant breeders to estimate genetic components of crop plants. Generation mean analysis is a simple but useful technique for characterizing gene affects for a polygenic character (Hayman 1958) which, it determines the presence and absence of non-allelic interactions. Breeders have been utilizing the available genetic resources to modify the varieties to meet the ever changing requirements. In this context the most important development in plant breeding in recent times is the extensive use of heterosis (Malik *et al*. 1987). However, in most self-pollinated crops, heterosis can't be exploited directly and hybrid vigor is used to identify superior hybrids as they offer the increased probability of developing better segregants (Sharif *et al*. 2001). The present study was done to observe the nature and magnitude of gene effects of yield and yield components through generation mean analysis which would help lentil breeders to formulate an efficient breeding program to achieve desired genetic improvement in lentil.

Materials and Methods

Experimental materials and field layout

Experimental materials were collected from ICARDA, Syria, and from RARS, BARI, Bangladesh. Materials were irradiated with different doses of Krad gamma-rays (Kr) i.e., 20 Kr, 25 Kr, and 30 Kr from the source of Co^{60} at the Institute of Food and Radiation Biology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh. Screening of the mutant lines was maintained on the basis of survivability and maturity for flowering. Crossing was done in a half-diallel fashion to obtain F_1 populations among Bari Masur-4 as parent 1 (P_1), Bari Masur-3 (20 Kr) as parent 2 (P_2), Bari Masur-2 (20 Kr) as parent 3 (P_3), Bari Masur-4 (30 Kr) as parent 4 (P_4), Bari Masur-4 (20 Kr) as parent 5 (P_5) and ILL 6002 (20 Kr) as parent 6 (P_6).

Field trial of F_1 and F_2 generations and parents was conducted under randomized complete block design with two replications having 48 plots. The plot size was about 50 cm × 30 cm with two rows and each row had three hills. In each hill, one plant was maintained. The gap between plants in the row was 25 cm, between rows was 30 cm, between plots was 40 cm, and between replications was 100 cm. After completing seed sowing with the experimental seeds, gaps were filled with Bari Masur-3 (20 Kr). All necessary cultural practices were done for the healthy experimental plants. In these practices, weeding, watering, and applying of fungicides and insecticides were done properly.

Collection of data

Twelve quantitative traits viz. days to flower (DF), plant height at first flower (PHFF), number of primary branches at first flower (NPBFF), number of secondary branches at first flower (NSBFF), canopy area at maximum flower (CAMF), number of secondary branches at maximum flower (NSBMF), number of pods per plant (NPdPP), pod weight per plant (PdWPP), number of seeds per plant (NSPP), seed weight per plant (SWPP), individual plant weight (IPlW), and root weight (RW) were recorded.

Techniques of the analysis of data

The collected data were analyzed following the biometrical technique as suggested by Mather (1949) based on the mathematical model of Fisher *et al*. (1932) and those of Cavalli (1952) and Mather and Jinks (1982). The methods in details are given below:

i) Estimation of mid-parent and high-parent heterosis

For estimation of heterosis for each character, the mean values of the 15 F_1s were compared with the better-parent for heterobeltiosis (BPH) and with mid-parent for heterosis over mid-parent value (MPH). Percent of MPH and BPH was calculated as:

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

Standard error (SE) for heterosis was calculated. Significance tests for heterosis were done by using pooled error from the analysis of variance of F_1 and parental populations.

SE of MPH = $\sqrt{(¼\ VP_1 + ¼VP_2 + VF_1) / N}$

N is the total number of populations for each generation. VP_1, VP_2, and VF_1 indicate the variance of P_1, P_2, and F_1 generations, respectively.

t = Estimated value of MPH / SE of MPH

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

SE of BPH = $\sqrt{(VF1 + VBP)} / N$

N is the total number of population of each F_1 and BP generations.

t = Estimated value of BPH / SE of BPH

ii) Test of potenc**e**

It was calculated by the following formula:

Potence = $\overline{F}_1 - \overline{F}_2$ with Standard error = $\sqrt{VF_1+VF_2}$ /N

Test of significance of potence was done by the 't' test as:

t = Estimated value of $\overline{F}_1 - \overline{F}_2$ / Standard error of the potence

Non-significance of this test will indicate no potence and hence no dominance genetic effect. Therefore, there is no obligation to include the parameter 'h' in the additive-dominance model for calculating chi-square (χ^2) value.

iii) Model fitting: Generation mean analysis

Model fitting is a procedure known as the joint scaling test proposed by Cavalli (1952). It consists of estimating parameters, m, [d] and [h] from the means of the available types of generations followed by a comparison of the observed generation means with the expected values derived from the estimates of the three parameters. In this study, the model was fitted consisting of three parameters viz. m, [d] and [h] by weighted least squares techniques and testing its goodness of fit using χ^2 for 4 – 3 =1 df (df = number of generations – number of parameters) from observed and expected values. In case of absence of potence, the 2-parameter model consisting m and [d] parameters was considered. The three-parameter model is as follows:

Generation	Mean	Weight (W_i) =1/V_{x^-}	Coefficients of parameters		
			M	[d]	[h]
P_1			1	1	0
P_2			1	-1	0
F_1			1	0	1
F_2			1	0	½

Here, $V_{\bar{x}}$ is the variance of the mean, 'm' measures mean, [d] measures the additive gene effects and [h] measures the dominance gene effects.

If the χ^2 value is significant, it indicates that the additive-dominance model is inadequate and the additive-dominance model is biased to an unknown extent. Therefore, further analysis is required in two lines as:

(a) Model must be extended by using more generations to include non-allelic interactions, or

(b) Alternatively, a scale must be sought on which the simple model is adequate.

Results

Estimates of heterosis over mid-parent and better-parent

The estimation of percent heterosis observed in the F_1 generations over the mid-parent and the better-parent for different characters are presented in Tables 1 and 2, respectively. In this study, all the characters and crosses showed non-significant mid-parent and better-parent heterosis except cross $P_5 \times P_6$. This cross showed significant mid-parent and better-parent heterosis for all the characters under studied. The values of 41.22 and 24.72 recorded as the highest significant mid-parent and better-parent heterosis, respectively for NSPP.

Test of potence

For all the characters and crosses the potence values were put in Table 3. This table revealed that in maximum cases the values of potence was non-significant. The non-significant potence indicates absence of dominance in the inherited traits. Potence noted non-significant in all the crosses for DF except crosses $P_1 \times P_3$, $P_3 \times P_4$, and $P_4 \times P_5$. Crosses $P_1 \times P_6$, $P_2 \times P_6$, $P_3 \times P_6$, and $P_5 \times P_6$ showed significant potence for PHFF. Table 3 revealed that potence was significant only in one cross viz. $P_1 \times P_3$ for NSBFF, $P_4 \times P_5$ for NPdPP, and $P_1 \times P_6$ both for PdWPP and SWPP, and $P_4 \times P_5$ for RW. Two crosses showed significant potence for different traits such as, $P_2 \times P_5$ and $P_3 \times P_5$ for NPBFF, $P_2 \times P_6$ and $P_3 \times P_6$ for CAMF, $P_2 \times P_5$ and $P_3 \times P_4$ for NSBMF, and $P_1 \times P_6$ and $P_4 \times P_5$ both for NSPP and IPlW.

Model fitting: Generation mean analysis

Through joint scaling test, the adequacy of additive-dominance model can be observed. The values of $\hat{m}$, [d], and [h] of different characters and crosses were shown in term of the three-parameters model in Table 3. The estimated χ^2 values of the joint scaling test (Cavalli 1952) with [h] and without [h] parameters with 1 and 2 degrees of freedom, respectively are shown in Table 3 for different characters and crosses.

The mean value of the parameter $\hat{m}$ found to be significant for all of the characters in all the crosses in this investigation indicating that characters are quantitative in nature.

For the trait DF, χ^2 value was found to be significant in the crosses $P_1 \times P_3$, $P_2 \times P_5$, $P_3 \times P_4$, $P_3 \times P_5$, $P_4 \times P_5$, and $P_4 \times P_6$. Significant χ^2 value indicated the presence of the non-allelic interaction. Additive component [d] was significant for $P_1 \times P_4$ and $P_3 \times P_4$ crosses indicating that additive gene played an important role in these crosses for this trait. Dominance component [h] was significant for $P_4 \times P_5$ indicating dominant gene played an important role in this cross for controlling the trait. In case of PHFF, estimated χ^2 found to be non-significant in all combinations except crosses $P_1 \times P_6$, $P_2 \times P_6$, $P_3 \times P_6$, and $P_5 \times P_6$. [d] was significant for $P_1 \times P_2$, $P_1 \times P_3$, $P_2 \times P_4$, $P_2 \times P_5$, $P_2 \times P_6$, $P_3 \times P_5$, and $P_3 \times P_6$ and [h] was significant only for $P_1 \times P_6$. For NPBFF, joint scaling test (χ^2 test) noted

Table 1. Percent heterosis over mid-parent of different yield and contributing characters of several crosses in lentil

	Crosses														
Characters	$P_1{\times}P_2$	$P_1{\times}P_3$	$P_1{\times}P_4$	$P_1{\times}P_5$	$P_1{\times}P_6$	$P_2{\times}P_3$	$P_2{\times}P_4$	$P_2{\times}P_5$	$P_2{\times}P_6$	$P_3{\times}P_4$	$P_3{\times}P_5$	$P_3{\times}P_6$	$P_4{\times}P_5$	$P_4{\times}P_6$	$P_5{\times}P_6$
DF	0.84	-4.09	-0.36	-0.75	3.62	-2.29	-6.24	-0.37	-2.49	-1.48	6.81	-4.29	0.86	0.62	0.813**
PHFF	4.72	2.78	6.17	6.94	1.69	-1.74	-5.23	6.49	-5.28	-0.01	-9.92	1.70	8.94	-1.79	6.36**
NPBFF	14.73	-6.45	18.90	8.10	-2.74	-9.34	-3.64	18.68	3.18	4.11	19.35	-6.38	1.92	34.16	10.641**
NSBFF	53.84	-9.15	2.28	10.92	-14.77	-26.25	-30.71	20.76	-4.70	-13.28	-27.63	-10.32	21.54	10.02	19.68**
CAMF	30.08	38.82	6.00	12.54	8.36	-21.22	-19.18	-6.22	-1.01	-0.24	-24.00	11.57	24.94	-36.72	24.37**
NSBMF	48.95	73.77	22.19	17.62	-12.03	-11.06	13.81	34.54	13.89	-0.37	-17.10	-5.39	1.57	4.87	12.28**
NPdPP	51.41	64.45	40.23	13.82	8.28	-17.00	10.58	-7.14	13.26	9.45	-13.77	-1.25	14.63	16.92	24.76**
PdWPP	80.77	55.19	-13.13	-7.67	17.28	-18.04	-3.56	-20.14	-1.27	-2.55	-22.50	-4.46	6.08	-35.63	16.92**
NSPP	23.84	35.61	26.39	27.06	27.26	-19.68	-2.50	-13.35	0.11	11.91	-21.57	-7.88	28.86	-3.46	41.22**
SWPP	81.27	43.51	-22.59	-15.47	8.30	-22.16	-5.98	-19.64	-5.03	2.70	-21.51	-10.68	17.31	-46.48	23.41**
IPlW	67.61	62.92	59.62	21.12	11.91	-23.86	46.68	11.93	15.42	-3.30	-23.97	5.19	7.77	-9.65	30.96**
RW	127.31	39.00	-13.54	28.14	73.01	-10.65	0.81	5.82	25.90	-12.15	-23.81	-6.31	0.83	-34.50	-5.76077**

**significant at 1% probability level; DF: days to flower; PHFF: plant height at first flower; NPBFF: number of primary branches at first flower; NSBFF: number of secondary branches at first flower; CAMF: canopy area at maximum flower; NSBMF: number of secondary branches at maximum flower; NPdPP: number of pods per plant; PdWPP: pod weight per plant; NSPP: number of seeds per plant; SWPP: seed weight per plant; IPlW: individual plant weight; RW: root weight

non-significant in all the crosses except $P_2{\times}P_5$, $P_3{\times}P_4$, and $P_4{\times}P_5$. At the same time [d] was recorded as non-significant in all the crosses for this trait. Regarding NSBFF, χ^2 found to be non-significant in all the crosses except $P_1{\times}P_3$, $P_3{\times}P_4$, and $P_4{\times}P_5$. [d] was significant for $P_1{\times}P_4$ and $P_4{\times}P_6$ combinations. In case of CAMF, χ^2 showed non-significant values for all of the character except in crosses $P_2{\times}P_6$ and $P_3{\times}P_6$. [d] was significant for $P_1{\times}P_2$, $P_1{\times}P_3$, $P_3{\times}P_5$, and $P_3{\times}P_6$. For trait NSBMF, χ^2 value was significant in three cases viz. $P_2{\times}P_5$, $P_3{\times}P_4$, and $P_4{\times}P_5$. The rest of the combinations showed non-significant χ^2 values. Only $P_1{\times}P_3$ showed significant additive value. In case of NPdPP, χ^2 value found to be non-significant for all crosses except $P_1{\times}P_4$ and $P_4{\times}P_5$. Item [d] was non-significant for all crosses and [h] was significant only for $P_4{\times}P_5$ for this trait. For character PdWPP, χ^2 value found to be non-significant for all of the crosses except $P_4{\times}P_5$. Additive component [d] noted significant for $P_1{\times}P_4$, $P_4{\times}P_5$, and $P_4{\times}P_6$ whereas dominant component [h] was recorded significant only for $P_1{\times}P_6$. Regarding NSPP, χ^2 value was non-significant in all of the crosses except $P_1{\times}P_6$ and $P_4{\times}P_5$. [d] showed non-significant values for all of the crosses and [h] was significant for $P_1{\times}P_6$ and $P_4{\times}P_5$. None of the crosses showed significant χ^2 values and [d] noted significant only in cross $P_4{\times}P_6$ for SWPP. For IPlW, χ^2 value was significant for $P_1{\times}P_6$ and $P_4{\times}P_5$. [d] was significant for $P_1{\times}P_2$, $P_1{\times}P_3$, and $P_3{\times}P_6$, and [h] was significant for $P_1{\times}P_6$ and $P_4{\times}P_5$. In case of RW, χ^2 value was non-significant for all of the crosses except $P_4{\times}P_5$ and [d] was significant for

Table 2. Percent heterosis over better-parent of different yield and yield contributing characters of different crosses in lentil

	Crosses														
Characters	$P_1 \times P_2$	$P_1 \times P_3$	$P_1 \times P_4$	$P_1 \times P_5$	$P_1 \times P_6$	$P_2 \times P_3$	$P_2 \times P_4$	$P_2 \times P_5$	$P_2 \times P_6$	$P_3 \times P_4$	$P_3 \times P_5$	$P_3 \times P_6$	$P_4 \times P_5$	$P_4 \times P_6$	$P_5 \times P_6$
DF	-1.03	-6.19	-4.88	-2.22	3.59	-6.16	-8.85	-0.75	-4.33	-7.91	2.96	-6.35	-2.31	-3.97	-0.71**
PHFF	-9.89	-9.54	0.72	3.84	-2.52	-4.28	-14.54	-6.01	-15.41	-7.64	-18.61	-7.00	6.35	-2.86	4.95**
NPBFF	12.26	-6.45	16.67	5.06	-13.98	-11.29	-3.91	16.12	15.80	2.15	19.35	-17.21	7.18	20.67	-2.15**
NSBFF	38.16	-25.43	-19. 90	-4.69	-18.78	-33.41	-40.71	14.85	-10.47	-18.37	-31.50	-23.41	8.67	-10.61	7.28**
CAMF	-6.28	1.73	-14.64	-0.77	6.55	-23.30	-30.40	-26.02	-27.92	-12.08	-38.82	-17.34	12.44	-48.37	11.30**
NSBMF	41.50	56.39	11.08	-0.08	-12.85	-16.00	8.64	19.51	7.25	-1.48	-22.33	-15.56	-5.83	-5.45	-5.34**
NPdPP	30.07	39.33	20.16	-5.03	5.73	-18.37	10.24	-10.34	-4.62	7.98	-15.37	-17.95	11.02	-1.78	2.13**
PdWPP	47.13	31.02	-32.79	-23.74	11.59	-21.66	-9.72	-21.62	-22.65	-12.53	-24.56	-22.53	-2.41	-51.91	-7.13**
NSPP	3.63	10.47	8.29	15.10	23.70	-22.32	-5.23	-20.72	-18.12	5.31	-30.38	-26.57	21.06	-19.21	24.72**
SWPP	47.18	21.40	-38.01	-27.18	0.29	-25.99	-7.67	-25.14	-27.28	-4.01	-23.19	-29.01	7.47	-59.53	-0.29**
IPlW	25.23	19.20	31.93	5.24	7.58	-26.25	28.86	-6.54	-11.36	-17.35	-38.11	-20.99	1.579	-22.84	17.85**
RW	92.50	21.62	-36.44	20.96	51.96	-14.00	-15.42	-5.75	-4.00	-28.53	-29.73	-26.57	-22.88	-55.59	-21.22**

**significant at 1% probability level; DF: days to flower; PHFF: plant height at first flower; NPBFF: number of primary branches at first flower; NSBFF: number of secondary branches at first flower; CAMF: canopy area at maximum flower; NSBMF: number of secondary branches at maximum flower; NPdPP: number of pods per plant; PdWPP: pod weight per plant; NSPP: number of seeds per plant; SWPP: seed weight per plant; IPlW: individual plant weight; RW: root weight

$P_1 \times P_4$, $P_2 \times P_6$, $P_3 \times P_4$, $P_3 \times P_6$, $P_4 \times P_5$, and $P_4 \times P_6$.

Discussion

Heterosis is the amount of which the mean of an F_1 exceeds its parents (Mather and Jinks 1982). Extent and magnitude of heterosis present in hybrids is important for any crop improvement program. The extent of heterosis depends on the magnitude of non-additive gene action and wide genetic diversity among parents (Ram *et al*. 2013). The direct utilization of heterosis in leguminous crops is limited due to their cleistogamous nature of flower (Ghaffar *et al*. 2015). Therefore, information regarding genetic parameters such as heterosis and heterobeltiosis may be useful for selection of superior hybrids. Both mid-parent and better-parent heterosis were found to be non-significant for all the characters in different cross combinations except the cross $P_5 \times P_6$. Positive as well as negative heterosis was found over mid-parent and better-parent for different characters and crosses in the present study. Non-significant high heterotic values were observed in both cases. Trait NSPP showed the highest significant mid-parent and better-parent heterosis in this investigation. Kumar *et al*. (1994) found high heterosis value for yield per plant in lentil. Chauhan and Singh (2000) reported that F_1 plants

Table 3. The estimated values of $\hat{m}$, [d], [h], potence, and χ^2 following three-parameter model of different yield and yield contributing characters of several crosses in lentil

Crosses	$P_1 \times P_2$	$P_1 \times P_3$	$P_1 \times P_4$	$P_1 \times P_5$	$P_1 \times P_6$	$P_2 \times P_3$	$P_2 \times P_4$	$P_2 \times P_5$	$P_2 \times P_6$	$P_3 \times P_4$	$P_3 \times P_5$	$P_3 \times P_6$	$P_4 \times P_5$	$P_4 \times P_6$	$P_5 \times P_6$
DF															
$\hat{m}$	67.23± 0.80*	66.56± 1.25*	68.69± 0.29*	66.78± 0.93*	66.06± 0.67*	65.58± 1.15*	67.85± 0.78*	65.29± 0.90*	67.55± 0.72*	64.37± 1.45*	69.29± 1.11*	63.55± 0.89*	64.75± 1.23*	66.93± 0.74*	67.63± 0.81*
[d]	-1.43± 1.11	0.061± 1.39	-3.15± 1.22*	-1.06± 1.22	-0.17± 0.82	-2.51± 1.51^{NS}	-1.07± 1.48	-0.87± 1.38	-1.70± 0.93	-4.27± 1.80*	-1.38± 1.65	-1.79± 1.11	-1.40± 1.65	-1.80± 1.05	-1.70± 1.02
[h]	.....	-3.86± 2.02	.....	.....	.....	.....	.....	.....	.....	0.18± 2.15	.....	.....	5.71± 1.31*	.....	.....
Potence	-2.95	-5.70*	-0.47	-0.56	1.59	-1.31	-2.58	6.74	-3.37	4.19*	-2.29	-4.65	6.09*	3.83	0.31
χ^2	1.77	7.05**	0.65	0.07	1.25	0.28	3.91	10.23**	3.25	10.79**	9.12*	4.95	21.16**	6.75*	1.47
PHFF															
$\hat{m}$	19.63± 0.45*	19.78± 0.15*	18.13± 0.61*	17.09± 0.54*	16.53± 0.60*	22.34± 0.50*	18.61± 0.70*	19.69± 0. 60*	19.41± 0.73*	20.31± 0.57*	18.92± 0.55*	19.17± 0.59*	17.57± 0.47*	18.14± 0.49*	16.93± 0.91*
[d]	3.13± 0.79*	2.44± 0.66*	1.25± 0.99	0.46± 0.91	0.79± 0.67	0.69± 0.75	3.41± 1.17*	2.89± 1.061*	2.07± 0.79*	1.44± 0.92	2.43± 0.86*	1.78± 0.64*	0.19± 1.40	0.006± 0.93	0.80± 0.98
[h]	.....	.....	.....	.....	1.18± 0.60*	.....	.....	.....	-0.89± 1.27^{NS}	.....	.....	-0.08± 1.06	.....	.....	1.49± 1.51
Potence	0.34	-0.16	0.94	1.91	2.26*	-0.77	1.15	2.97	3.93*	-2.30	-1.14	2.73*	3.29	0.97	3.40*
χ^2	0.18	0.97	0.72	1.39	8.15**	0.24	3.60	2.43	14.96**	3.304	1.50	8.67**	3.88	0.46	4.88*
NPBFF															
$\hat{m}$	7.46± 0.36*	8.25± 0.39*	8.04± 0.50*	6.84± 0.28*	6.48± 0.37*	7.55± 0.15*	7.15± 0.38*	7.15± 0.52*	6.98± 0.23*	6.03± 0.35*	7.29± 0.52*	6.74± 0.37*	5.96± 0.35*	6.95± 0.308*	7.10± 0.38*
[d]	0.14± 0.52	-0.08± 0.60	0.17± 0.75	-0.05± 0.68	0.69± 0.54	0.24± 0.44	0.15± 0.55	-0.01± 0.54	0.65± 0.40	0.95± 0.62	0.20± 0.59	0.90± 0.46	0.51± 0.72	0.82± 0.55	0.97± 0.53
[h]	.....	.....	.....	.....	.....	.....	.....	1.29± 0.98	.....	.....	1.34± 0.95	.....	.....	.....	.....
Potence	0.87	-2.11	1.59	0.75	1.00	-1.00	-0.29	3.05*	-0.56	2.46	2.02*	-0.15	2.96	0.72	1.36
χ^2	0.48	4.16	2.26	2.36	1.83	1.45	0.14	5.83*	1.45	8.858*	3.56	0.48	8.26*	0.80	1.89
NSBFF															
$\hat{m}$	11.31± 0.69*	13.21± 1.34*	12.82± 0.35*	10.32± 0.91*	8.56± 0.85*	13.00± 0.18*	11.87± 0.93*	12.32± 0.95*	11.06± 0.68*	7.54± 0.60*	11.77± 0.76*	11.52± 0.91*	10.26± 0.89*	13.44± 0.96*	11.96± 1.01*
[d]	0.97± 1.33	2.16± 1.41	3.55± 1.65*	1.92± 1.42	0.94± 1.32	1.25± 1.23	1.51± 1.44	0.63± 1.26	0.62± 1.16	-1.41± 1.49	0.69± 1.30	1.78± 1.21	0.45± 1.53	3.00± 1.42*	1.29± 1.23
[h]	.....	-0.55± 2.35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Potence	4.68	-8.43*	0.26	2.66	0.64	-4.62	-2.84	5.45^{S}	-0.38	6.61	-0.55	-0.50	11.16	1.89	3.88
χ^2	3.37	11.46**	0.05	1.26	1.50	1.93	4.32	3.08	0.05	32.49**	2.76	0.89	15.02**	0.38	1.42

								CAMF							
$\hat{m}$	487.07± 64.30*	537.18± 46.79*	399.56± 22.76*	320.89± 42.68*	332.84± 4.98*	659.47± 62.18*	404.32± 48.85*	523.62± 66.45*	326.34± 69.80*	544.03± 32.05*	436.64± 39.51*	428.58± 47.00*	368.95± 31.98*	393.33± 37.18*	360.76± 37.63*
[d]	188.84± 94.78*	173.52± 70.65*	96.41± 78.64	53.00± 68.70	-1.89± 43.86	0.21± 87.04	27.25± 95.61	135.02± 86.06	28.72± 74.94	93.80± 71.75	130.64± 63.26*	132.53± 50.23*	29.70± 69.67	73.58± 51.14	35.85± 46.52
[h]	…..	…..	…..	…..	…..	…..	…..	…..	110.64± 100.01	…..	…..	21.87± 81.83	…..	…..	…..
Potence	75.10	179.30	23.75	132.42	40.08	-159.42	117.76	26.08	258.89*	36.47	10.67	221.62*	234.08	-97.52	197.90
χ^2	0.19	2.11	0.04	1.071	0.38	0.47	4.77	0.078	12.04**	0.41	3.68	9.65**	4.41	1.05	2.65
								NSBMF							
$\hat{m}$	21.02± 1.54*	25.91± 1.61*	20.23± 1.21*	20.45± 1.70*	15.99± 1.09*	22.35± 2.01*	20.02± 1.80*	20.42± 2.57*	18.45± 1.25*	19.26± 2.70*	20.95± 1.59*	20.61± 1.14*	16.26± 1.22*	20.08± 1.18*	22.12± 1.77*
[d]	0.94± 2.38	5.28± 2.68*	2.06± 2.70	3.54± 2.73	-0.47± 2.04	3.28± 2.66	0.74± 2.68	2.23± 2.72	0.99± 2.02	2.73± 3.04	0.83± 3.03	3.78± 2.22	1.92± 3.08	2.21± 2.25	4.17± 2.34
[h]	…..	…..	…..	…..	…..	…..	…..	0.89± 5.61	…..	-7.64± 5.13	…..	…..	…..	…..	…..
Potence	6.17	14.09	5.46	8.46	0.88	-1.98	6.00	16.49*	5.50	11.75*	0.98	-2.00	12.14	0.77	5.27
χ^2	3.24	3.46	0.84	2.04	1.22	0.54	1.11	7.23**	2.63	14.54**	4.56	1.13	9.38**	0.08	1.13
								NPdPP							
$\hat{m}$	158.54± 17.39*	187.01± 18.57*	183.13± 13.42*	137.99± 15.68*	110.88± 9.91*	173.12± 12.10*	164.65± 18.95*	164.46± 19.75*	144.36± 13.20*	151.23± 15.17*	154.74± 18.38*	148.23± 12.55*	110.23± 20.49*	171.39± 14.00*	161.85± 19.44*
[d]	25.02± 24.21	32.54± 24.37	27.07± 24.07	26.28± 26.59	6.41± 20.02	5.22± 25.34	0.61± 25.05	3.77± 27.83	19.91± 20.88	4.14± 25.21	-4.11± 27.97	24.62± 20.95	-8.24± 27.70	29.38± 20.85^{NS}	31.07± 23.73
[h]	…..	…..	…..	…..	…..	…..	…..	…..	…..	…..	…..	…..	79.00 ±26.81*	…..	…..
Potence	16.19	53.30	68.23	54.46	34.48	-34.73	41.84	16.21	28.07	64.65	32.63	-11.37	85.70*	-28.50	52.73
χ^2	0.55	5.43	6.45*	1.65	2.67	0.34	0.38	0.51	0.78	3.03	1.95	0.26	12.63**	2.19	0.88
								PdWPP							
$\hat{m}$	4.378± 0.70*	4.97± 0.57*	4.20± 0.23*	3.42± 0.51*	2.22± 0.57*	4.74± 0.19*	4.33± 0.53*	4.40± 0.67*	3.63± 0.45*	4.38± 0.42*	3.904± 0.55*	3.62± 0.417*	3.81± 0.37*	4.23± 0.38*	4.07± 0.59*
[d]	0.99± 0.96^{S}	0.45± 0.81	1.29± 0.48*	0.75± 0.85	-0.34± 0.72	0.33± 0.87	1.02± 0.63	0.10± 0.94	0.71± 0.76	0.95± 0.52	0.06± 0.80	0.59± 0.66^{S}	1.36± 0.52*	1.25± 0.45*	0.82± 0.71
[h]	…..	…..	…..	…..	1.25± 0.58*	…..	…..	…..	…..	…..	…..	…..	…..	…..	…..
Potence	1.37	0.65	-0.67	0.99	1.25*	-1.08	1.94	-0.15	0.87	1.52	0.57	-0.58	2.50	-1.09	1.37
χ^2	0.64	4.58	1.79	1.00	3.53	0.39	2.95	0.34	1.00^{S}	2.70	1.08	0.37	9.16*	0.85	0.69

NSPP															
m̂	196.42± 25.60*	245.81± 20.87*	233.93± 0.07*	165.23± 21.14*	108.31± 24.23*	236.56± 4.81*	210.69± 27.15*	188.71± 25.36*	176.22± 18.92*	200.77± 21.77*	188.38± 23.60*	180.59± 17.76*	139.61± 25.41*	201.89± 19.70*	190.23± 24.22*
[d]	38.11± 38.39	43.02± 35.91	25.72± 33.55	18.64± 33.52	14.05± 31.10	4.10± 38.70	3.36± 36.47	14.00± 36.28	29.06± 32.97	7.551± 34.01	20.55± 33.93	35.53± 31.10	12.68± 31.80	31.95± 29.35	19.02± 29.35
[h]	…..	…..	…..	…..	81.00± 25.28*	…..	…..	…..	…..	…..	…..	…..	93.59± 33.98*	…..	…..
Potence	-17.39	33.45	48.87	85.00	75.15*	-60.53	14.15	-9.14	29.93	81.71	15.20	-13.52	112.63*	-45.82	87.41
χ^2	0.09	3.32	.10	1.82	5.48*	0.65	0.23	0.60	0.76	2.02	1.12	0.50	10.97**	1.15	2.04
SWPP															
m̂	3.17± 0.55*	3.591438± 0.425603*	2.87± 0.13*	2.28± 0.38*	1.49± 0.43*	3.41± 0.11*	2.86± 0.39*	3.08± 0.52*	2.55± 0.35*	3.042± 0.34*	2.73± 0.43*	2.49± 0.32*	2.56± 0.30*	2.82± 0.30*	2.79± 0.46*
[d]	0.73± 0.76	0.324315± 0.639129^{NS}	0.76± 0.42	0.37± 0.66	-0.21± 0.56	0.27± 0.69	0.60± 0.52	0.27± 0.74	0.55± 0.60	0.46± 0.44	0.10± 0.63	0.44± 0.53	0.80± 0.45	0.78± 0.39*	0.48± 0.55
[h]	…..	…..	…..	…..	0.65± 0.54	…..	…..	…..	…..	…..	…..	…..	…..	…..	…..
Potence	1.07	-0.052	-0.85	0.36	0.83*	-0.97	1.22	-0.26	0.56	1.10	0.23	-0.69	1.92	-1.19	0.94
χ^2	0.64	3.61	4.98	0.50	3.38	0.73	2.70	0.18	0.81	1.61	0.48	0.81	5.60	1.72	0.83
IPlW															
m̂	2.85± 0.34*	3.51± 0.36*	2.40± 0.26*	2.03± 0.25*	1.36± 0.27*	3.92± 0.40*	2.39± 0.27*	3.15± 0.38*	2.60± 0.26*	2.95± 0.30*	2.89± 0.28*	2.94± 0.25*	1.73± 0.31*	2.52± 0.22*	2.42± 0.29*
[d]	1.32± 0.48*	1.41± 0.47*	0. 50± 0.43	0.33± 0.42	0.33± 0.34	0.40± .54	0.23± 0.49	0.62± 0.48	0.68± 0.38	0.70± 0.48	0.86± 0.47	1.05± 0.37*	0.13± 0.42	0.45± 0.33	0.31± 0.34
[h]	…..	…..	…..	…..	0.73± 0.32*	…..	…..	…..	…..	…..	…..	…..	1.14± 0.33*	…..	…..
Potence	1.09	1.77	1.76	1.023	0.84*	-1.00	3.36	0.78	1.29	1.17^{NS}	0.02^{S}	0.81	1.11*	-0.38	1.14
χ^2	0.86	1.87	1.12	1.79	6.98**	0.91	5.86	0.33	4.00	5.38	2.81	2.04	10.53**	0.49	1.73
RW															
m̂	0.18± 0.02*	0.18± 0.02*	0.20± 0.01*	0.14± 0.02*	0.13± 0.02*	0.19± 0.01*	0.20± 0.02*	0.18± 0.02*	0.16± 0.01*	0.14± 0.02*	0.14± 0.02*	0.17± 0.02*	0.17± 0.02*	0.17± 0.01*	0.14± 0.02*
[d]	0.03± 0.03	0.04± 0.05	0.06± 0.03*	0.007± 0.03	0.02± 0.02	0.008± 0.04	0.04± 0.02	0.02± 0.02	0.05± 0.02*	0.13± 0.03*	-0.01± 0.04	0.07± 0.032*	0.07± 0.02*	0.08± 0.02*	0.03± 0.02
[h]	…..	…..	…..	…..	…..	…..	…..	…..	…..	…..	…..	…..	0.04± 0.03	…..	…..
Potence	0.14	0.08	-0.03	0.09	0.08	-0.02	0.10	0.05	0.03	0.09	-0.003	-0.07	0.09*	-0.05	0.04
χ^2	2.18	2.10	0.77	1.17	1.11	0.084	4.68	1.71	1.0	2.27	0.09	2.30	10.69**	2.69	1.54

*,**significant at 5% and 1% probability level, respectively; DF: days to flower; PHFF: plant height at first flower; NPBFF: number of primary branches at first flower; NSBFF: number of secondary branches at first flower; CAMF: canopy area at maximum flower; NSBMF: number of secondary branches at maximum flower; NPdPP: number of pods per plant; PdWPP: pod weight per plant; NSPP: number of seeds per plant; SWPP: seed weight per plant; IPlW: individual plant weight; RW: root weight

exhibiting heterosis for seed yield also showed high heterotic response for major yield attributes in lentil. Rathi and Kumar (2001) found that heterosis of yield had positive association with vigor's of its component characters like test weight and pods per clusters in lentil. Singh and Singh (2006) found moderate value of heterosis for seed yield in lentil. They observed that high heterosis was attributed due to luxuriant plant growth coupled with high frequency of pods seed. Milan *et al*. (2010) also observed that yield per plant showed high heterosis value over better-parent in lentil. The presence of heterosis in food legumes for grain yield and its components have been reported by several workers viz. Arora and Pandey (1987), Shinde and Deshmukh (1989), Patil *et al*. (1998), Gupta *et al*. (2003), Hedge *et al*. (2007), and Adeyanju (2009). Zubair *et al*. (2010) found greater heterotic effects for number of pods per plant, number of grain per pod, and grain yield per plant in some crosses of mungbean. High heterosis was also observed for all studied characters in wheat by Said (2014). Maximum heterosis and heterobeltosis in some characters and crosses in chickpea was observed by Ghaffar *et al*. (2015). Patial *et al*. (2018) recorded significant mid-parent, better-parent, and standard heterosis for seed yield per plant and protein content in some crosses in urdbean. The presence of heterosis can only be utilized in pulse crops for development of high yielding pure line varieties (Singh 1971).

In this investigation, potence was found to be non-significant in maximum cases indicating dominance is absent in this material. Non-significant potence was obtained by Farshadfar *et al*. (2008) in barley, Samad *et al*. (2009), Nahar *et al*. (2010), and Haquq *et al*. (2013) in blackgram and Samad *et al*. (2016) in chickpea.

Among the three parameters, $\hat{m}$ found to be significant in all cases, but [d] and [h] showed significant in few cases. Significant mean values indicating quantitative inheritance of these traits. Giri *et al*. (2020) found significant mean values in his studied materials. Kunkaew *et al*. (2010) found additive, dominance and interaction of both gene effects in Azuki bean. Deshmukh and Gawande (2015) observed that both additive and non-additive gene action contributes significantly in the inheritance of various quantitative characters in chickpea. Uzokwe *et al*. (2017) noted additive, dominance, and epistatic gene effects in soybean. Both additive and non-additive types of gene effects found to be significant in cowpea by Sobda *et al*. (2018).

Joint scaling test of Cavalli (1952) is more effective than any other test in detecting the adequacy of model. It detects information from all the generations available for each cross at a time. The non-significant χ^2 values exhibited the presence of only additive-dominance relationship in the inheritance of the studied characters and crosses in this piece of experiment. Sharmila *et al*. (2007) noted that additive-dominance model was adequate in few cases in sesame. Deb and Khaleque (2009) in chickpea observed the adequacy of the additive-dominance model for NPBFF, PHMF, PWH, PdW/P, and NS/P in cross 1; NPBFF, PWH, and PdW/P in cross 2, and PHMF, PWH, NPd/P, PdW/P, NS/P, and SW/P in cross 3. Simple additive-dominance model was sufficient only for pod length in lentil (Khodambashi *et al*. 2012). The additive-dominance model was found to be adequate for description of variation in generation means for number of nodes per plant, number of effective tillers per plant, grain yield per plant, and biological yield per plant in pearl millet (Jog *et al*. 2016). Adequate additive-dominance model was also reported by Samad *et al*. (2009) and Nahar *et al*. (2010) in blackgram, and Eshghi *et al*. (2010) in barley. On the other hand, in few cases joint scaling test showed significant χ^2 values which indicated failure of additive-dominance model and presence of higher order interactions in the studied characters. Similar result was obtained for different traits in chickpea by Deshmukh and Gawande (2015). Additive-dominance model exhibited lack of good fit for all the studied traits in all the crosses, except days to maturity in cross 2 in sesame by Daba *et al*. (2015). Again, Philanim *et al*. (2019) noted three-parameter model was inadequate in few cases in Indian mustard. In the present work, maximum characters in crosses showed non-significant χ^2 values indicating additive-dominance model is adequate which is helpful to lentil breeders to gain some knowledge about gene action in lentil crops.

Conclusions

Through heterosis study, cross $P_5 \times P_6$ comparatively showed significant high MPH for NSPP, IPlW, NPdPP, CAMF, and SWPP, and high BPH for NSPP and IPlW. So these characters and crosses should be cared in the future breeding experiment. The χ^2 values were non-significant for most of the traits indicating the three-parameter model was adequate for these attributes. Adequate additive-dominance model is able to explain the good relationship among the generations. That means no other disturbing factors like as non-allelic interaction, linkage and, genotype × environment interaction exist in most of the inherited traits except additive and dominant genes. Since maximum characters and crosses of this investigation follow additive-dominance model, therefore this information would be helpful for lentil breeders to improve the lentil crops.

Author Contributions

AC Deb has designed and developed the experiments as well as prepared the manuscript. AR Chowdhury has carried out the experiment and analysis of the collected data.

Conflict of Interest

The authors declare that they have no conflict of interest with any organization in relation to the subject of the manuscript.

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