DOI : 10.5958/0974-0112.2020.00094.8

Indian J. Hort. 77(4), December 2020: 655-662

Heterosis and combining ability of fruit yield and quality traits in intraspecific hybrids of okra

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ABSTRACT

Estimation of combining ability and magnitude of heterosis in okra for fruit yield and quality traits was conducted at Experimental Farm of Department of Vegetable Science and Floriculture, CSKHPKV Palampur, Himachal Pradesh, by involving 8 parents and 28 cross-combinations obtained from half diallel mating design. The data on fruit yield and quality traits were recorded in the present study. Among visually observed characters, dark green, green and yellowish green fruit colour at immature stage, downy to slightly rough pubescence and five ridges per fruit in all parents and hybrids were recorded. Out of 28 F_1 hybrids, seven crosses *viz*., VRO-4 × HU (40.53%), Tulsi-I × SKBS-11 (33.23%), P-20 × Tulsi-I (32.75%), 9801 × SKBS-11 (22.70%), VRO-4 × PK (21.51%), P-8 × Tulsi-I (20.78%) and PK × SKBS-11 (20.75%) exhibited significantly positive heterosis for fruit yield in okra. The most promising crosses showing significant SCA effects and standard heterosis for fruit yield and quality traits were 'VRO-4 × HU', 'Tulsi-I × SKBS-11' and 'P-20 × Tulsi-I' and appear to be worthy for exploitation of segregation and varietal development.

Key words: *Abelmoschus esculentus*, standard heterosis, combining ability, mucilage, dry matter.

INTRODUCTION

India is the largest producer of okra [*Abelmoschus esculentus* (L.) Moench] in the world with total area of 0.51 million hectares and production 6.09 (62% of the total world production) million tonnes green pods, whereas productivity of the crop is 11.97 metric tonnes/ha (Anonymous, 2). Among the vegetables, contribution of rainy and summer season cultivated crop okra is 5.7 % in area with 3.9 % share in production. It is a member of the Malvaceae family and one of the most important fruit vegetables grown throughout the tropics, sub-tropics and warmer parts of the temperate regions in the world. In India, okra is one of the major summer and rainy season vegetables, grown for its tender green pods. The prominent position of okra among Indian vegetables can be due to its easy cultivation, dependable and regular yield and wider adaptability. It is extensively cultivated throughout India mainly in Indo-Gangetic plains during summer and rainy seasons for its large, slender and immature green fruit. Matured pods and stem containing crude fibres are used in paper industry and purifying sugarcane juice in preparation of jaggary in sugar industry. It occupies good place in kitchen garden having two crops per year along with additional medicinal attributes e.g. anti-ulcer and relief in gastro-intestinal ulcer by neutralizing the digestive acids. Okra is an often-cross pollinated crop as the natural crossing occurs in this crop up to a range of 4-19%, improvement in the past was based on selection in locally adapted populations. During recent past, exploitation of hybrid vigour and selection of parents on the basis of combining ability effects have opened a new line of approach in crop improvement. A large number of okra genotypes have been developed which differ in their yielding potential, adaptability to varying climatic conditions and resistance to Yellow Vein Mosaic Virus. Heterosis and combining ability provides important information for improving desirable characteristics in okra. Diallel analysis is one of the most powerful tool for characterizing the genetic architecture of plant genotypes and selecting the parents with desirable GCA effects and crosses with desirable SCA effects for the exploitation of heterosis. Diallel mating design has been used extensively by several researchers to measure combining ability and heterosis for fruit yield and yield components in okra (Nagesh *et al*., 12; Hadiya *et al*., 8; Chowdhury and Kumar, 5; Kerure *et al.,* 10).

The dry matter and mucilage content are the important traits of consumer preference and processing industry. Okra fruits can be preserved after sun drying and the quantity and quality of finished product depends on the dry matter content of fruit. Its fruits are rich in mineral content and 100g of okra fruit on dry weight basis has 0.7 g of minerals like calcium, magnesium, phosphorus, iron, sodium, potassium, copper, sulphur and iodine. Due to these minerals, okra is good for people suffering

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from leucorrhoea, goiter and inflammation. In spite of immense economic and medicinal importance, biochemical traits are completely ignored while formulating breeding strategy for okra improvement and practically no information is available about the genetic control of these traits. Therefore, the objective of this research was to study the combining ability and heterosis for fruit yield and quality traits in okra through diallel analysis.

MATERIALS AND METHODS

The present investigation was carried out during summer-rainy, 2011-13 at the Vegetable Experimental Farm, CSKHPKV Palampur (H.P.) which is situated at 32°6' N latitude, 76°3' E longitude and 1290.8 m altitude. The location is characterized by humid, sub-temperate climate with an annual rainfall of 2500 mm of which 80 per cent is received during June to September and represents the mid-hill zone of Himachal Pradesh. The average weekly meteorological data recorded at Palampur during the cropping season is given in Fig. 1 (Anonymous, 1).

Eight diverse inbred lines, the breeding lines P-20, 9801, Tulsi-I and SKBS-11, and the cultivars VRO-4, Parbhani Kranti (PK), P-8 and Hisar Unnat (HU) (Table 1) maintained through selfing during summer-rainy, 2011 and then they were crossed in 8 × 8 diallel design without reciprocals during summer-rainy, 2012 to get 28 F_1 crosses. During 2013, the 8 parental lines, 28 F_1 hybrids alongwith standard check "Hybrid Tulsi" were grown in a randomized block design with three replications in row to row and plant to plant spacing of 45 cm and 15 cm, respectively at the Experimental Farm of Department of Vegetable Science and Floriculture, Palampur, Himachal Pradesh. Standard recommended cultural practices were followed during experimentation. Observations were recorded on fruit yield and quality parameters like immature fruit colour, fruit pubescence, ridges per fruit, fruit yield per plant, dry matter (%) and mucilage (%) from ten randomly selected plants in each replication and mean data was used for statistical analysis. SPAR I (developed by the Indian Agricultural Statistics Research Institute, New Delhi, India) software was used for statistical analysis. The analysis of variance (ANOVA) for RBD was estimated crosswise according to Panse and Sukhatme (13) and ANOVA for diallel analysis was done according to Griffing (7). Heterosis over standard check (Hybrid Tulsi) was estimated by following the method of Hayes *et al*. (9) and expressed as;.

$$\text{Standard Heterosis} = \frac{F_1 - \text{Check}}{\text{Check}}$$

Where, F1= mean performance of cross and Check = mean performance of standard variety and significance of heterosis is tested with the help of standard error using 't' test.

Traits *viz*., immature fruit colour, fruit pubescence and ridges per fruit were observed visually and categorized according to Minimal Descriptors for Agri-Horticultural crops (Srivastava *et al*., 16).

Dry matter (%) was estimated as per procedure of Arora *et al*. (3).

$$\text{Dry matter (\%)} = \frac{W_2 - W_1}{W} \times 100$$

where, W_2 = Weight of dried sample + Weight of empty Petri dish (g)
W_1 = Weight of empty Petri dish (g)
W = Weight of sample taken (g)

Mucilage (%) was estimated as per procedure of Woolfe *et al*. (18). 25 g of fresh immature fruit sample was ground in 125 ml of distilled water and kept in flask overnight. It was then filtered and centrifuged at 4000 *g* for 15 minutes and the clear viscous solution decanted. The solution was then heated at 70°C temperature for 5 minutes to inactivate enzymes. The mucilage was precipitated with 3 volumes of ethanol (75 ml) and washed with more ethanol followed by acetone. The cream coloured solid collected on pre-weighed Whatman's No. 1 filter paper was dried under vacuum at 25°C for 12 hours. The mucilage (%) was calculated as per Rao and Sulladamath (15):

Table 1. Okra genotypes used in present investigation and their sources.

S. No.	Genotypes	Source
1.	P-20	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, HP
2.	9801	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, HP
3.	VRO-4	Indian Institute of Vegetable Research, Varanasi, UP
4.	Prabhani Kranti (PK)	Marathwada Agricultural University, Parbhani, Maharashtra
5.	P-8	Punjab Agricultural University, Ludhiana, Punjab
6.	Hissar Unnat (HU)	CCS Haryana Agricultural University, Hissar, Haryana
7.	Tulsi-I	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, HP
8.	SKBS-11	SK University of Agricultural Sciences & Technology, Srinagar, J&K

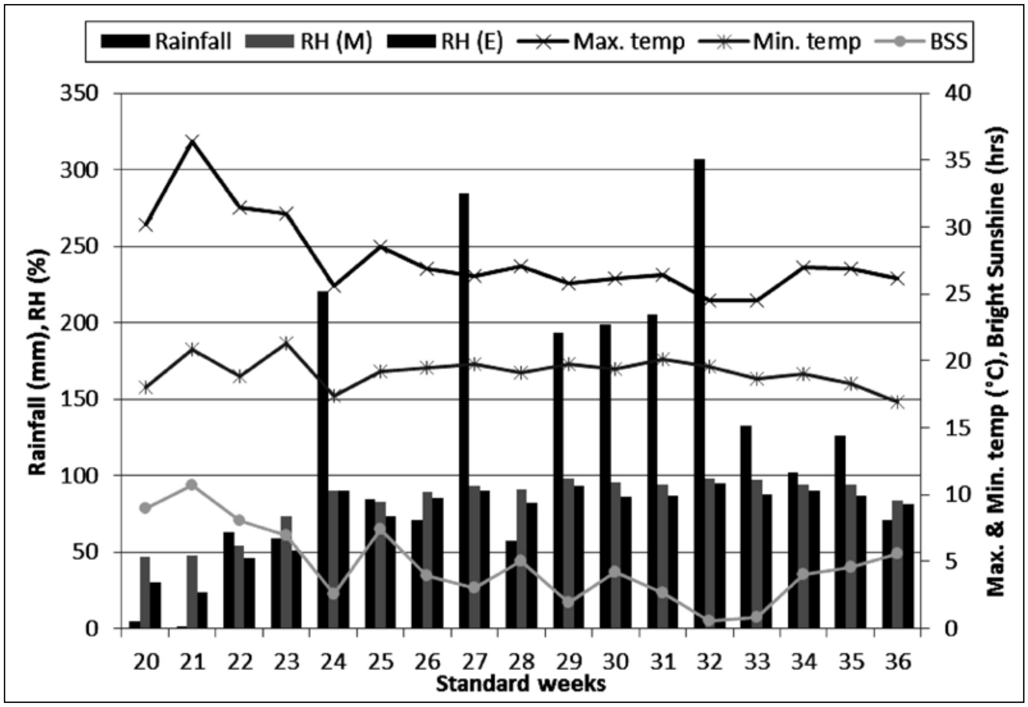

Fig. 1. Mean weekly meteorological data recorded at Palampur (May to September, 2013).

$$\text{Mucilage (\%)} = \frac{W_2 - W_1}{W} \times 100$$

where, W_2 = Weight of filter paper + mucilage solid after drying (g)
W_1 = Weight of filter paper (g)
W = Weight of fruit sample taken (g)

RESULTS AND DISCUSSION

Colour pigments are attractive traits for visualization of diverse okra genotypes in which green colour pod is most preferable for edible purpose. Immature fruits of three colour intensities were observed. Within 8 parental lines, parents VRO-4, PK, P-8, HU, Tulsi-I and SKBS-11 and standard check "Hybrid Tulsi" produced green fruits, whereas parent P-20 and 9801 produced dark green fruits. The colour of okra genotypes expressed dominant genetic effect on their hybrids. Out of 28 hybrids mostly were green except eight 9801 × VRO-4, 9801 × P-8, 9801 × Tulsi-I, 9801 × SKBS-11, VRO-4 × P-8, VRO-4 × Tulsi-I, PK × P-8 and P-8 × HU were yellowish green (Table 2). The dominant characters for female parents of okra were studied by Udengwu (17). In case of fruit pubescence, two types of fruit pubescences *viz*., downy and slightly rough were recorded. Among parents, VRO-4 and SKBS-11 produced fruits with slightly rough pubescence whereas rest of the parents produced fruits with downy pubescence. Among crosses, 9801 × SKBS-11, VRO-4 × P-8, VRO-4 × SKBS-11, PK × P-8, P-8 × HU, P-8 × Tulsi-I, P-8 × SKBS-11 and HU × SKBS-11 produced fruits with slightly rough pubescence while the remaining crosses produced fruits with downy pubescence. No variation was observed for ridges per fruit since all the parents and crosses had five ridges per fruit, which is a desirable quality character.

Fruit colour and fruit texture are the most important quality characters on the basis of which the consumers prefer green to dark green and smooth textured fruits, and these observations often provide preconceived idea about other quality attributes. Fruits of all the parents and crosses showed downy to slightly rough pubescence and had five ridges per fruit. The variation in fruit colour, pubescence and ridges per fruit is a varietal character.

Significant variances due to treatment were obtained for fruit yield per plant and mucilage except dry matter that showed significant deviation (Table 3). Further, treatment variance was partitioned into parent, hybrid and parents vs hybrids. The analysis of variance for parents and hybrids revealed significant differences due to parents, hybrids and parents vs hybrids for fruit yield per plant and mucilage when tested against error, indicating appreciable diversity in the experimental material except dry matter (parents, parents vs hybrids).

The combining ability analysis has been extensively used to identify potential parents either to be used in the development of hybrids or recombinant

Table 2. Variation in visually observed traits among parents and hybrids of okra.

Parents/F_1 hybrids and standard check	Immature fruit colour	Fruit pubescence	Ridges per fruit
P-20	dark green	downy	5
9801	dark green	downy	5
VRO-4	Green	slightly rough	5
PK	Green	downy	5
P-8	Green	downy	5
HU	green	downy	5
Tulsi-I	green	downy	5
SKBS-11	green	slightly rough	5
P-20 × 9801	green	downy	5
P-20 × VRO-4	green	downy	5
P-20 × PK	green	downy	5
P-20 × P-8	green	downy	5
P-20 × HU	green	downy	5
P-20 × Tulsi-I	green	downy	5
P-20 × SKBS-11	green	downy	5
9801 × VRO-4	yellowish green	downy	5
9801 × PK	green	downy	5
9801 × P-8	yellowish green	downy	5
9801 × HU	green	downy	5
9801 × Tulsi-I	yellowish green	downy	5
9801 × SKBS-11	yellowish green	slightly rough	5
VRO-4 × PK	green	downy	5
VRO-4 × P-8	yellowish green	slightly rough	5
VRO-4 × HU	green	downy	5
VRO-4 × Tulsi-I	yellowish green	downy	5
VRO-4 × SKBS-11	green	slightly rough	5
PK × P-8	yellowish green	slightly rough	5
PK × HU	green	downy	5
PK × Tulsi-I	green	downy	5
PK × SKBS-11	green	downy	5
P-8 × HU	yellowish green	slightly rough	5
P-8 × Tulsi-I	green	slightly rough	5
P-8 × SKBS-11	green	slightly rough	5
HU × Tulsi-I	green	downy	5
HU × SKBS-11	green	slightly rough	5
Tulsi-I × SKBS-11	green	downy	5
Hybrid Tulsi	green	downy	5

Table 3. ANOVA for parents and hybrids by diallel analysis for fruit yield and quality traits in okra.

Source	df	Fruit yield per plant (g)	Dry matter (%)	Mucilage (%)
Replication	2	117.26	0.62	0.01
Treatment	35	1723.01*	0.82	0.05*
Parents	7	1967.30*	0.56	0.07*
Hybrids	27	1009.60*	0.91*	0.04*
Parents vs Hybrids	1	19275.00*	0.00	0.06*
Error	70	536.74	0.54	0.01

*Significant at 5% level

breeding for getting elite purelines. GCA effects are the measure of additive gene action which represent the fixable components of genetic variance and are used to classify the parents for the breeding behaviour in hybrid combinations. Among the various breeding methods, diallel method which has been used in the present study, is very useful in isolating the parental lines. For fruit yield per plant, GCA effects ranged from -5.086 to 5.014 (Table 4). All the genotypes exhibited non-significant GCA effects, thus, categorized as average general combiners for fruit yield per plant. Similarly, Hadiya *et al*. (8) have also noticed only average general combiners for this trait. Negative significant GCA effect for dry matter and mucilage are well exploited. The GCA effects for dry matter ranged from -0.178 to 0.198. None of the genotype showed significant GCA effect and thus, considered as average general combiners. P-8 (-0.038) emerged as good general combiner and

Table 4. GCA effects of parents for fruit yield and quality traits in okra.

Parents	Fruit yield/ plant (g)	Dry matter (%)	Mucilage (%)
P-20	1.201	-0.017	0.018
9801	0.414	0.125	-0.023
VRO-4	5.014	-0.133	0.015
PK	-0.829	0.079	0.029
P-8	-5.086	-0.071	-0.038*
HU	3.028	-0.178	-0.022
Tulsi-I	-4.819	-0.003	0.011
SKBS-11	1.077	0.198	0.010
SE(gi)±	3.957	0.125	0.017
SE(gi-gj)±	5.982	0.189	0.026
CD	7.891	0.025	0.034

*Significant at 5% level

having desirable significant negative GCA effect for mucilage whereas all other parents showed non-significant GCA effects. As observed in the present study, Hadiya *et al*. (8) have also reported that all the parents included in the study cannot be good general combiners for all the traits, which is due to the different genetic make up of the parents included in the study.

SCA effects are the measure of non-additive gene action which is related to non-fixable component of genetic variance. The common approach of choosing the parents on the basis of performance, adaptation and genetic variability does not necessarily lead to useful results because of the differential ability of the parents. Therefore, it is important to assess the GCA and SCA effects in the selection of the parents and the formulation of an appropriate crossing plan. Out of twenty eight crosses, four displayed positive significant SCA effect for fruit yield per plant as represented in Table 5. The cross VRO-4 × HU (46.311) had the highest magnitude of significant positive SCA effect followed by Tulsi-I × SKBS-11 (44.028), P-20 × Tulsi-I (42.971) and P-8 × Tulsi-I (26.191) and were categorized as good specific combiners for fruit yield per plant as similar reported by Kumar *et al*. (11), Eswaran and Anbanandan (6) and Hadiya *et al*. (8). The perusal of SCA effects for dry matter revealed that only one cross-combination *i.e*. VRO-4 × Tulsi-I (-1.156) had significant negative effect and was designated as good specific cross-combination. Out of twenty eight F_1 hybrids, four crosses 9801 × PK (-0.220), P-20 × PK (-0.191), P-8 × SKBS-11 (-0.158) and HU × SKBS-11 (-0.129) were exhibiting negative values for SCA effects indicating their good specific combining ability for mucilage content.

For the characters studied, the crosses with significant SCA effects involved parents with average × average and good × average GCA effects. The combinations exhibiting high SCA effects derived from good or average general combiners will be of main interest as they certainly perform better for a particular trait. Cross combination (P-8 × SKBS-11) involving one good or other average combiner may give transgressive segregants in the later generations if the additive effect of one parent and complimentary epistatic effects (if present in the cross) act in the same direction and maximize the desirable plant character. In present investigation VRO-4 × HU followed by Tulsi-I × SKBS-11, P-20 × Tulsi-I and P-8 × Tulsi-I, appeared to be cross combination with high significant positive SCA effects for fruit yield per plant, therefore, these combinations could be exploited in hybrid breeding programme.

Heterosis estimated among F_1 was calculated with respect to standard check Hybrid Tulsi (Table 5) for fruit yield and quality traits. A number of hybrids showed superiority over their parents for characters studied (Fig. 2), although no hybrid showed increase of all the characters, there were significant differences between mean of hybrids for all measured characters. Fruit yield/plant being a complex trait, is a multiplicative product of several basic components. From the data, it was observed that, the fruit yield per plant of parents and crosses ranged between 140.83g (Tulsi-I) to 217.67g (9801) and 186.97g (9801 × HU) to 270.93g (VRO-4 × HU), respectively. The range of standard heterosis for fruit yield per plant varied from -3.03% (9801 × HU) to 40.53% (VRO-4 × HU). Out of 28 crosses, seven displayed significant positive heterosis over standard check. Maximum heterosis for fruit yield was 40.53% (VRO-4 × HU) over standard check. Increased yield in heterotic hybrids of okra has been observed in the present investigation, confirmed by Nagesh *et al*. (12), Patel *et al*. (14), Chowdhary and Kumar (5) and Kerure *et al*. (10) in their study.

The negative heterosis is desirable and useful for dry matter and mucilage content. Magnitude of heterosis over the standard check, ranged from -23.19% (VRO-4 × Tulsi-I) to -0.81% (PK × SKBS-11) for dry matter content. Significant negative heterosis was observed in nine crosses over standard check. The range of heterosis for mucilage content varied from 3.67% to 96.09% over standard check. None of the cross-combination showed significant negative heterosis over standard check.

In the present study, the significance of the heterotic performance was highly affected by the genetic background of parental genotypes. The heterosis among these germplasm indicates that the considerable potential exist in these materials for developing hybrids. Based on *per se* performance, SCA effects and heterosis, progenies 'VRO-4 × HU', 'Tulsi-I × SKBS-11' and 'P-20 × Tulsi-I' were the most promising cross-combinations for fruit yield and quality traits. These results are in agreement with the findings of Nagesh *et al*. (12), Bhatt *et al*. (4) and Eswaran and Anbanandan (6) who also observed cross combinations with high heterosis and SCA effects in their respective studies. Fruits of these cross-combinations were green coloured with downy pubescence and five ridges which are desirable traits for fresh market. These hybrids could be exploited through heterosis breeding and may also give transgressive segregants in subsequent generations and, therefore, it would be worthwhile to use them for improvement.

DECLARATION

The authors declare no conflict of interest.

Table 5. SCA effects and heterosis (%) over standard check of crosses for fruit yield and quality traits in okra.

Cross No.	Hybrids	Fruit yield/plant (g)		Dry matter (%)		Mucilage (%)	
		SCA	Heterosis	SCA	Heterosis	SCA	Heterosis
1.	P-20 × 9801	-22.229	1.64	-0.666	-15.73*	-0.101	22.99
2.	P-20 × VRO-4	5.838	18.59	-0.125	-12.85*	0.273*	96.09*
3.	P-20 × PK	11.248	18.36	-0.630	-15.83*	-0.191*	16.11
4.	P-20 × P-8	-1.862	9.35	0.373	-7.15	-0.058	27.84
5.	P-20 × HU	-5.976	11.43	0.240	-9.59	0.249*	85.31*
6.	P-20 × Tulsi-I	42.971*	32.75*	0.268	-7.53	0.043	54.62*
7.	P-20 × SKBS-11	-19.292	3.51	-0.656	-14.88*	0.087	62.32*
8.	9801 × VRO-4	-1.642	14.30	0.069	-9.42	-0.013	38.03*
9.	9801 × PK	13.668	19.21	0.561	-2.27	-0.220*	3.67
10.	9801 × P-8	17.858	19.17	0.134	-8.14	0.007	32.11*
11.	9801 × HU	-33.056*	-3.03	0.001	-10.58	0.201*	69.43*
12.	9801 × Tulsi-I	6.391	13.36	0.486	-3.86	-0.003	39.22*
13.	9801 × SKBS-11	18.494	22.70*	0.332	-3.39	-0.035	33.29*
14.	VRO-4 × PK	13.501	21.51*	-0.728	-18.00*	-0.081	35.07*
15.	VRO-4 × P-8	-2.976	10.75	0.151	-10.58	-0.071	24.88
16.	VRO-4 × HU	46.311*	40.53*	0.355	-9.59	-0.073	27.37
17.	VRO-4 × Tulsi-I	-0.109	12.38	-1.156*	-23.19*	-0.080	32.11*
18.	VRO-4 × SKBS-11	6.961	19.10	0.122	-8.14	-0.042	38.63*
19.	PK × P-8	12.201	15.59	-0.010	-10.07	0.032	45.73*
20.	PK × HU	4.054	15.58	-0.473	-15.86*	-0.070	30.33*
21.	PK × Tulsi-I	9.268	14.21	0.245	-6.78	-0.094	32.11*
22.	PK × SKBS-11	15.971	20.75*	0.631	-0.81	0.054	58.18*
23.	P-8 × HU	14.011	18.53	-0.734	-20.03*	0.037	37.44*
24.	P-8 × Tulsi-I	26.191*	20.78*	0.818*	-2.47	0.120*	58.18*
25.	P-8 × SKBS-11	-16.872	1.50	0.344	-5.25	-0.158*	8.65
26.	HU × Tulsi-I	3.478	13.21	-0.108	-12.98*	0.003	40.40*
27.	HU × SKBS-11	-8.486	10.06	-0.166	-11.53	-0.129*	16.71
28.	Tulsi-I × SKBS-11	44.028*	33.23*	0.319	-4.81	-0.048	37.09*
	SE (Sij) ±	12.129		0.384		0.053	
	SE (Sij-Sik) ±	17.945		0.569		0.078	
	SE (Sij-Skl) ±	16.919		0.536		0.073	
	CD	24.190		0.767		0.105	
	SE(d)		18.916		0.600		0.082

*Significant at 5% level

ACKNOWLEDGEMENT

The authors gratefully acknowledges the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur for providing the research facilities for this research.

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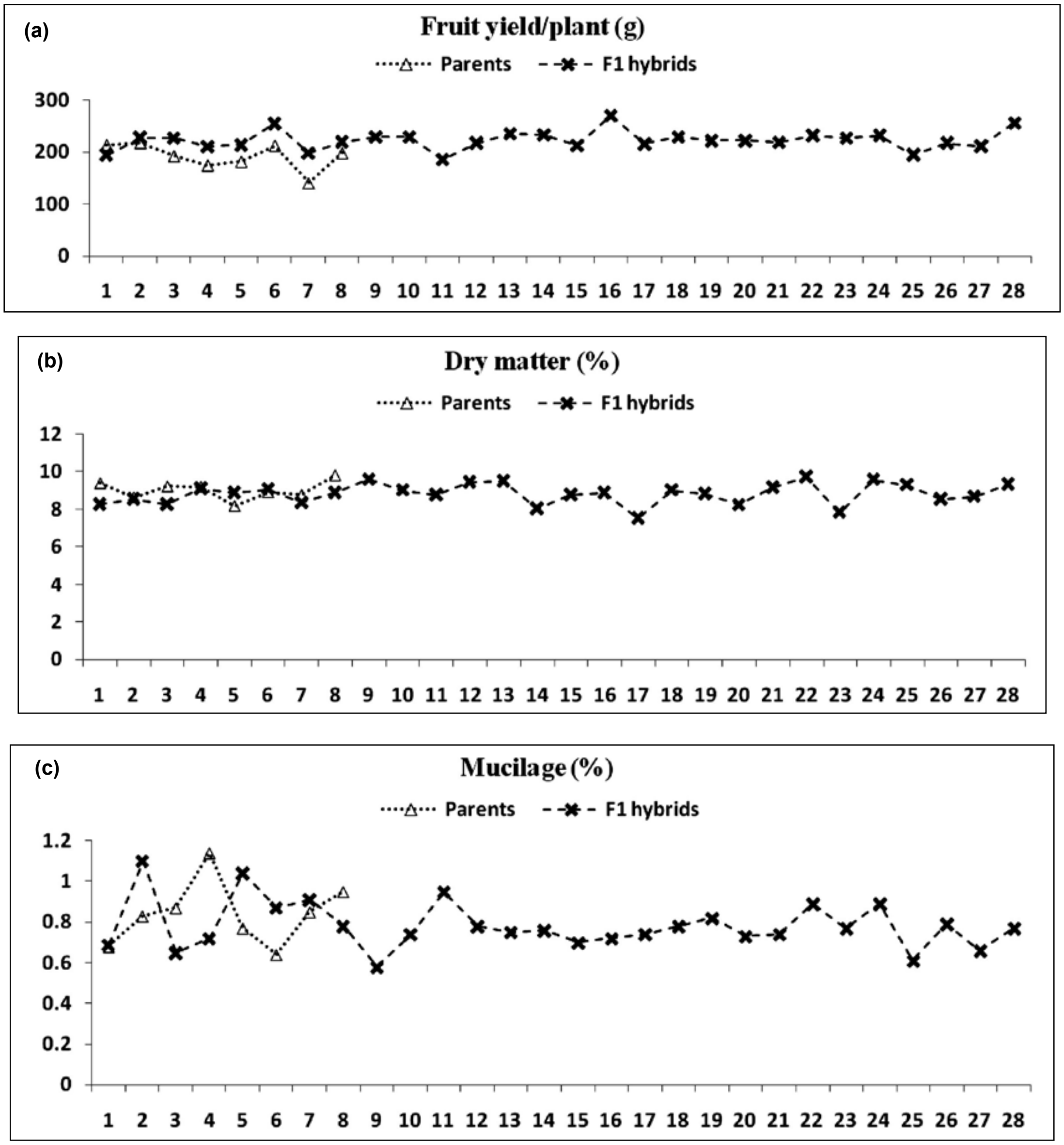

Fig. 2. Mean performances of parents and F_1's for (a) fruit yield/plant (g), (b) dry matter (%) and (c) mucilage (%).

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(Received : September, 2017; Revised : October, 2020; Accepted : October, 2020)