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Studies on heterobeltiosis and inbreeding depression for fruit yield and it's attributing traits in okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract
The aim of the current research on okra (*Abelmoschus esculentus* (L.) Moench) was to determine the degree of heterobeltiosis and the level of inbreeding depression for fruit yield and related traits using generation mean analysis. Mean performance of F_1 hybrids exceeded the value of their better parent in desired direction in the cross AOL 16-01 X AOL 18-08 for fruit weight, fruits per plant. In the cross GAO 5 X Red One Long for fruit length, fruit weight, fruits per plant, fruit yield per plant, branches per plant, plant height, internodes on main stem. In the cross AOL 19-10 X AOL 20-03 for fruit length, fruit girth, fruit weight, fruits per plant, fruit yield per plant, internodes on main stem, total soluble solids. In the cross Phule Prajatika X GAO 5 for plant height, internodes on main stem, length of internode, while for days to initiation of flowering, none of the F_1 *per se* performance was lower than its better parent. Mean performance of backcross progenies was not consistent in different crosses for different traits. These generation could be further utilized for selecting higher fruit yield per plant. For selection of any traits the generation which is superior to the parents can be advanced for future breeding programme.

Keywords: Okra, heterobeltiosis and inbreeding depression

Introduction
India is world's largest producer of okra and contributes more than 72% (6 million tonnes) to the global production from an area of 0.5 million hectares. Okra with its significant share in fresh vegetable exports has immense potential for earning foreign exchange. According to FAO estimates around 75 percent of the okra market is in India and 12% is in Nigeria. Cultivated both as a rain-fed and irrigated crop it is the most valued and popular vegetable consumed in fresh and dried forms. Over the last few years okra is gaining ground as a global crop because of the recognition of its nutritional values by the growing number of consumers. Especially after the COVID pandemic importance of healthy and balanced diet is getting ingrained in the global consumer mindset. India exports okra seeds to over 20 countries. In the recent past several research papers have been published by the Asian and African scientists working on okra genetics, breeding, genomics and agronomy. This further indicates okra's growing popularity as a global crop. Over 90 percent of the okra seed market in India is covered by hybrid seeds. Global seed requirement of okra is expected to touch 6000 MT mark valued at $ 300m by 2030 (GORT 2022) [6]. In India okra was grown in 546 thousand hectare area with production of 6700 thousand MT and 12.27 tonnes productivity. (Anon., 2021-22) [2]. The important okra growing states in India are Gujarat, Maharashtra, Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Karnataka, Haryana and Punjab, in which it is cultivated as a *Kharif* as well as summer season crop. Okra, is an important annual vegetable crop raised for its young, green, and edible fruits without fibrous skin. In several African nations, people also eat leaves in addition to fruits. Okra is now frequently found in cafeterias, salad bars, and restaurants as a fried or boiled vegetable dish. Okra stems and roots are used to purify the cane juice that is used to make gur or jaggery. Both young okra and frozen okra are in high demand right now.

Materials and Methods
The experimental materials for present investigation comprised of four families *viz*., AOL 16-01 × AOL 18-08, GAO 5 × Red One Long, AOL 19-10 × AOL 20-03 and Phule Prajatika × GAO 5 each with twelve basic generations *viz*., P_1, P_2, F_1, F_2, B_1, B_2, B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} and B_{2S}. All the parents of these four crosses were selected from diverse genetic stocks

available at Main Vegetable Research Station, Anand Agricultural University, Anand. Each replication was divided into four compact blocks each consists of single family and blocks were consisted of twelve plots comprised of twelve basic generations of each family. The families were assigned to each block and twelve generations of a family were randomly allotted to individual plot within the block. The plots of various generations were sown in different number of rows *i.e*., parents and F_1 in single row, B_1, B_2 in two rows and F_2, B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} and B_{2S} in four rows. Each row was 3.0 m long with 60 and 30 cm inter and intra row spacing, respectively, each row accommodated ten plants. The observations were recorded on individual plant basis in each replication randomly selected five plants from P_1, P_2 and F_1, ten plants from first backcross (B_1 and B_2) and twenty plants of F_2, B_{11}, B_{12}, B_{21}, B_{22}, B_{1S} and B_{2S} generations. The plants were selected at random from each plot and tagged before the emergence of flower. The characters under study were days to initiation of flowering, fruit length, fruit girth, fruit weight, fruits per plant, fruit yield per plant, branches per plant, plant height, internodes on main stem, length of internode, and total soluble solids.

Results and Discussion

Highly significant estimates of desirable heterobeltiosis for early flowering was observed for the crosses Phule Prajatika × GAO 5 (-10.66%), GAO 5 × Red One Long (-8.91%) and AOL 19-10 × AOL 20-03 (-3.13%). This trait is an important in case of okra as early picking of fruits may fetch higher price in the market. Therefore, this trait may be exploited through heterosis breeding. Present findings are in accordance with the results obtained earlier by Modha (2009) [15], Khanorkar and Kathiria (2010) [10], Aware *et al.,* (2014) [3], Chavan *et al.,* (2018) [5], Jogi *et al.,* (2018) [7] and Kerure and Pitchaimuthu (2019) [9], while significant and positive heterobeltiosis for days to flowering observed by Srikanth *et al.,* (2019) [21]. The cross AOL 19-10 × AOL 20-03 (8.52%) manifested significant heterobeltiosis in desirable direction for fruit length, this result is in accordance with Biju (2005) [4]. Sabesan *et al.,* (2016) [19], Chavan *et al.,* (2018) [5] and Srikanth *et al.,* (2019) [21]. The cross AOL 19-10 × AOL 20-03 (4.64%) manifested significant heterobeltiosis in desirable direction for fruit girth.

None of the crosses manifested significant heterobeltiosis in desirable direction for fruit weight. In case of fruits per plant, crosses GAO 5 × Red One Long (10.53%) and AOL 19-10 × AOL 20-03 (10.42%) depicted significant heterobeltiosts in desirable direction. Similar findings were also reported by Modha (2009) [15]. Singh *et al.,* (2009) [20], Khanorkar and Kathiria (2010) [10], Mistry (2012) [14], Aware *et al.,* (2014) [3], Sabesan *et al.* (2016) [19] and Srikanth *et al.,* (2019) [21]. Significant and negative heterosis over better parent was observed in the cross AOL 16-01 × AOL 18-08 (-25.29%) for fruit yield per plant. This finding is in contrary with Modha (2009) [15], Kalpande *et al.,* (2009) [8], Khanorkar and Kathiria (2010) [10], Mistry (2012) [14], Aware *et al.,* (2014) [3], Rajput (2014) [18], Neetu *et al.,* (2015) [16].

For fruit yield per plant, crosses AOL 19-10 × AOL 20-03 (9.99%) and GAO 5 × Red One Long (17.18%) depicted significant heterobeltiosts in desirable direction, significant and negative heterosis over better parent was observed in the crosses AOL 16-01 × AOL 18-08 (-12.75%) and Phule Prajatika × GAO 5 (-10.92%) for fruit yield per plant. Similar findings were also reported by Patel (2013) [17]. None of the crosses manifested significant heterobeltiosis in desirable direction for branches per plant, this result is in contradiction with Sabesan *et al.,* (2016) [19], Chavan *et al.,* (2018) [5] and Srikanth *et al.,* (2019) [21]. For plant height, significant heterobeltiosis in negative direction was observed for the crosses AOL 16-01 × AOL 18-08 (-9.84%) and AOL 19-10 × AOL 20-03 (-5.40%), which is in accordance with Biju (2005) [4], Amutha *et al.* (2007) [1] and Sabesan *et al.,* (2016) [19]. While Kumar *et al.,* (2004) [11], Amutha (2007) [1], Modha (2009) [15], Khanorkar and Kathiria (2010) [10], Aware *et al.,* (2014) [3], Mahajan *et al.,* (2017) [13], Chavan *et al.,* (2018) [5], Jogi *et al.,* (2018) [7] and Srikanth *et al.,* (2019) [21] found contradictory results for plant height.

The crosses AOL 19-10 × AOL 20-03 (8.60%) and GAO 5 × Red One Long (8.33%) in desirable direction for internodes on main stem as showed by Patel (2013) [17]. Modha (2009) [15] found contradictory result. The length of internode is also an important character in okra as shorter internodes are preferred because it restricts plant height from extra tall and imparts suitable height. For length of internode, crosses AOL 19-10 × AOL 20-03 (-25.68%) and GAO 5 × Red One Long (-19.11%) exhibited negative and significant heterosis over better parent, this result is consistent with Srikanth *et al.,* (2019) [21] and contrasting with Sabesan *et al.,* (2016) [19] and Chavan *et al.,* (2018) [5]. The cross AOL 19-10 × AOL 20-03 (13.39%), in desirable direction for total soluble solids, significant and negative heterosis over better parent was observed in the crosses Phule Prajatika × GAO 5 (-42.61%) and GAO 5 × Red One Long (-5.91%).

The inbreeding depression is an important criterion for breeding programme in crop improvement. The positive and significant inbreeding depression was found for days to initiation of flowering in the cross AOL 16-01 × AOL 18-08 (8.75%). It predicts better chances to obtain desirable segregants for earliness in the subsequent filial generations of this cross. In context to literatures on inbreeding depression, Modha (2009) [15]. Khanorkar and Kathiria (2010) [10] and Rajput (2014) [18] observed positive inbreeding depression for days to flowering. Whereas, the negative inbreeding depression was also reported for this character by Sabesan *et al.* (2016) [19] and Srikanth *et al.,* (2019) [21].

None of the crosses depicted significant inbreeding depression in negative direction for fruit length, fruits per plant, fruit yield per plant result is comparable with Modha (2009) [15]. Significant inbreeding depression of 13.71% and 11.44% in positive direction was observed in the cross AOL 19-10 × AOL 20-03 for fruits per plant and fruit yield per plant respectively. Same result was reported by Modha (2009) [15], Kalpande *et al.,* (2009) [8], Singh *et al.,* (2009) [20], Mistry (2012) [14], Sabesan *et al.,* (2016) [19] Mahajan *et al.,* (2017) [13], Chavan *et al.,* (2018) [5], Jogi *et al.,* (2018) [7] and Snikanth *et al.,* (2019). In context to literatures inbreeding depression, contrary result for this trait reported by Khanorkar and Kathiria (2010) [10]. Aware *et al* (2014) [3], Rajput (2014) [18] and Sabesan *et al.,* (2016) [19].

The negative and significant inbreeding depression for fruit girth and fruit weight is desirable in okra breeding programme. GAO 5 × Red One Long (-12.05%) and Phule Prajatika × GAO 5 (-20.83%) respectively exhibited significant inbreeding depression in desirable direction. Similar findings were also reported by Kumar (2021) [12]. Higher branches per plant is desirable as it increase the yield

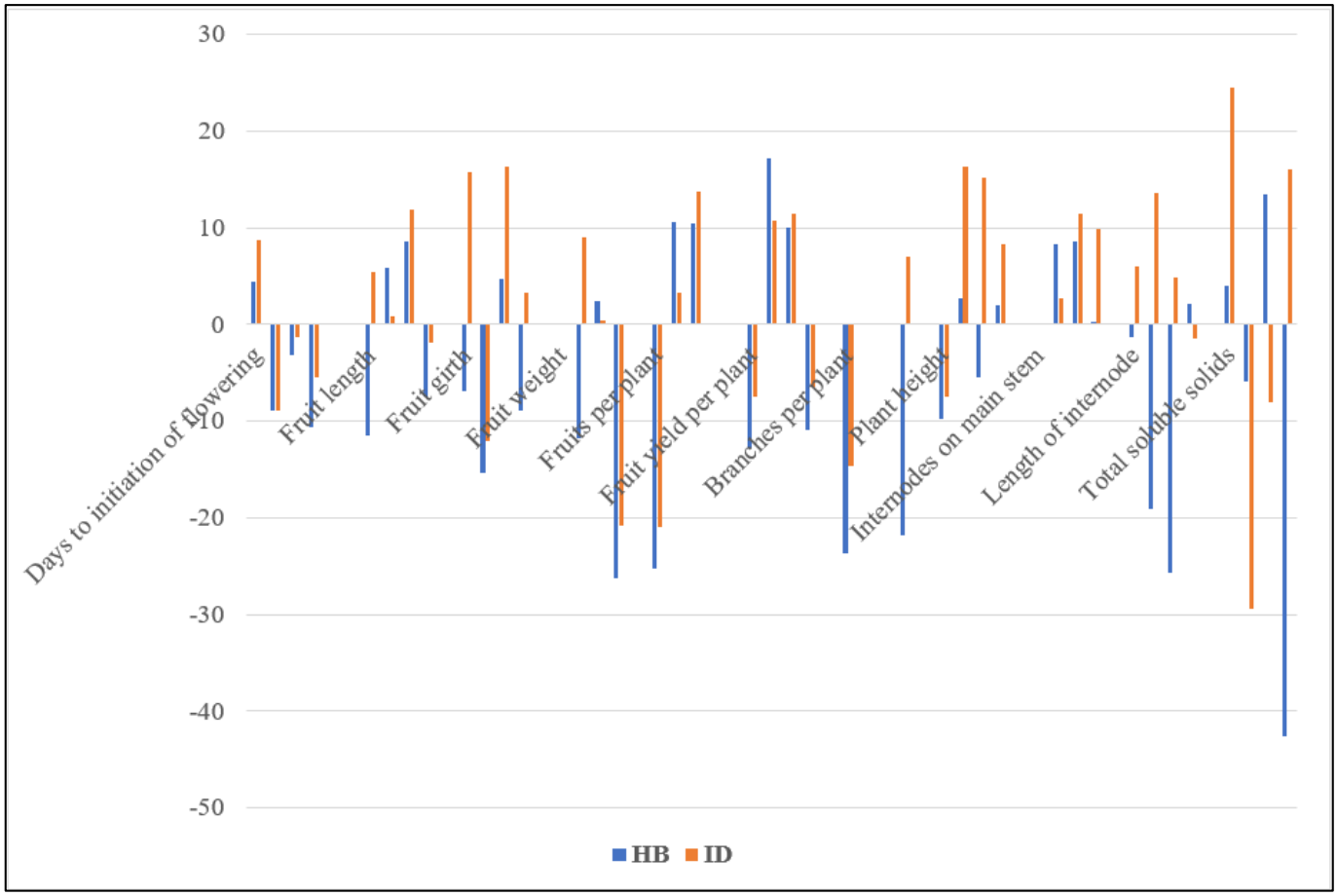
cross AOL 16-01 × AOL 18-08 (-14.66%) exhibited inbreeding depression in desirable direction, Similar findings were also reported by Kumar (2021) [12]. The significant and positive inbreeding depression was also reported for branches per plant by Chavan *et al*., (2018) [5], Srikanth *et al*., (2019) [21]. The negative and significant inbreeding depression for plant height is desirable in okra breeding programme. cross AOL 19-10 × AOL 20-03 (-7.41%) exhibited significant inbreeding depression in desirable direction, similar findings were also reported by Sabesan *et al*., (2016) [19] and Mahajan *et al*., (2017) [13]. While positive and significant inbreeding depression for plant height was recorded in crosses GAO 5 × Red One Long (16.36%), AOL 19-10 × AOL 20-03 (15.24%) and Phule Prajatika × GAO 5 (8.29%) same results were reported by Biju (2005) [4], Chavan *et al*., (2018) [5], Srikanth *et al*., (2019) [21].

Each node bears flower which may lead to fruit formation, so higher number of internodes on main stem indirectly increase the yield. However, none of the cross exhibited significant inbreeding depression in desirable direction. Positive and significant inbreeding depression for internodes on main stem was recorded, similar findings were also reported by Sabesan *et al* (2016) [19], Chavan *et al*., (2018) [5] and Srikanth *et al*., (2019) [21]. Shorter internodes are preferred because it restricts plant height from extra tall and imparts suitable height, cross GAO 5 × Red One Long (13.64%) revealed positive and significant inbreeding depression for this trait was desirable and agreement with Sabesan *et al*., (2016) [19]. The negative and significant inbreeding depression for total soluble solids is desirable in okra breeding programme. Crossess GAO 5 × Red One Long (-29.36%) and AOL 19-10 × AOL 20-03 (-8.08%) exhibited significant inbreeding depression in desirable direction. These generation could be further utilized for selecting higher fruit yield per plant. For selection of any traits the generation which is superior to the parents can be advanced for future breeding programme.

Table 1: Heterobeltiosis and inbreeding depression for different characters in okra

	AOL 16-01 × AOL 18-08	GAO 5 × Red One Long	AOL 19-10 × AOL 20-03	Phule Prajatika × GAO 5
Days to initiation of flowering				
HB	4.44*	-8.91**	-3.13*	-10.66**
ID	8.75**	-8.90**	-1.29**	-5.46**
Fruit length				
HB	-11.49	5.86	8.52*	-7.42
ID	5.36	0.81	11.93**	-1.83
Fruit girth				
HB	-6.93*	-15.40**	4.64	-8.91**
ID	15.69**	-12.05**	16.28**	3.28
		Fruit weight		
HB		-11.84	2.42	-26.30**
ID		9.05	0.46	-20.83**
Fruits per plant				
HB	-25.29**	10.53**	10.42**	0.33
ID	-20.88	3.33	13.71**	12.38**
Fruit yield per plant				
HB	-12.75*	17.18*	9.99**	-10.92**
ID	-7.45	10.72	11.44**	-6.42
Branches per plant				
HB	-23.68*			-21.88
ID	-14.66			7.00
Plant height				
HB	-9.84**	2.66	-5.40*	1.97
ID	-7.41**	16.36**	15.24**	8.29**
Internodes on main stem				
HB		8.33**	8.60**	0.26
ID		2.69	11.51**	9.93**
Length of internode				
HB	-1.37	-19.11**	-25.68**	2.11
ID	5.98	13.64**	4.84	-1.42
		Total soluble solids		
HB	3.93	-5.91*	13.39**	-42.61**
ID	24.53**	-29.36**	-8.08**	15.98**

*, ** indicates significant at 5 and 1% levels respectively, HB: heterobeltiosis, ID: inbreeding depression



Graphical representation as per cent heterobeltiosis and inbreeding depression for different characters in four crosses of okra (AOL 16-01 × AOL 18-08, GAO 5 × Red One Long, AOL 19-10 × AOL 20-03 and Phule Prajatika × GAO 5)

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