Estimates of heterosis and potence through model fitting of ten quantitative traits in onion

Anil Chandra Deb[1]* and Rumman Ara[2]

[1]Department of Genetic Engineering and Biotechnology, University of Rajshahi, Rajshahi-6205, Bangladesh

[2]Spices Research Centre, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Dhaka, Bangladesh

*Corresponding Author: anil_deb2001@yahoo.com, debac@ru.ac.bd

Abstract: This investigation was undertaken to measure the heterotic effects and adequacy of the additive-dominance model in onion. Maximum crosses exhibited significant heterosis over mid and better-parents for most of the characters indicating good sign for improvement onion varieties. Potence found to be non-significant in maximum crosses indicating the absence of dominance. Significant and non-significant χ^2 values with [h] and without [h] were noted in different crosses for different characters. In all the crosses for number of leaves except $P_1 \times P_3$ with dominance showed non-significant $\chi2$ values indicated that the model is adequate. Besides, $P_1 \times P_3$ and $P_1 \times P_5$ for bulb weight, $P_2 \times P_5$ for bulb yield/plot with dominance showed non-significant χ^2 values as well as significant potence indicated the adequacy of the model. Again, crosses $P_2 \times P_3$ and $P_3 \times P_4$ without dominance for bulb weight and bulb yield/plot showed the adequacy of the model. A similar trend was recorded for bulb volume in all the crosses except $P_1 \times P_4$ and $P_2 \times P_5$. The adequacy of the model indicated that only additive and dominant genes are responsible for controlling these traits. From this study, it may conclude that crosses $P_1 \times P_3$ $P_1 \times P_5$, $P_2 \times P_5$, $P_3 \times P_4$ and $P_3 \times P_5$ are promising in respect of bulb weight, bulb yield/plot and bulb volume and indicate that they would likely help do successful breeding plan easily for the improvement of potential varieties in onion.

Keywords: Heterosis, Potence, Genetic parameters, Joint scaling test, Onion.

INTRODUCTION

Onion (*Allium cepa* L.) is one of the most important spice crops, and is grown more or less all over the country in the world. The worldwide use of onion is very versatile. It is used as a vegetable as well as spice and is commonly used for salad and culinary purposes for its flavor, aroma and taste in preparation of different dishes. Onion has many medicinal values (Vohra *et al*., 1974). Augusti (1974) reported that regular use of onion by a diabetic patient lowered his insulin dosage considerably. The distinctive characteristics of onion are pungency, which is due to a volatile oil known as *allyl-propyl disulphide* mainly found in the scales of bulb (Yawalkar, 1969). It is one of the few vegetable crops that can be kept for a comparatively long period and can safely withstand the hazards of rough handling including long-distance transport. There is thus a lesser risk of over production in onion than in most other vegetables, which have to be marketed at once after harvest (Pandey & Singh, 1993). The agro-climatic condition of Bangladesh is favourable for production, processing and marketing of onion.

Onion is on the list of 15 most commonly grown vegetables in the world (Best, 2008; Jahromi & Amirizadeh, 2015). Still, now Bangladesh is not sufficient in onion production though per acre yield and production increases in the subsequent year (BBS, 2019). Looking to the importance of this crop greater attention is needed for its improvement. Development of high-yielding varieties through breeding research is therefore given emphasized. Fundamental of any breeding method control of pollination is the key aspect (Brewster, 1994) on which a breeder can exercise his aptitude for the success of pollination. Nevertheless, pollination control in onion is extremely difficult, considering each umbel has several hundred tiny individual perfect flowers. So, it is very important to understand the flowering habits of onion and the inheritance of as many characteristics as possible to be efficient in taking breeding experiments of this crop (Pike, 1986). Insect pollination was the most efficient means of ensuring a seed crop of onion (Jones & Emsweller, 1934). Onion is a cross-pollinating species (75-90%), whereas it has a strong inbreeding depression. Such knowledge leads the plant breeder to develop commercial varieties.

The inheritance studies of quantitative characters have to imply through biometrical genetics by the construction of special models and procedures. Model fitting in biometrical genetics aims to determine the simplest model of gene and environmental interaction that will account for the observed variances. The exploitation of heterosis in the breeding method and development of crop hybrids has made an enormous contribution to the 20th century agriculture, although

the genetic basis of the phenomenon remains unclear (Sinha & Khanna, 1975). Geneticists and Plant Breeders describe heterosis as the manifestation of greater vigour, growth and yield in a hybrid in comparison with parents (Allard, 1960). Today, like many other hybrid crops all over the world, a lot of hybrid varieties in horticultural crops like tomato, capsicum, eggplant, watermelon, cabbage, radish etc. are frequently grown in large scale. Genetic information of onion is not available, as little or no work on heterosis and potence on the basis on model fitting with respect to higher yield has been done in Bangladesh. Keeping this view in mind, the present study was undertaken to observe the genetic effects of ten bulb yield contributing traits for the improvement of potential onion varieties through the estimation of heterosis, potence, genetic parameters *viz.*, m, [d] and [h] and joint scaling test based on two and three-parameter model.

MATERIALS AND METHODS

Experimental setup

The study was conducted at the central farm of Spices Research Center (SRC), Bangladesh Agricultural Research Institute (BARI), Shibgonj, Bogura, Bangladesh. The location of the experimental site is at 24°θ 51′ N latitude and 89°θ 22′ E longitude at an elevation of about 18m from the average sea level. The experimental field was a high land and non-calcareous grey/ brown flood plain soils. The soil type was sandy to loam. Organic matter of the soil was 1.1 % with a pH value of 6.8.

The four released varieties and one promising line of onion from SRC, BARI, Bogura, Bangladesh were used in the present experiment. BARI Piaz-1(P_1), BARI Piaz-4 (P_4) and ON 0256 (P_5) are winter varieties and promising line, respectively, originated and collected from Bangladesh and BARI Piaz-2(P_2) and BARI Piaz-3 (P_3) are summer varieties introduced from India developed by SRC, BARI, Bogura through selection method and adapted to the location. All the varieties and line are open pollinated. These materials were considered due to their different characteristics regarding bulb shape, size, yield and shelf life. A 5×5 diallel cross of the above excluding reciprocals have been done for obtaining F_1 and F_2generations were the materials of this investigation. The experiment was set up in a randomized complete block design with three replications. The size of each plot was 3.0 m × 1.0 m. The space between row and plant was 15 × 10 cm. The treatments were distributed at random within each of the blocks. Careful observation was always paid to the crop. Suitable cultural practices such as weeding, watering and applying fertilizers were done and also for crop protection, fungicides and insecticides etc. were sprayed regularly to obtain healthy plants.

Selfing and crossing

Selfing was done by putting individual bamboo made frames with cotton net (20 meshes) over the plants of each parent as soon as the first flower opened. After anthesis the umbels were rubbed against each other daily for a few days to ensure pollination. This rather inexpensive method of selfing is used when only a small quantity of seeds is needed (Jones & Mann, 1963). For seed production of F_2 generation and parents, 20 × 20 cm row and plant spacing was maintained in 1×1 m sized plot with 25 F_1 plants and individual parent, respectively.

Individual bamboo made frame fitted on each plot where onion bulbs of two parents planted and cotton net (20 meshes) fixed over the frame in each combination of parents in one plot during flowering stage to check cross-pollination with other parents. Five plants of each parent are used for crossing. Flower thinning and emasculation was done prior to anthesis. For a few days in the morning, the male umbel was gently rubbed over the emasculated umbel (female parent) to ensure pollen shedding and cross-pollination. Simultaneously, horseflies (*Tabanus* sp.) were introduced into individual net to encourage pollination between two parents. Introduction of flies in the net was continued up to the formation of seeds. For production of F_1 seeds, two rows per plot having 1.0 m long and 30 cm space between them was used and the plants were spaced 20 cm from each other in the rows. Of the three replications each contained 10 plots with 10 plants in each.

Fly production

In this study, a two parts (lower and upper) wooden box was made for production of flies used in net for pollination. Lower part of the box has a small outlet (door) through which flies can go outside. Poultry extracts with numerous eggs of fly were placed on net of the upper part of the box. After 2-3 days, larvae modified to pupae and deposited in lower part of the box through net. Pupae grew up on rice husk layer and metamorphosed into adult after 10-12 days. Then these flies were ready for pollination after 1-2 days. Adult flies were then introduced in each of the net at three to four day's interval.

Collection of seeds and bulbs

After crossing between two umbels of two parents, seeds of female parents were collected when 10% mature seeds exposed from each umbel. Harvested seeds were dried in the sun, cleaned and put in polythene packet with about 8% moisture. F_1's, F_2's and parental seeds were packed separately and were then kept in the refrigerator. The crop (bulb)

was harvested when the plants showed the sign of maturity by neck fall, foliage senescence and drying out most of the leaves (Pandita, 1994). Harvested bulbs were cured and stored in bamboo rake maintaining individual crossing patterns.

Evaluated traits

Data on ten bulb yield contributing traits such as bulb diameter, bulb length, neck diameter, neck length, plant height, number of leaves, leaf length, bulb weight, bulb yield /plot and bulb volume were taken from 20 randomly selected plants for F_1 and F_2 and 25 for parents. Data on plant height, number of leaves and leaf length were recorded one (01) month before harvesting. After curing the harvested bulbs, rest of the traits were measured on the same day.

Biometrical analysis

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 & Jinks (1971). The methods in details are given below:

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

For estimation of heterosis in each parameter, the mean values of the 10 F_1s have been compared with better-parents (BP) for heterobeltoisis and with mid-parent (MP) for heterosis over mid parent value. Percent of heterosis was calculated as:

$$\text{Heterosis (MP)} = \frac{\overline{F_1} - MP}{MP} \times 100$$

$$\text{Heterosis (BP)} = \frac{\overline{F_1} - BP}{BP} \times 100$$

Standard error for each individual and overall heterosis was calculated. Significance tests for heterosis were done by using pooled error from the analysis of variance of F_1 and parental populations.

$$\text{Mid-parent} = \tfrac{1}{2}(P_1+P_2) \text{ and variance of mid-parent} = \tfrac{1}{4}(VP_1+VP_2)$$

$$\text{Standard error of mean of MP and } F_1 = \sqrt{(\tfrac{1}{4}VP_1 + \tfrac{1}{4}VP_2 + VF_1)/N}$$

VP_1, VP_2 and VF_1 indicate the variance of P_1, P_2 and F_1 generation, respectively.

Here, N = Total number of populations $(P_1+P_2+F_1)$

t = Estimated value of MP heterosis / Standard error of mean

$$\text{Standard of error of mean of BP} = \sqrt{VBP} / N$$

Here, N = Total number of populations (F_1)

t = Estimated value of BP heterosis / standard error of mean of BP

A general specification of heterosis must, therefore, be able to accommodate heterosis both in the positive $(F_1>P_1)$ and in the negative $(F_1<P_2)$ directions. If heterosis is measured on a scale on which an additive-dominance model is adequate, then for positive heterosis, its expected magnitude is given by:

Heterosis = $\overline{F_1} - P_1 = [h] - [d]$ and for heterosis to occur [h] must be positive and greater than [d]. For negative heterosis the comparable expectation is given by:

Heterosis = $\overline{F_1} - P_2 = [h] - (-[d])$ and heterosis will occur only when [h] is negative and greater than [d].

Where, [d] and [h] indicate additive and dominance components of mean. If the additive-dominance model is inadequate, its specification becomes complex.

ii) Test of potence

It could be done by comparing F_1 and F_2 means and calculated by the following formula:

$$\overline{F_1} = m + [h]$$
$$\overline{F_2} = m + \tfrac{1}{2}[h]$$
$$\overline{F_1} - \overline{F_2} = \tfrac{1}{2}[h]$$

$$\text{Test of significance by "t" test (t)} = \frac{\text{Estimated value of } \overline{F_1} - \overline{F_2}}{\text{Standard error of mean}}$$

Non-significance of this test will indicate no difference between F_1 and F_2 and there will be no potence and hence there is no obligation to include the parameter 'h' in the model.

On the other hand, the ratio [h] / [d] measuring overall dominance on the basis of following two points as (i) the genes of like effects are completely associated in the parental strains, i.e. complete association and (ii) that all the increment genes have the same sign, i.e. dominance is unidirectional at all loci. Neither assumption can be true, so it is better to speak as the potence ratio, {[h] / [d] = $[\sum^k h_i / rd \sum^k d_i]$ = potence ratio} measuring the relative potence of the parental gene set (Mather, 1949). Assumptions (i) and (ii) indicate when only one gene is responsible for the difference between the parental strains and hence the potence ratio is identical with the dominance ratio in this limiting case.

iii) Additive-dominance model

Cavalli's (1952) joint scaling test was done following additive-dominance model consisting the parameters of m, [d] and [h].

In the present study, the model was fitted consisting of m, [d] and [h] by weighted least squares techniques and testing its goodness of fit using χ^2 for 1 df (df = number of generations – number of parameters = 4 – 3 = 1) from observed and expected values. The 3-parameter model was considered as follows:

Generation	Mean	Weight (W_i) =1/variance	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

Where, 'm' [d] and [h]measure the mean, additive gene effects and dominance gene effects, respectively which need to be estimated. The expected mean values of all generations were calculated using matrix knowledge as follows:

$$M = J^{-1} S$$

Where, M = estimate of the parameters, J = information matrix, J^{-1} = inverse of the information matrix and is a variance-covariance matrix and S = matrix of scores.

Calculation of score matrix (S) as:

$\sum[\text{Coef. m} \times Y_i \times W_i]$, $\sum[\text{Coef. d} \times Y_i \times W_i]$, $\sum[\text{Coef. h} \times Y_i \times W_i]$

Calculation of information matrix (J) as:

$\sum[\text{Coef. m}^2 \times W_i]$, $\sum[\text{Coef. m} \times \text{Coef. d} \times W_i]$, $\sum[\text{Coef. m} \times \text{Coef. h} \times W_i]$

$\sum[\text{Coef. d}^2 \times W_i]$, $\sum[\text{Coef. d} \times \text{Coef. h} \times W_i]$, $\sum[\text{Coef. h}^2 \times W_i]$

The inverse of the information matrix (J^{-1}) has been done through the adjoint method.

After getting the values of the three parameters, $\hat{m}$, [d]and [h] using matrix the significance of these parameters are tested against their standard errors as:

t = Estimate of the parameter / standard error of the parameter.

Testing the goodness of fit of the 3-parameter model for four generations following two steps are involved:

(a) Computation the expected means of these four families using estimates of m, [d] and [h] in a manner given below:

$$\overline{P}_1 = m + [d], \quad \overline{P}_2 = m - [d], \quad \overline{F}_1 = m + [h] \text{ and } \overline{F}_2 = m + \frac{1}{2} [h]$$

(b) Calculation of the squared deviation of the observed mean from the expected mean for each family and calculation of the χ^2 values as follows:

Generation	Observed (O)	Expected (E)	(O − E)	$(O − E)^2$	Weight	$\chi^2 = (O − E)^2 \times \text{Weight}$
P_1						
P_2						
F_1						
F_2						
					$\sum\chi^2 =$	$(O − E)^2 \times \text{Weight}$

If the χ^2 value is significant, it indicates that the additive-dominance model is inadequate and the estimate of 3-parameter model is biased to an unknown extent by the effects not attributable to the additive and dominant actions of the genes. As the model is inadequate, further analysis is required in two lines as:

(a) Model must be extended to include those components such as non-allelic interactions, which were excluded from the simple model, or

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

RESULTS

Estimation of mid-parent and better-parent heterosis

Heterosis is the amount by which the mean of an F_1 exceeds its parents (Mather & Jink, 1971). The estimation of percent heterosis observed in F_1 generation over mid-parent and better-parent for different characters are presented in table 1 and 2. Heterosis over mid-parent (Table 1) of different crosses for bulb diameter was recorded non-significant in some crosses viz., $P_1 \times P_5$, $P_2 \times P_4$ and $P_3 \times P_4$. The highest percent of heterosis over mid-parent was recorded to be 12.740 in $P_3 \times P_5$ for this character. Out of the ten cross combinations, all hybrids showed significant heterosis over better-parent (Table 2) for bulb diameter. Both negative and positive heterosis over better-parent was recorded and the highest heterobeltotic effect for this character was observed in $P_2 \times P_4$ with 11.890 followed by $P_3 \times P_5$ with 11.590. All the crosses showed highly significant positive heterosis both over mid-parent and better-parent for bulb length. The highest heterosis with 22.826 was recorded in $P_3 \times P_4$ over mid-parent and that of 19.750 was recorded in two crosses, $P_1 \times P_3$ and $P_2 \times P_3$ over better-parent, respectively.

Table 1. Percent heterosis over mid-parent of ten bulb yield contributing traits of different crosses in onion.

Characters	Crosses									
	$P_1 \times P_2$	$P_1 \times P_3$	$P_1 \times P_4$	$P_1 \times P_5$	$P_2 \times P_3$	$P_2 \times P_4$	$P_2 \times P_5$	$P_3 \times P_4$	$P_3 \times P_5$	$P_4 \times P_5$
Bulb diameter	-8.802**	5.290**	-11.890**	0.930[NS]	11.496**	0.007[NS]	10.550**	0.116[NS]	12.740**	-3.200**
Bulb length	12.132**	21.380**	3.920**	10.990**	21.380**	17.790**	16.910**	22.826**	17.630**	12.360**
Neck diameter	10.800**	-98.670**	22.670**	43.860**	26.779**	31.510**	34.290**	16.462**	95.170**	32.680**
Neck length	-11.900**	-13.807**	-3.039**	14.980**	11.520**	-5.180**	-13.770**	-0.920[NS]	-11.200**	-9.020**
Plant height	7.840**	-98.780**	-4.192**	1.080[NS]	6.010**	-8.700**	11.490**	5.656**	8.210**	-15.900**
No. of leaves	6.590**	2.439*	21.827**	12.740**	9.570**	31.080**	21.750**	29.870**	27.160**	19.770**
Leaf length	4.170**	3.619**	1.2845*	-1.430[NS]	3.665**	6.890**	3.770**	7.590**	4.350**	34.010**
Bulb weight	-5.377**	9.190**	-14.20**	-6.680**	3.810**	-5.740**	13.270**	2.480*	23.030**	-5.320**
Bulb yield /plot	8.310**	9.430**	-14.020**	7.870**	2.980**	-5.760**	12.740**	2.820**	23.170**	-7.150**
Bulb volume	5.982[NS]	11.539[NS]	38.365**	53.740**	27.990**	35.480**	38.460**	45.220**	47.330**	18.000[NS]

Note: *and ** indicate significant at 5% and 1% level, respectively and NS indicates non-significant.

Table 2. Percent heterosis over better-parent of ten bulb yield contributing traits of different crosses in onion.

Characters	Crosses									
	$P_1 \times P_2$	$P_1 \times P_3$	$P_1 \times P_4$	$P_1 \times P_5$	$P_2 \times P_3$	$P_2 \times P_4$	$P_2 \times P_5$	$P_3 \times P_4$	$P_3 \times P_5$	$P_4 \times P_5$
Bulb diameter	-14.802**	-9. 916**	-17.340**	2.320**	9.400**	11.890**	5.14**	-10.376**	11.590**	-10.740**
Bulb length	7.078**	19.750**	3.919**	5.570**	19.750**	9.580**	3.78**	12.85**	8.970**	6.780**
Neck diameter	6.030**	-98.640**	5.143**	28.120**	-21.560**	17.140**	21.87**	-0.008[NS]	40.930**	26.990**
Neck length	-22.480**	-26.790**	-15.662**	33.330**	7.140**	-6.310**	24.64**	-3.570**	-19.570**	-19.870**
Plant height	3.840**	-4.690**	-9.773**	6.480**	0.530[NS]	-0.970[NS]	-5.600**	1.260[NS]	1.330[NS]	10.990**
No. of leaves	12.370**	-7.220**	19.990**	3.910**	8.000**	21.250**	5.870**	21.750**	11.960**	11.960**
Leaf length	-1.3393[NS]	2.230*	1.0700[NS]	-6.920**	2.480*	2.900**	-6.420**	2.060*	-4.910**	28.450**
Bulb weight	8.4970**	8.602**	-30.500**	-21.970**	1.360[NS]	-25.330**	-7.480**	17.330**	2.412**	-1.340[NS]
Bulb yield /plot	5.380**	8.600**	-30.280**	22.540**	1.000[NS]	-25.130**	-7.910**	-17.110**	2.170**	-10.440**
Bulb volume	1.980[NS]	9.434[NS]	15.400[NS]	20.200[NS]	25.490[NS]	-0.940[NS]	5.320[NS]	7.550[NS]	22.340[NSS]	11.320[NS]

Note: *and ** indicate significant at 5% and 1% level, respectively and NS indicates non-significant.

For neck diameter, all the crosses except $P_1 \times P_3$ showed positive significant heterosis over mid-parent. Out of ten cross combinations, seven F_1s showed positive significant heterosis over better-parents. Two crosses $P_1 \times P_3$ and $P_2 \times P_3$ showed negative but significant values and that of remaining one cross $P_3 \times P_4$ showed negative and non-significant heterosis over better-parent for this character. Most of the crosses showed negative but significant heterosis over mid and better-parent for the character, neck length. Only cross $P_3 \times P_4$ exhibited negative and non-significant heterosis over mid-parent. The highest heterosis over both mid and better-parents were 14.980 and 33.330, respectively recorded for the cross combination of $P_1 \times P_5$ (Table 1 & 2). One non-significant value of 1.080 was estimated in $P_1 \times P_5$ over mid-parent heterosis for plant height. The highest significant positive heterosis percent over mid-parent of 11.490 was recorded in $P_2 \times P_5$. Different crosses for this character exhibited non-significant to significant, negative to positive heterosis over better-parent. The highest percent better-parent heterosis of 10.990 was recorded in $P_4 \times P_5$. All of the cross combinations exhibited significant positive heterosis over mid and better-parent except $P_1 \times P_3$, which estimated

negative but significant heterosis over better-parent of -7.220 for number of leaves. Out of ten cross combinations, all except one F_1 ($P_1 \times P_5$) showed positive significant heterosis over mid-parent for leaf length. On the other hand, eight F_1s showed significant heterosis over better-parent though two F_1s ($P_1 \times P_5$ and $P_2 \times P_5$) showed negative values. The rest of the two F_1s was found to be non-significant.

Regarding mid-parent heterosis, all crosses for bulb weight exhibited significant results. The highest positive significant heterosis of 23.030 was recorded in $P_3 \times P_5$. Positive significant heterosis ranged from 2.412 to 17.330 was recorded in different crosses over better-parent. Four cross combinations had negative significant estimations and the remaining two characters showed non-significant results. It is evident from Table 1 that all F_1s showed significant heterosis over mid-parent though three negative estimations were found in $P_1 \times P_4$, $P_2 \times P_4$ and $P_4 \times P_5$, respectively for bulb yield. The positive heterosis percent was ranged from 2.820 to 23.170 as recorded for this character. All of the cross combinations except $P_2 \times P_3$ showed significant heterosis over better-parent and the highest percent positive heterosis of 22.540 was recorded in $P_1 \times P_5$. All F_1s showed significant positive heterosis over mid-parent though three non-significant estimations were found in $P_1 \times P_2$, $P_1 \times P_3$ and $P_4 \times P_5$, respectively for bulb volume. The highest significant positive heterosis over mid-parent of 53.740 was recorded in $P_1 \times P_5$ while all the crosses showed non-significant heterosis over better-parent for this trait.

Test of potence

The test of potence was done in ten crosses for different bulb yield contributing traits and the values of tests were put in table 3. The non-significant potence shows that there was no dominance. Potence noted non-significant in all the crosses for bulb diameter (Table 3). But $P_1 \times P_2$ and $P_1 \times P_4$ for bulb length, potence was significant and remaining all crosses for this character non-significance potence was calculated. Table 3 revealed that potence was significant in only one cross, $P_2 \times P_5$ for neck diameter and $P_2 \times P_3$ for neck length. However, it was highly significant regarding $P_1 \times P_2$, $P_1 \times P_3$, $P_1 \times P_5$ and $P_3 \times P_5$ for plant height. But in remaining crosses it was non-significant. For number of leaves in all ten crosses, non-significant potence was estimated. But potence was significant in four crosses for leaf length. For bulb weight, significant potence was estimated for the crosses $P_1 \times P_3$, $P_1 \times P_4$, $P_1 \times P_5$ and $P_4 \times P_5$, though rest of the crosses indicated non-significant potence. Significant potence was noted for five crosses in bulb yield/plot, while all the crosses showed non-significant potence for bulb volume except $P_2 \times P_3$.

Table 3. Observed and expected magnitude of heterosis, genetic parameters (m, [d] and [h]) and χ^2 values based 3 and 2-parameter model of ten bulb yield contributing traits of different crosses in onion.

Bulb diameter

Heterosis	$P_1 \times P_2$	$P_1 \times P_3$	$P_1 \times P_4$	$P_1 \times P_5$	$P_2 \times P_3$	$P_2 \times P_4$	$P_2 \times P_5$	$P_3 \times P_4$	$P_3 \times P_5$	$P_4 \times P_5$
Observed F_1- P_1	-0.7063	-0.4733	-0.2700	-0.1500	0.4050	-0.6483	0.2366	-0.6530	0.5300	-0.5900
Expected [h] - [d]	-1.4417	-0.4602	-0.9665	-11.6010	0.3415	-0.6571	0.5284	-0.4090	0.5090	0.9979
m	4.4304	4.4923	5.0688	4.6630	4.1179	4.7862	4.3650	4.8463	4.4931	3.3940
	±0.1079	±0.1055	± 0.1025	±0.1079	±0.1383	±0.1195	±0.1198	±0.1311	±0.1310	±0.1213
[d]	0.3597	0.2478	0.3318	0.0894	0.0704	0.6520	-0.0617	0.3771	0.1340	0.4744
	±0.1125	±0.1083	±0.1115	±0.1116	±0.1416	±0.1238	±0.1257	±0.1406	±0.1580	±0.1250
[h]	-1.0820	-0.2124	-0.6347	-11.5116	0.4119	-0.0051	0.4667	-0.0319	0.6430	1.4723
	±0.1513	±0.1292	±0.1797	±0.0604	±0.2633	±0.1537	±0.1607	±0.1864	±0.1447	±0.1410
Potence [h]/[d]	0.6750^{NS}	1.3068^{NS}	0.7000^{NS}	0.5820^{NS}	1.9499^{NS}	0.9930^{NS}	0.00013^{NS}	0.5643^{NS}	1.0400^{NS}	1.6975^{NS}
$\chi^2_{(1)}$With [h]	55.2853**	3.3691^{NS}	17.5130**	17.0900**	2.5472^{NS}	1.0497^{NS}	5.6211*	2.6619^{NS}	0.6308^{NS}	171.603**
$\chi^2_{(2)}$Without[h]	22.8322**	12.5022**	24.9688**	0.9718^{NS}	7.6229**	1.05233^{NS}	28.1862**	2.52028^{NS}	141.694**	644.361**

Bulb length

	$P_1 \times P_2$	$P_1 \times P_3$	$P_1 \times P_4$	$P_1 \times P_5$	$P_2 \times P_3$	$P_2 \times P_4$	$P_2 \times P_5$	$P_3 \times P_4$	$P_3 \times P_5$	$P_4 \times P_5$
Observed F_1- P_1	0.3900	0.3067	0.2283	-0.3600	0.9900	0.5583	0.2434	0.7483	0.5800	0.4384
Expected [h] - [d]	0.4093	0.3079	0.2179	-0.3701	0.9072	0.5732	0.2482	0.7548	0.5840	0.4422
m	5.2110	5.1828	5.6518	5.9631	4.9910	5.4466	5.7583	5.4584	5.6904	6.1523
	±0.1194	±0.1205	±0.0930	±0.0945	±0.1324	±0.1099	±0.1127	±1.0090	±0.1089	±0.0839
[d]	0.2614	0.3187	0.1613	0.4839	0.0708	0.3927	0.7202	0.4289	0.7890	0.3221
	±0.1223	±0.1224	±0.0943	±0.0974	± 0.1326	±0.1124	±0.1152	±0.1061	±0.1098	±0.0854
[h]	0.6707	0.6266	0.3792	-0.1138	0.9779	0.9659	0.9684	1.1837	1.3730	0.7643
	±0.1419	±0.1565	±0.1468	±0.1486	±0.2489	±0.1625	±0.1578	±0.1389	±0.1508	±0.1414
Potence [h]/[d]	3.0134**	1.4100^{NS}	5.5010**	1.3400^{NS}	1.7200^{NS}	0.9190^{NS}	1.1655^{NS}	0.8300^{NS}	0.4640^{NS}	1.1800^{NS}
$\chi^2_{(1)}$With [h]	3.4618^{NS}	0.2596^{NS}	0.9348^{NS}	1.3338^{NS}	0.9253^{NS}	1.0656^{NS}	0.4558^{NS}	8.7420**	1.3894^{NS}	0.1338^{NS}
$\chi^2_{(2)}$Without[h]	87.9870**	42.2992**	12.7700**	2.3463^{NS}	24.3706**	74.1517**	85.5382**	212.3872**	180.796**	48.6117**

Neck diameter

Observed F_1- P_1	0.0550	0.1966	0.0600	0.3000	0.1966	0.2000	0.2333	-0.0001	0.4366	0.4149
Expected [h] - [d]	0.0545	0.1983	0.0584	0.2969	0.18503	0.07942	0.2271	0.00003	0.3821	0.3159
m	0.8699	0.8342	0.9907	0.9489	0.8873	1.0361	0.9743	0.9857	0.9347	1.1189
	±0.0762	±0.0767	±0.0818	±0.0785	±0.0573	±0.0667	±0.0609	±0.0639	±0.0592	±0.0684
[d]	0.0399	0.0019	0.1690	0.1184	0.0372	0.12689	0.0764	0.16642	0.1169	0.0506
	±0.0780	±0.0766	±0.0844	±0.0802	±0.0577	±0.0676	±0.0624	±0.0654	±0.0600	±0.0698
[h]	0.0944	-0.2002	1.1998	0.4153	0.2222	0.2063	0.3035	10.1665	0.4990	0.3665
	±0.1132	±0.1310	±0.1178	±0.1230	±0.11995	±0.1028	±0.0983	±0.0996	±0.0748	±0.1101
Potence $\frac{[h]}{[d]}$	0.3750[NS]	0.5580[NS]	1.0260[NS]	1.1329[NS]	1.0506[NS]	1.0035[NS]	2.0136*	0.2109[NS]	0.4592[NS]	0.8097[NS]
$\chi^2_{(1)}$With [h]	0.0134[NS]	0.0002[NS]	0.1807[NS]	0.0046[NS]	1.5047[NS]	2.5775[NS]	1.1808[NS]	0.00008[NS]	4.5506*	22.3263**
$\chi^2_{(2)}$Without[h]	1.4411[NS]	3.9455[NS]	11.4344**	21.5136**	4.2688[NS]	18.5154**	18.3591**	0.0006[NS]	168.738	41.8943**

Neck length

Observed F_1- P_1	-0.3867	-0.5000	-0.2767	-0.7667	0.1333	-0.1114	-0.5667	-0.0667	-0.4500	-0.4500
Expected [h] - [d]	-0.3910	-0.4966	-0.2540	-0.3907	0.2502	-0.1006	-0.6285	-0.0335	-0.5231	-0.4824
m	1.4719	1.556	1.5020	0.2605	1.7457	1.7147	1.9679	1.7370	2.0563	1.9931
	±0.0904	±0.0945	±0.1051	±0.0867	±0.0899	±0.0995	±0.0796	±0.0982	±0.0822	±0.0945
[d]	0.2122	0.2822	0.2247	0.9236	-0.0718	0.0166	0.2959	0.0679	0.2267	0.2236
	±0.0946	±0.0971	±0.1087	±0.0890	±0.0908	±0.1036	±0.0821	±0.1060	±0.0850	±0.0982
[h]	-0.1788	-0.2144	-0.0293	1.3143	0.1784	-0.0840	-0.33261	.03466	-0.2964	-0.1988
	±0.1329	±0.1308	±0.1332	±0.1222	±0.1562	±0.1421	±0.1477	±0.1229	±0.1684	±0.1525
Potence $\frac{[h]}{[d]}$	0.7900[NS]	0.7650[NS]	0.9950[NS]	1.1359[NS]	2.4220*	0.6806[NS]	0.0874[NS]	1.9052[NS]	0.4412[NS]	0.7325[NS]
$\chi^2_{(1)}$With [h]	2.0655[NS]	1.7391[NS]	1.2843[NS]	304.279**	7.3430**	0.9422[NS]	4.2219*	3.9594*	1.6103[NS]	1.7289[NS]
$\chi^2_{(2)}$Without[h]	6.1445*	7.9542*	1.4337[NS]	564.220**	9.8327**	1.7752[NS]	12.4784**	4.1934[NS]	6.5199*	5.2772[NS]

Plant height

Observed F_1- P_1	1.6666	-2.2167	-5.0333	-3.500	0.2499	-0.5000	-0.3000	0.6500	0.7166	-9.6700
Expected [h] - [d]	1.3933	-2.4011	-5.0819	-3.6011	-4.4715	-0.5605	-0.4009	0.5779	0.5911	-9.7320
m	43.9385	46.4787	48.6707	49.8705	44.7379	46.8890	48.1149	49.3171	50.5160	37.0024
	±0.3881	±0.4344	±0.4181	±0.4323	±0.3869	±0.3694	±0.3860	±0.4169	±0.4311	±0.3612
[d]	1.7438	0.6516	2.7948	4.0223	2.4302	4.5808	-5.8463	2.1524	3.3921	1.2485
	±0.3900	±0.4355	±0.1761	±0.4346	±0.3879	±0.3701	±0.3869	±0.4186	± 0.4327	±0.4168
[h]	3.1371	-1.7495	-2.2871	0.4212	-2.0413	4.0203	5.4454	2.7303	3.9832	-8.4835
	±0.7060	±0.8723	±0.7502	±0.7807	±0.7330	±0.77997	±0.7512	±0.8270	±0.7927	±0.9428
Potence $\frac{[h]}{[d]}$	5.9173**	2.9992**	0.5446[NS]	4.5557**	1.8643[NS]	1.7416[NS]	0.7878[NS]	1.7000[NS]	3.1690**	0.8289[NS]
$\chi^2_{(1)}$With [h]	27.0348**	8.0604**	1.0484[NS]	3.1631[NS]	58.8008**	1.1746[NS]	3.3587[NS]	1.5944[NS]	5.8290*	1804.878**
$\chi^2_{(2)}$Without[h]	58.6469**	13.0880**	14.7384**	3.6514[NS]	19.9550**	35.7660**	75.5276**	43.119**	42.2707**	1521.258**

Number of leaves

Observed F_1- P_1	-8.8003	0.1670	1.3330	0.3000	0.4667	1.4166	0.4499	1.4500	0.9166	0.9166
Expected [h] - [d]	-0.9329	-0.4375	0.8714	0.0954	0.4722	1.3865	-1.4430	1.4134	0.8670	1.2322
m	5.8906	5.1988	6.4151	6.9493	5.7115	6.1519	6.40794	6.2083	6.7107	6.8531
	±0.5221	±0.5346	±0.5255	±0.5777	±0.4982	±0.5427	±0.5029	±0.5932	±0.5600	±0.5925
[d]	0.3439	0.2600	0.3284	0.6125	0.7380	0.4944	0.9404	0.4122	0.9172	0.5369
	±0.5361	±0.5609	±0.6252	±0.5903	±0.5104	±0.3162	±0.5067	±0.6024	±0.5662	±0.5989
[h]	-0.5890	-0.1775	1.1998	0.7079	0.4722	1.8809	2.3834	1.8255	1.7842	-1.7691
	±0.9322	±0.8228	±1.1480	±1.1060	±0.9988	±1.1250	±1.0569	±1.0322	±1.0156	±0.9358
Potence $\frac{[h]}{[d]}$	1.0420[NS]	1.5400[NS]	1.3000[NS]	1.1257[NS]	0.4874[NS]	0.6162[NS]	0.6378[NS]	0.8763[NS]	1.3851[NS]	0.464[NS]
$\chi^2_{(1)}$With [h]	1.8694[NS]	5.7070*	1.2091[NS]	0.9312[NS]	0.1134[NS]	0.0385[NS]	0.9718[NS]	0.1578[NS]	0.2870[NS]	0.3461[NS]
$\chi^2_{(2)}$Without[h]	2.522[NS]	5.1508[NS]	2.9789[NS]	1.5550[NS]	5.3397[NS]	3.8245[NS]	3.5890[NS]	5.1301[NS]	4.8641[NS]	6.1485*

Leaf length

Observed F_1- P_1	0.5000	-0.8337	-1.0833	4.0033	0.9000	0.1160	-2.8334	0.8333	-2.1667	12.5666
Expected [h] - [d]	0.5136	0.9096	-1.2266	-2.9251	-8.7055	0.0721	-7.5046	0.7038	-2.3659	12.3246
m	36.2010	36.7343	38.8771	40.6890	35.8758	37.9898	39.7093	38.3572	40.0938	42.0749
	± 0.7118	±0.5584	± 0.3910	± 0.5004	± 0.5884	± 0.4304	± 10.5311	± 0.5335	± 0.6163	± 0.4726

[d]	0.8039	0.5422	1.5903	3.3952	-7.4449	2.5032	8.4005	2.1181	3.9430	1.7201
	±0.7157	± 0.5613	±0.3923	±0.5026	±0.7705	±0.4316	±0.5341	±0.5373	±0.6231	±0.4748
[h]	1.3175	1.4818	0.36374	0.4701	-1.2607	2.5753	0.8959	2.8219	1.5771	14.0447
	±1.1243	±0.8327	±0.9105	± 1.0056	±1.0816	±1.0107	±1.0685	±1.0086	±1.0916	±0.8713
Potence $\frac{[h]}{[d]}$	2.6198**	1.8500^{NS}	1.2500^{NS}	1.2249^{NS}	0.9721^{NS}	0.7784^{NS}	2.3665*	0.5568^{NS}	1.9887*	8.0092**
$\chi^2_{(1)}$With [h]	5.9684*	2.7043^{NS}	1.4480^{NS}	1.3609^{NS}	201.9935**	0.1026^{NS}	64.4911**	1.3084^{NS}	2.8355^{NS}	25.2248**
$\chi^2_{(2)}$Without[h]	8.3317*	7.2389*	1.6466^{NS}	1.6394^{NS}	196.1164**	8.1436*	66.1939**	12.425**	6.0525*	402.5493**
Bulb weight										
Observed F_1- P_1	1.6667	2.6667	-11.3667	-10.1334	0.4166	-12.666	-3.4501	-8.6667	1.1166	-4.500
Expected [h] - [d]	1.5366	1.6081	-11.6657	-10.1553	0.3340	-6.3886	-3.53117	-8.8067	1.1989	-4.6169
m	29.9735	30.9070	38.2652	38.4100	29.8826	19.8215	37.6144	40.2577	38.4295	47.8698
	±0.5984	±0.5727	±0.5771	±0.5776	±0.5698	±0.3893	±0.5693	±0.5215	±0.5463	±0.5255
[d]	0.8993	0.2609	7.5883	7.5740	0.7301	5.1687	8.4533	9.6735	7.7256	1.9604
	±0.6078	±0.5797	±0.5828	±0.5829	±0.5731	±0.3919	±0.5762	±0.5261	±0.5505	±0.5295
[h]	2.4359	1.8690	-4.0774	-2.5813	1.0651	-1.2199	4.92209	0.8648	8.92443	-2.6565
	±1.0811	±1.0731	±0.9994	±0.8339	±1.0381	±0.6969	±2.0575	±1.0148	±1.0092	±0.8385
Potence $\frac{[h]}{[d]}$	1.8940^{NS}	2.2958*	2.4430*	1.2868*	1.1307^{NS}	1.2491^{NS}	1.8121^{NS}	1.2636^{NS}	1.6559^{NS}	2.2353**
$\chi^2_{(1)}$With [h]	1.8754^{NS}	3.5525^{NS}	12.0962**	3.6244^{NS}	0.9103^{NS}	2095.316**	0.3531^{NS}	1.1089^{NS}	0.7385^{NS}	8.3671**
$\chi^2_{(2)}$Without[h]	9.5579**	10.3712**	38.0691**	22.7407**	2.4424^{NS}	2025.645**	32.4931**	2.2133^{NS}	112.097**	25.4177**
Bulb yield/plot										
Observed F_1- P_1	0.4167	0.6667	-3.7550	-2.6000	0.0767	-3.1334	-0.9166	-2.1334	0.2517	-0.4183
Expected [h] - [d]	0.5376	1.6135	-3.5618	-2.3091	1.0994	-3.1049	-0.846	-2.0794	0.7619	-1.7074
m	7.4096	7.5686	9.8538	9.9851	7.4400	9.8587	9.4076	9.9547	9.6004	11.6578
	±0.2058	±0.1994	±0.2844	±0.2698	±0.1443	±0.2521	±0.2262	±0.2391	±0.2229	±0.2860
[d]	0.1419	0.9811	2.3053	1.2477	0.1437	2.5353	2.0873	2.3535	1.3387	0.4125
	±0.2144	±0.2053	±0.2943	±0.0390	±0.1475	±0.2538	±0.2346	±0.2455	±0.2414	±0.3108
[h]	0.6795	0.6324	-1.2565	-1.0614	1.2431	-0.5696	1.2413	0.27371	2.2116	-0.6611
	±0.2703	±0.3296	±0.3402	±0.2901	±0.2509	±0.3562	±0.2670	±0.3612	±0.2673	±0.3693
Potence $\frac{[h]}{[d]}$	2.7900**	2.7000**	1.9884*	1.0350^{NS}	1.8924^{NS}	0.8305^{NS}	2.2873*	1.4585^{NS}	2.5281*	1.8754^{NS}
$\chi^2_{(1)}$With [h]	3.9694*	34.1097**	10.5588**	11.2959**	31.8710**	1.3920^{NS}	0.4693^{NS}	1.5855^{NS}	12.6408**	9.0794**
$\chi^2_{(2)}$Without[h]	22.2634**	41.2616**	62.1027**	136.928**	3.6551^{NS}	6.7182*	93.4966**	2.8492^{NS}	280.952**	19.8681**
Bulb volume										
Observed F_1- P_1	0.3500	1.6667	19.0000	20.0000	5.0000	18.6667	16.6667	21.0000	21.333	4.0000
Expected [h] - [d]	0.35787	1.6831	17.3945	0.5180	-26.2676	-0.2820	16.1108	2.6616	12.0018	4.0126
m	17.0043	17.33175	26.7807	25.6716	16.5756	25.9187	23.2298	26.3359	24.3927	33.3613
	±0.5363	±0.5089	±0.4799	±0.6488	±0.5730	±0.5419	±0.6858	±0.6791	±0.6788	±0.6548
[d]	0.6657	0.3336	-6.9041	6.9143	0.3396	9.9806	-5.9942	9.2245	7.2440	1.9876
	±0.5399	±0.5176	±0.4854	±0.6539	±0.5773	±0.5477	±0.7017	± 0.6856	±0.6856	±0.6605
[h]	1.0236	2.0167	10.4904	7.4323	-25.9280	9.1986	10.1166	11.8861	19.2458	6.0002
	±1.0318	±0.9457	±0.0957	±0.8928	±0.3043	±3.0329	±1.1726	± 1.0445	±1.0571	±0.9354
Potence $\frac{[h]}{[d]}$	0.1448^{NS}	0.6468^{NS}	0.20158^{NS}	0.9947^{NS}	2.198*	1.4036^{NS}	1.70299^{NS}	0.8299^{NS}	0.9852^{NS}	1.0039^{NS}
$\chi^2_{(1)}$With [h]	0.0047^{NS}	0.00039^{NS}	1070.502**	67.376**	1492.192**	1.0890^{NS}	370.3110**	2.8055^{NS}	49.8633**	0.0857^{NS}
$\chi^2_{(2)}$Without[h]	0.00008^{NS}	0.000009^{NS}	1060.820**	3.8606^{NS}	0.02485^{NS}	0.02435^{NS}	368.8493**	0.0566^{NS}	0.1085^{NS}	0.0018^{NS}

Note: * and ** indicate significant at 5% and 1% level, respectively and NS indicates non-significant.

Joint scaling test (χ^2-test)

Through the joint scaling test not only the test the of adequacy of the additive-dominance model, but it also provided the best positive estimation of all the parameters required to account for differences among family means when the model was adequate. The values of genetic parameters viz., m, [d] and [h] were calculated in terms of 3-parameter model is shown in Table 3 for different characters in which 'm' measures a constant (base population mean), [d] and [h] estimate the algebraic sum of the additive and dominance gene effects, respectively. Table 3 showed both significant and non-significant m, [d] and [h] values in different crosses of the studied traits.

Depending on potence, the χ^2 test was done to test the goodness of fit of the observed means with that of the expected means based on the 3 and 2-parameter model. The χ^2 values with [h] and without [h] based on 3 and 2-

parameter with 1 and 2 degrees of freedom (df), respectively obtained for different characters in each of the crosses are shown in table 3. For bulb diameter, the χ^2 values with [h] were found to be non-significant in five crosses and χ^2 values without [h] were found to be non-significant in three crosses, viz., $P_1 \times P_5$, $P_2 \times P_4$ and $P_3 \times P_4$. In all of the cross combinations except $P_3 \times P_4$, the χ^2 values with [h] were found to be non-significant for bulb length, whilst χ^2 values without [h] were found to be significant in all crosses except $P_1 \times P_5$. The non-significant χ^2 values indicated an adequacy of the additive-dominance model in this character. The χ^2 values with [h] were found to be non-significant in all crosses except $P_3 \times P_5$ and $P_4 \times P_5$ for neck diameter. But most of the crosses were found to be significant according to the χ^2 values without [h]. Table 3 revealed that for neck length, six cross combinations except $P_1 \times P_5$, $P_2 \times P_3$, $P_2 \times P_5$ and $P_3 \times P_4$ were found to be non-significant when χ^2 tests were done with [h]. On the other hand, six combinations were found to be significant when χ^2 tests were done without [h].

Out of 10 crosses, the χ^2 values with [h] were found to be significant in 5 crosses for plant height. But the all cross combinations exhibited significant χ^2 without [h] values except $P_1 \times P_5$. For number of leaves, χ^2 values with [h] were found to be non-significant in all crosses except cross $P_1 \times P_3$ and without [h] χ^2 values were found to be significant except $P_4 \times P_5$. In case of leaf length, $P_1 \times P_2$, $P_2 \times P_3$, $P_2 \times P_5$ and $P_4 \times P_5$ were found to be significant when tested against χ^2 with [h]. On the other hand, χ^2 values without [h] for $P_1 \times P_4$ and $P_1 \times P_5$ were found to be non-significant for this character and remaining all eight crosses were found to be significant. In case of the cross combinations $P_1 \times P_4$, $P_2 \times P_4$ and $P_4 \times P_5$, χ^2 values with [h] were found to be significant for bulb weight while all the cross combinations except $P_2 \times P_3$ and $P_3 \times P_4$ also showed significant χ^2 without [h] values for this character. In most of the crosses when χ^2 values were tested with [h] and without [h], they showed significant values for bulb yield. Only three crosses exhibited non-significant χ^2 with [h] values and two crosses indicated non-significant χ^2 values without [h]. Table 3 also revealed that five crosses showed significant χ^2 values when tested with [h] and all crosses showed non-significant χ^2 values without [h] except $P_1 \times P_4$ and $P_2 \times P_5$ for bulb volume.

DISCUSSION

The foundation for a more comprehensive understanding of heterosis was laid by Shull 1908 (cited by Sprague, 1983). Shull was more concerned with the genetic basis for his observations. He concluded that a variety was a complex mixture of genotypes. He also demonstrated that when certain lines were combined, F_1 yields exceeded those of the parental varieties. Maximum crosses of the studied traits in this material exhibited significant mid-parent heterosis. Some of the crosses for different traits showed both positive and negative non-significant mid-parent values. Similar result was obtained by Abubakar & Ado (2008) in tropical onion. Joshi & Tandon (1976) found that heterosis to the extent of 72 % as measured from the mid-parent in onion. Hosfield et al. (1977) found 39% heterosis over mid-parent in onion.

Most of the crosses exhibited significant heterosis over better-parent for most of the traits. Some of the non-significant heterotic values over better-parent were negative and others were positive, but non-significant values were not so high in this study, which was not in agreement with the results of Hosfield et al. (1977) in onion. They found non-significant high heterosis percent over better-parent for some characters. Both negative and positive significant heterotic values over better-parent were recorded for different characters in this study. Profound heterotic effect in the desired direction for bulb yield and pungency in onion in different crosses were tested by Madalageri & Bajappa (1986). Pathak et al. (1987) observed positive heterosis in nine onion hybrids over better-parent for total bulb yield. Singh (1995) identified the best performing crosses which were Sel.102-1 × Sel.126, Sel.126 × Punjab selection and Pusa red × Sel.126, in onion, respectively. Abubakar & Ado (2008) also noted positive and negative significant high parent heterosis in their study. Appreciable amount of heterobeltosis and standard heterosis was noticed for all the traits studied by Evoor et al. (2007) in onion and the high-parent heterosis value varied from -76 to 111 percent observed by Farid et al. (2012) in shallot. Cross PR-121 × EG exhibited 81.60% heterobeltiosis and 79.70% standard heterosis and considered as the most promising hybrid, the other promising hybrids for yield were PR-121 × I-33, and PR-121 × Sel.131. PR-121 × EG, PR-121 × Sel.397 and PR-121 × PRO-6 were superior for polar and equatorial diameter of bulb, weight of ten bulbs, neck thickness of bulb and plant (Popat et al., 2020). Heterosis and yielding potential has been used as the basic consideration for breeding of hybrid onion (Aghora & Pathak, 1991; Netrapal & Singh, 1999; Evoor et al., 2007).

In fact, [h] / [d] ratio obtain from generation means is a potence ratio and not the degree of dominance. Only in an exceptional situation of no cancelling effect of genes, or in a limiting case when the difference between the parents for the character concerned is due to one locus only, the potence ratio is identical with the degree of dominance (Singh & Pawar, 2005). In this work, potence was found to be non-significant for most of the crosses in all the characters indicating dominance is absent in this material. This result corroborate with the findings of Singh & Ramanujam (1972)

in coriander, Farshadfar *et al*. (2008) in barley, Samad *et al*. (2009), Nahar *et al*., (2010) and Haque *et al*. (2013) in blackgram and Samad *et al*. (2016) in chickpea.

Joint scaling test of Cavalli (1952) is more effective than any other test in detecting the adequacy of model, since it detects information from all the generations available for each cross at a time. In this piece of an experiment, the non-significant χ2 values exhibited the presence of only additive-dominance relationships that means only additive and dominant genes are responsible for the inheritance of studied characters and crosses. Deb & 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. Besides, Samad *et al*. (2009) and Nahar *et al*. (2010) in blackgram, Eshghi *et al*. (2010) and Farshadfar *et al*. (2008) in barley also got the non-significant χ^2-values for different characters and crosses.

The χ2 values with [h] and without [h] were both significant and non-significant in different crosses for different characters (Table 3). Significant χ^2 test indicated that the additive-dominance model is inadequate to explain the relationship among the generation and hence to know the genetic nature of these traits need to extend the model including epistasis, linkage and G × E interaction parameters either individually or in combination at a time. In this study, all the crosses for number of leaves except $P_1 \times P_3$ showed non-significant χ2 values indicated that the model is adequate. Bal & Singh (1997) found that basic additive-dominancee model was inadequate to explain the variation and suggested the presence of non-allelic interactions in the inheritance of fruit number and fruit weight in chilli. Significant χ^2 values were also noticed by Ray & Islam (2008) in rice, Deb & Khaleque (2009) in chickpea, Nahar *et al*. (2010) in blackgram and Kumar *et al*. (2011) in sweet sorghum for different characters and crosses. Regarding bulb yield, five crosses showed non-significant χ2 values with [h] indicating that these crosses would likely help in doing a successful breeding plan easily for the improvement of potential onion varieties.

CONCLUSION

In the inheritance study through heterosis, it is found that $P_1 \times P_3$, $P_1 \times P_5$, $P_2 \times P_5$, $P_3 \times P_4$ and $P_3 \times P_5$ are the promising crosses in respect of bulb weight, bulb yield/plot and bulb volume. Among them, cross $P_3 \times P_5$ is leading to show the highest heterosis percent over mid-parent for bulb weight, bulb yield/plot and that of second highest for bulb volume. Crosses $P_3 \times P_4$ and $P_1 \times P_5$ showed maximum heterosis over better-parent for bulb weight and bulb yield/plot, respectively. A noticeable significant heterosis over better-parent was also recorded in $P_1 \times P_3$ for bulb weight and bulb yield/plot. Cross $P_1 \times P_5$ exhibited the highest heterosis for bulb volume over mid-parent. On the other hand, the cross combinations of $P_1 \times P_3$ and $P_1 \times P_5$ for bulb weight and $P_2 \times P_5$ for bulb yield/plot showed the adequacy of additive-dominance model as well as they showed significant potence. Nevertheless, crosses $P_3 \times P_4$ and $P_1 \times P_5$ without dominance showed the adequacy of the model as well as the highest better-parent and mid-parent heterosis for bulb weight and bulb volume, respectively. Therefore, considering all the above crosses $P_1 \times P_5$ and $P_3 \times P_5$ may consider as the good breeding material as they showed the highest mid-parent heterosis for bulb volume and bulb yield/plot, respectively and other two crosses $P_1 \times P_3$ and $P_2 \times P_5$ may also be considered in this regard for bulb weight and bulb yield/plot. In addition, $P_3 \times P_4$ may be considered for the same as it showed the highest better-parent heterosis for bulb weight. The χ^2 values were found to be non-significant in maximum cases. Thus it exhibited the presence of only additive-dominance effects and no other disturbing factors like linkage, non-allelic interaction and G × E interaction are associated in the inheritance of these characters and crosses and hence only additive-dominance relationship of these characters and crosses would likely be helpful in doing the successful breeding plan for the development of potential onion lines.

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