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Estimation of standard heterosis over environments for fruit yield and its attributes in Okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract
Heterosis breeding has proven to be a potential method of increasing yield in the crops. It enables early identification of superior/potential crosses which is necessary to handle the material in advance generations, effectively and gainfully. An experiment was conducted to evaluate 35 genotypes in four different environments at Navsari Agricultural University. The experimental material consisted of 35 genotypes; representing 24 hybrids developed in line x tester mating of 10 diverse parents and commercial hybrid check 'OH-102'. Significant and high estimates of standard heterosis were observed for fruit yield/plant in all environments. Among the hybrids, AOL-16-04 x Parbhani Kranti was consistent with respect to higher heterotic effect for fruit yield/plant across the environments, while cross AOL-16-04 x Arka Anamika was consistent for heterotic effects in environments E_1, E_2 and E_3 and the cross NOL 17-09 x Arka Anamika was consistent in E_1, E_3 and E_4 for fruit yield/plant. These crosses may be exploited for commercial cultivation and may also be advanced as those would likely yield superior transgressive segregants.

Keywords: Standard heterosis, over the environment, line x tester, okra

Introduction
Vegetables, an important and essential component of human diet provide nutritional security particularly to vegetarian population, are highly remunerative and generate more employment opportunities in India. The vegetable production is much less than our requirement and serves per capita intake of only 135 g as against the requirement of 300 g per capita per day for balanced diet. Owing to the increasing demand of vegetables day by day to feed the increasing population of the country, there is an urgent need to increase vegetable production by developing high yielding varieties of different vegetable crops to bridge this gap. Okra [*Abelmoschus esculentus* (L.) Moench], a popular vegetable crop is grown in the tropical, sub-tropical low altitude regions of Asia, Africa, America and temperate regions of the Mediterranean basin. India is a major okra producing country in the world comprising of 72 per cent of total area under okra (Anonymous, 2017) [1]. In India, okra is commercially grown in the states of Gujarat, Maharashtra, Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Karnataka, Haryana and Punjab as a *kharif* as well as summer season crop. It is cultivated in the area of 511 ('000 ha) with the annual production of 62.19 lakh tonne and productivity of 12.17 MT/ha (Anonymous, 2019) [2]. In Gujarat, its area, production and productivity is 76 ('000 ha), 925 thousand metric tonnes and 12.17 MT/ha, respectively (Anonymous, 2019) [2]. According to de Candolle (1883), the probable centres of origin for okra might be Ethiopia (Abyssinian region) and West Africa. However it is also believed to be originated in the Hindustani center of origin, of which chiefly in India (Zeven and Zhukovsky, 1975). It belongs to family Malvaceae and genus *Abelmoschus*. The cultivated species *Abelmoschus esculentus* is an amphidiploid (29T + 36Y) having 2n = 130 chromosomes. The average nutritive value (ANV) of okra is 3.21%, which is higher than tomato, brinjal and cucurbitaceous vegetables (Sharma and Arora, 1993) [9]. Cultivation of low yielding open pollinated varieties, lack of location specific high yielding varieties/hybrids with high degree of resistance to pests and diseases like fruit and shoot borer, okra yellow vein mosaic virus (YVMV) and enation leaf curl virus (ELCV) are the major reasons of low productivity in India and Gujarat. Further, the economic

returns to the okra growers are also low owing to the sub-optimal pod quality. In spite of the numerous advantages of available open pollinated varieties (OPVs), the importance of hybrid varieties (F_1 hybrids) has recently been pointed out by farmers, scientists and technologists of developing countries. The F_1 hybrids in general, have more vigor, higher yield and quality, production stability, suitability to high input agriculture, shorter life cycle, uniform growth and maturity and greater disease resistance than many of the open pollinated varieties. The presence of sufficient hybrid vigour is an important prerequisite for successful production of hybrid varieties. Heterosis is the only effective means of combining together the desirable characters of two distinct varieties. Heterosis breeding is an important genetic tool that can facilitate yield enhancement from 30 to 40% and helps enrich many other desirable quantitative and qualitative traits in crops (Srivastava, 2000) [11]. Thus, heterosis breeding in okra for yield and quality with disease and pest resistance offers quantum jump in yield within short period of time. In okra, hybrid vigour can be exploited and hybrid seed production is feasible commercially owing to large flower size and monadelphous nature of the stamens, the ease in hand emasculation, pollination and fruit set, high percentage of fruit set and good number of seeds per pod. These characteristics offer greater possibilities of crop improvement through hybridization. Being an often cross pollinated crop it can open pollinate up to the range of 4% to 42% due to entomophily (Kumar, 2006), hence it is heterozygous in constitution in spite of its adoption for self pollination. It offers much scope for improvement through heterosis breeding which can further be utilized for the development of desirable recombinants. A clear understanding for heterosis of the traits under consideration will help in deciding the appropriate breeding methods to improve the genetic makeup as well as productivity. Thus, knowledge of heterosis for yield and its component characters should be placed greater emphasis for the improvement of this crop. The first report of hybrid vigor in okra was demonstrated by Vijayaraghavan and Warier (1946) [12]. Marked heterosis of 38 to 71 per cent has been reported in okra for yield and its components (Laxmiprasanna, 1996 and Singh *et al.*, 1975) [5, 10]. Thus, present investigation was carried out to estimate heterosis for yield and its components using line x tester mating design in okra.

Material and Methods

The present investigation was carried out at College farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari. The experimental material consisted of 35 genotypes; representing 24 hybrids developed in line x tester mating of 10 diverse parents (six lines *viz*., GAO-5, GO-6, AOL-16-04, NOL 17-05, NOL 17-06, NOL 17-09 and four testers *viz*., Arka Anamika, Arka Abhay, Kashi Kranti and Parbhani Kranti) and commercial hybrid check 'OH-102'. All the genotypes were evaluated in Randomized Complete Block Design (RBD) replicated thrice in four environments created by four dates of sowing *viz.*, E_1: summer (14/2/2019), E_2: late summer (14/03/2019), E_3: *kharif* (20/06/2012) and E_4: late *kharif* (22/07/2019). Observations were recorded on 13 characters *viz*., days to 50% flowering, days to first picking, days to last picking, average fruit length, average fruit girth, average fruit weight, plant height at final harvest, branches/plant at final harvest, internodes/plant at final harvest, internodal length at final harvest, fruits/plant, fruit yield/plant and fiber content. The data was subjected to Line x Tester analysis and magnitude of heterosis was calculated as per standard procedure and significance of heterosis was worked out using the formula suggested by Wynne *et al.* (1970) [16].

Results and Discussion

In present study, heterosis analysis is carried out to find out the best combination of parents giving high degree of standard heterosis, and its exploitation to get better and economic transgressive segregants, and characterization of parents for their prospects for future use in breeding programme. The range of mean, range of standard heterosis and number of significant crosses over the environments presented in Table-1. The degree and magnitude of various heterotic effects varied from cross to cross and character to character. Considerable amount of standard heterosis was observed for fruit yield and its attributes. The magnitude of heterosis varied in different environments for various traits. In case of days to 50% flowering, heterosis in negative direction is desirable as early initiation of flowering would get more number of fruits and thereby higher fruit yield. The estimates of standard heterosis varied from -13.60% (AOL-16-04 x Parbhani Kranti and NOL 17-05 x Parbhani Kranti) to 0.80% (AOL-16-04 x Arka Abhay) in E_1, -13.11% (NOL 17-09 x Arka Anamika) to 7.38%. (NOL 17-05 x Arka Abhay) in E_2, -6.02% (GAO-5 x Parbhani Kranti) to 10.53% (GO-6 x Arka Abhay) in E_3 and -15.75% (NOL 17-05 x Parbhani Kranti and NOL 17-06 x Arka Abhay) to 2.05% (NOL 17-06 x Kashi Kranti) in E_4. The promising hybrids were AOL-16-04 x Parbhani Kranti (-13.60%), NOL 17-05 x Parbhani Kranti (-13.60%), GAO-5 x Kashi Kranti (-10.40%) in E_1, NOL 17-09 x Arka Anamika (-13.11%), NOL 17-06 x Kashi Kranti (-11.48%), NOL 17-05 x Kashi Kranti (-9.02%) in E_2 and NOL 17-05 x Parbhani Kranti (-15.75%), NOL 17-06 x Arka Abhay (-15.75%), GAO-5 x Arka Anamika (-13.70%), GAO-5 x Kashi Kranti (-13.70%), GO-6 x Arka Anamika (-13.70%), NOL 17-09 x Arka Anamika (-13.01%) in E_4. For this trait negative and significant standard heterosis was reported by Patel *et al*. (2015) [8], Verma and Sood *et al*. (2015) [15], Bhatt *et al*. (2016) [3], Nama *et al.* (2017) [7], Vekariya *et al*. (2019) [13, 14] and Koli (2020) [4]. For days to first picking, also the negative heterosis depicting less days is desirable. It is directly related with number of pickings in the whole life cycle of the crop. Fruit yield of the genotype may be higher when it starts early in production of marketable fruits. The quantum of standard heterosis ranged from -13.99% (AOL-16-04 x Parbhani Kranti) and 0.00% (GO-6 x Parbhani Kranti) in E_1, -10.45% (NOL 17-06 x Kashi Kranti) to 8.21% (NOL 17-09 x Arka Abhay) in E_2, -2.70% (NOL 17-05 x Kashi Kranti) to 15.54% (GO-6 x Arka Abhay) in E_3 and -14.02% (NOL 17-05 x Parbhani Kranti) to 4.27% (NOL 17-06 x Arka Anamika) in E_4. The promising hybrids were AOL-16-04 x Parbhani Kranti (-13.99%), AOL-16-04 x Arka Anamika (-11.89%), NOL 17-05 x Parbhani Kranti (-11.89%), GAO-5 x Kashi Kranti (-11.19%), GO-6 x Arka Abhay (-11.19%) in E_1, NOL 17-06 x Kashi Kranti (-10.45%), NOL 17-09 x Arka Anamika (-9.70%) in E_2 and NOL 17-05 x Parbhani Kranti (-14.02%), GAO-5 x Kashi Kranti (12.20%), GAO-5 x Arka Anamika (-10.37%), GO-6 x Arka Anamika (-10.37%), AOL-16-04 x Arka Anamika (-10.37%), NOL 17-06 x Arka Abhay (-10.37%) in E_4. For this trait, significant and negative standard heterosis was reported by Verma and Sood (2015) [15], Nama *et al.* (2017) [7] and Vekariya *et al.* (2019) [13, 14]. Days to last picking is also related with number of pickings which increase the fuit yield of the crop. The standard heterosis ranged from -3.70% (GO-6 x Arka Abhay) to 10.70% (NOL 17-09 x Arka Anamika) in E_1, -18.40% (NOL 17-06 x Kashi Kranti) to -1.42% (AOL-16-04 x Parbhani Kranti) in E_2, 0.00% (GAO-5 x Parbhani Kranti, NOL 17-09 x Arka Abhay) to 21.74% (GO-6 x Arka Abhay) in E_3 and -13.06% (NOL 17-05 x Parbhani Kranti) to 3.67% (NOL 17-06 x Arka Anamika) in E_4. The promising hybrids were NOL 17-09 x Arka Anamika (10.70%) in E_1 and GO-6 x Arka Abhay (21.74%), NOL 17-09 x Arka Anamika (16.21%), NOL 17-09 x Kashi Kranti (14.62%) in E_3. For this trait, significant and positive standard heterosis was reported by Verma and Sood (2015) [15] and Vekariya *et al.* (2019) [13, 14]. Good marketable quality of okra fruit consist of tender and smooth fruit with medium length. Thus, too much length is undesirable. For average fruit length, the per cent standard heterosis was in the range of -1.34% (NOL 17-05 x Arka Abhay) to 33.12% (AOL-16-04 x Arka Anamika) in E_1, -8.67% (NOL 17-06 x Parbhani Kranti) to 18.02% (NOL 17-09 x Arka Anamika) in E_2, 0.62% (NOL 17-05 x Parbhani Kranti) to 43.51% (NOL 17-05 x Arka Abhay) in E_3 and -12.37% (GO-6 x Kashi Kranti) to 33.80% (NOL 17-09 x Arka Anamika) in E_4.The promising hybrids were AOL-16-04 x Arka Anamika (33.12%), GO-6 x Arka Anamika (28.56%), NOL 17-09 x Arka Anamika (28.56%), GAO-5 x Arka Anamika (28.29%) in E_1, NOL 17-09 x Arka Anamika (18.02%) in E_2, NOL 17-05 x Arka Abhay (43.51%), NOL 17-09 x Arka Anamika (29.62%), NOL 17-09 x Arka Abhay (25.64%) in E_3 and NOL 17-09 x Arka Anamika (33.80%), NOL 17-06 x Arka Anamika (31.01%), NOL 17-06 x Kashi Kranti (28.01%) in E_4. For this trait, significant and positive standard heterosis was reported Patel *et al.* (2015) [8], Verma and Sood (2015) [15], Bhatt *et al.* (2016) [3], Nama *et al*. (2017) [7], Vekariya *et al*. (2019) [13, 14] and Koli (2020) [4]. Fruit girth should be moderate usually in proportion with fruit length. The standard heterosis ranged from -4.59% (GO-6 x Arka Abhay) to 25.51% (AOL-16-04 x Kashi Kranti) in E_1, -16.00% (NOL 17-06 x Parbhani Kranti) to 3.11% (NOL 17-09 x Arka Anamika) in E_2, -0.53% (GO-6 x Arka Anamika) to 140.11% (NOL 17-09 x Arka Abhay) in E_3 and -5.43% (GAO-5 x Parbhani Kranti) to 139.13% (NOL 17-09 x Arka Abhay) in E_4. The promising hybrids were AOL-16-04 x Kashi Kranti (25.51%), AOL-16-04 x Parbhani Kranti (19.90%), NOL 17-09 x Kashi Kranti (18.37%) in E_1, NOL 17-09 x Arka Abhay (140.11%), NOL 17-09 x Kashi Kranti (136.90%), NOL 17-05 x Kashi Kranti (122.46%) in E_3 and NOL 17-09 x Arka Abhay (139.13%), NOL 17-09 x Kashi Kranti (126.63%), NOL 17-05 x Kashi Kranti (117.93%) in E_4. For this trait, significant and positive standard heterosis was reported by Verma and Sood (2015) [15], Nama *et al*. (2017) [7] and Koli (2020) [4]. More fruit weight with more pulp and small seed is considered as good for marketable fruit quality. The quantum of standard heterosis ranged from -4.95% (NOL 17-06 x Parbhani Kranti) to 38.04% (AOL-16-04 x Arka Anamika) in E_1, -8.44% (NOL 17-06 x Parbhani Kranti) to 16.59% (AOL-16-04 x Arka) in E_2, 8.59% (NOL 17-05 x Parbhani Kranti) to 62.11% (NOL 17-09 x Arka Abhay) in E_3 and -9.44% (NOL 17-06 x Parbhani Kranti) to 35.57% (AOL-16-04 x Parbhani Kranti) in E_4. The promising F_1s were AOL-16-04 x Arka Anamika (38.04%), GAO-5 x Arka Anamika (28.30%), AOL-16-04 x Parbhani Kranti (27.37%) in E_1, AOL-16-04 x Arka Abhay (16.59%), NOL 17-09 x Arka Abhay (14.89%), AOL-16-04 x Kashi Kranti (14.22%) in E_2, NOL 17-09 x Arka Abhay (62.11%), NOL 17-09 x Arka Anamika (48.16%), AOL-16-04 x Arka Anamika (43.10%) in E_3 and AOL-16-04 x Parbhani Kranti (35.57%), AOL-16-04 x Arka Anamika (29.26%), NOL 17-09 x Parbhani Kranti (26.93%) in E_4. For this trait, significant and positive standard heterosis was reported by Patel *et al.* (2015) [8], Verma and Sood (2015) [15], Bhatt *et al.* (2016) [3], Nama *et al*. (2017) [7] and Koli (2020) [4]. A good commercial variety has higher plant height with more number of fruits, less internodal distance and moderate branching habit. A perusal of the data on plant height revealed that the per cent standard heterosis was in the range of -6.85% (NOL 17-09 x Arka Abhay) to 21.87% (NOL 17-05 x Parbhani Kranti) in E_1, -2.49% (NOL 17-09 x Parbhani Kranti) to 25.83% (AOL-16-04 x Parbhani Kranti) in E_2, -2.60% (NOL 17-09 x Parbhani Kranti) to 27.46% (AOL-16-04 x Parbhani Kranti) in E_3 and -22.31% (NOL 17-09 x Arka Abhay) to 0.11% (AOL-16-04 x Kashi Kranti) in E_4. The promising hybrids were NOL 17-05 x Parbhani Kranti (21.87%), AOL-16-04 x Arka Anamika (20.68%), GAO-5 x Arka Abhay (20.02%), NOL 17-05 x Arka Abhay (20.02%) in E_1, AOL-16-04 x Parbhani Kranti (25.83%), GO-6 x Arka Abhay (24.64%), NOL 17-09 x Arka Anamika (24.41%) in E_2 and AOL-16-04 x Parbhani Kranti (27.46%), AOL-16-04 x Arka Anamika (22.87%), NOL 17-06 x Kashi Kranti (22.56%) in E_3. For this trait, significant and positive standard heterosis was reported by Verma and Sood (2015) [15], Nama *et al.* (2017) [7] and Koli, (2020) [4].

The quantum of standard heterosis ranged from -93.75% (NOL 17-05 x Kashi Kranti) to -31.25% (AOL-16-04 x Parbhani Kranti) in E_1, -81.25% (NOL 17-06 x Parbhani Kranti) to -15.63% (AOL-16-04 x Kashi Kranti and AOL-16-04 x Parbhani Kranti) in E_2, -40.74% (GO-6 x Arka Abhay) to 81.48% (NOL 17-09 x Arka Anamika) in E_3 and -64.29% (GAO-5 x Kashi Kranti) to 17.14% (NOL 17-09 x Arka Abhay) in E_4 for the character branches per plant. The crosses NOL 17-09 x Arka Anamika (81.48%), NOL 17-06 x Arka Anamika (62.96%), NOL 17-09 x Parbhani Kranti (59.26%) in E_3 and NOL 17-09 x Arka Abhay (17.14%) in E_4 were promising for the trait branches/plant at final harvest. For this trait, significant and positive standard heterosis was reported by Bhatt *et al.* (2016) [3], Nama *et al.* (2017) [7], Vekariya *et al.* (2019) [13, 14] and Koli, (2020) [4]. A perusal of the data revealed that for internodes/plant at final harvest, the per cent standard heterosis was in the range of -8.60% (NOL 17-06 x Kashi Kranti) to 11.29% (NOL 17-05 x Kashi Kranti) in E_1, -12.21% (NOL 17-06 x Kashi Kranti) to 24.42% (GAO-5 x Arka Anamika) in E_2, 0.35% (NOL 17-09 x Parbhani Kranti) to 23.05% (NOL 17-05 x Kashi Kranti) in E_3 and -4.31% (NOL 17-09 x Parbhani Kranti) to 17.70% (NOL 17-09 x Arka Anamika) in E_4. the promising hybrids were GAO-5 x Arka Anamika (24.42%), AOL-16-04 x Parbhani Kranti (20.35%), NOL 17-09 x Arka Anamika (20.35%), AOL-16-04 x Arka Anamika (19.77%) in E_2, NOL 17-05 x Kashi Kranti (23.05%), NOL 17-05 x Arka Abhay (18.79%), NOL 17-05 x Parbhani Kranti (18.09%) in E_3 and NOL 17-09 x Arka Anamika (17.70%), NOL 17-05 x Arka Abhay (15.31%), NOL 17-09 x Arka Abhay (14.35%) in E_4. For this trait, significant and positive standard heterosis was reported by Bhatt *et al.* (2016) [3] and Nama *et al.* (2017) [7]. For internodal length at final harvest, per cent standard heterosis was in the range of -18.42% (NOL 17-09 x Arka Abhay) to 42.11% (AOL-16-04 x Kashi Kranti) in E_1, -28.00% (NOL 17-09 x Parbhani Kranti) to 28.80% (GO-6 x Arka Abhay) in E_2, -15.17% (NOL 17-09 x Arka Abhay) to 15.40% (GAO-5 x Kashi Kranti) in E_3 and -32.78% (GO-6 x Arka Anamika) to 11.67% (GAO-5 x Arka Abhay and GAO-5 x Kashi Kranti) in E_4. The promising F_1s were NOL 17-09 x Parbhani Kranti (-28.00%) in E_2 and GO-6 x Arka Anamika (-32.78%), NOL

17-09 x Arka Abhay (-25.00%), GO-6 x Kashi Kranti (-23.33%) in E_4 for this trait. For this trait, significant and negative standard heterosis was reported by Patel *et al.* (2015) [8], Verma and Sood (2015) [15], Bhatt *et al.* (2016) [3], Nama *et al.* (2017) [7], Vekariya *et al.* (2019) [13, 14] and Koli (2020) [4].

Increase in number of fruits per plant would automatically improve fruit yield of the crop. For fruits/plant the spectrum of variation was ranged between -6.63% (NOL 17-06 x Kashi Kranti) to 18.67% (NOL 17-09 x Arka Anamika) in E_1, -31.61% (NOL 17-06 x Kashi Kranti) to -1.55% (AOL-16-04 x Parbhani Kranti) in E_2, 5.95% GAO-5 x Parbhani Kranti) to 38.89% (NOL 17-09 x Arka Anamika) in E_3 and -12.25% (NOL 17-06 x Parbhani Kranti) to 11.76% (AOL-16-04 x Kashi Kranti) in E_4. The promising hybrids were NOL 17-09 x Arka Anamika (18.67%), AOL-16-04 x Kashi Kranti (17.47%) in E_1 and NOL 17-09 x Arka Anamika (38.89%), AOL-16-04 x Arka Anamika (30.16%), AOL-16-04 x Parbhani Kranti (28.57%) in E_3. For this trait, significant and positive standard heterosis was reported by Patel *et al.* (2015a) [8], Verma and Sood (2016), Nama *et al.* (2017) [7] and Koli (2020) [4]. Fruit yield is a complex character and its estimate is based on combined action of many yield attributing traits. The estimates of heterosis varied from -4.67% (NOL 17-06 x Parbhani Kranti) to 36.27% (AOL-16-04 x Arka Anamika) in E_1, -12.44% (NOL 17-06 x Parbhani Kranti) to 31.70% (AOL-16-04 x Parbhani Kranti) in E_2, 18.90% (GAO-5 x Parbhani Kranti) to 96.91% (NOL 17-09 x Arka Anamika) in E_3 and -17.86% (NOL 17- 06 x Parbhani Kranti) to 25.87% (NOL 17-09 x Arka Anamika) in E_4. The promising hybrids were AOL-16-04 x Arka Anamika (36.27%), NOL 17-09 x Arka Anamika (32.37%), AOL-16-04 x Parbhani Kranti (28.40%), AOL-16-04 x Parbhani Kranti (31.70%), AOL-16-04 x Arka Anamika (20.22%) in E_2, NOL 17-09 x Arka Anamika (96.91%), AOL-16-04 x Arka Anamika (79.14%), NOL 17-09 x Arka Abhay (68.94%) in E_3 and NOL 17-09 x Arka Anamika (25.87%), AOL-16-04 x Parbhani Kranti (25.16%) in E_4 for this trait. For this trait, significant and positive standard heterosis was reported by Patel *et al.* (2015) [8], Bhatt *et al.* (2016) [3], Nama *et al.* (2017) [7] and Koli (2020) [4]. For fiber content, low value is desirable quality parameter. A perusal of the data revealed that the per cent standard heterosis was in the range of -11.62% (NOL 17-05 x Arka Abhay) to 10.55% (GAO-5 x Arka Anamika) in E_1, -12.53% (NOL 17-05 x Arka Abhay) to 10.80% (GO-6 x Kashi Kranti) in E_2, -8.45% (NOL 17-05 x Parbhani Kranti) to to 12.94%.(GO-6 x Kashi Kranti) in E_3 and 0.32% (NOL 17-09 x Parbhani Kranti) to 17.81% (GAO-5 x Kashi Kranti) in E_4. The promising hybrids were NOL 17-05 x Arka Abhay (-11.62%), NOL 17-05 x Parbhani Kranti (-9.05%) in E_1 and NOL 17-05 x Arka Abhay (-12.53%) in E_4. For this trait, significant and negative standard heterosis was reported Patel *et al.* (2015) [8] and Vekariya *et al.* (2019) [13, 14]. The estimates and magnitude of heterotic effects varied with cross combinations and characters. Similar findings were recorded by Patel (2015a) [8], Vekariya *et al.* (2019) [13, 14] and Koli (2020) [4]. Inconsistent performance of most of the crosses across the environments for various characters suggested that parental genes and their combinations responded differently to environmental variation, which is the general feature of quantitative inheritance. Similar findings were recorded by More (2015) and Vekariya (2019) [13, 14]. A comparative performance of the most heterotic crosses for fruit yield/plant and its component characters in each individual environment is presented in Table 2. The persual of results revealed that for the heterotic effects of fruit yield/plant, only one cross, AOL-16-04 x Parbhani Kranti was consistent across the environments; however, cross AOL-16-04 x Arka Anamika was consistent for heterotic effects in environments E_1, E_2 and E_3. The cross NOL 17-09 x Arka Anamika was consistent in E_1, E_3 and E_4. The photograph of these three crosses is exhibited below as Photograph 1. In general, the crosses which had higher estimates of heterosis for fruit yield also had higher heterotic effects for two or more traits like average fruit length, average fruit girth, average fruit weight, plant height at final harvest, internodes/plant at final harvest and fruits/plant. Similar results were reported by Patel *et al*. (2015) [8], Verma and Sood *et al*. (2015) [15], Vekariya *et al*. (2019) [13, 14] and Koli (2020) [4]. Therefore, heterotic effects for fruit yield/plant could be outcome of direct effects of the above stated component characters. The heterotic effects for fruit yield/plant could be a result of combinational heterosis. However, positive and negative estimates of heterosis for rest of the characters could have checked each other for expression of heterotic effects. Hence, to obtain maximum heterotic effects for fruit yield, desired level of heterosis of each component character should be worked out to identify superior cross combinations. Similar results were reported by Patel *et al*. (2015) [8], Bhatt *et al*. (2016) [3], Vekariya *et al*. (2019) [13, 14] and Koli (2020) [4]. The hybrids with high heterotic effects may offer better chances for cultivation and identification of desirable pure lines in the following advanced generations. Among the parental genotypes, AOL-16-04, NOL 17-09, Arka Anamika and Parbhani Kranti yielded superior heterotic crosses for fruit yield and its component characters; however, undesirable effects of these parents for some of other characters may be looked in to while developing superior hybrids in respect to all the economic attributes. It was evident that, only few component characters of yield *viz*., average fruit length, average fruit girth, average fruit weight, plant height at final harvest, internodes/plant at final harvest and fruits/plant were important for the expression of heterotic effects, however, the heterotic effects of those component characters were greatly influenced by the imposed environmental differences (More, 2015 and Vekariya, 2019) [13, 14]. Therefore, as a breeding strategy the promising hybrids should be evaluated over array of environments.

Table 1: Range of mean, range of standard heterosis and number of significant crosses in okra over the environments.

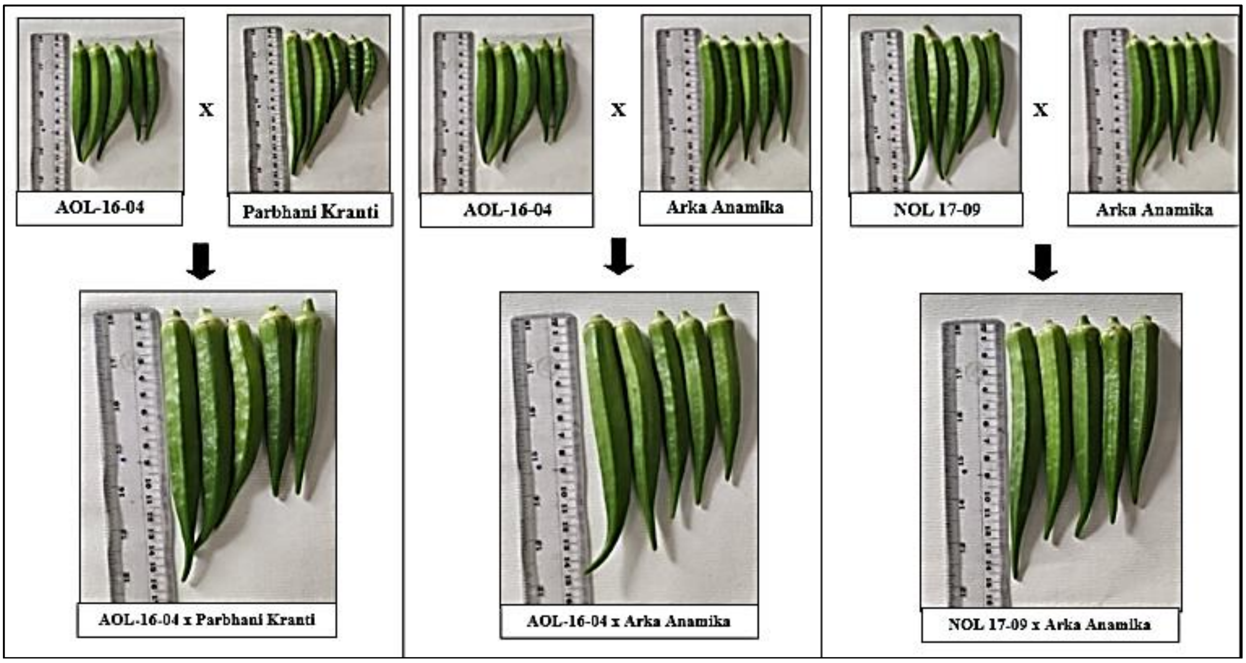
Character	Environment	Range of		Number of significant crosses	
		Mean performance	Standard heterosis	Positive	Negative
Days to 50% flowering	E_1	36.00 - 42.00	-13.60 - 0.80	00	03
	E_2	35.33 - 43.67	-13.11 - 7.38	00	03
	E_3	41.67 - 49.00	-6.02 - 10.53	02	00
	E_4	41.00 - 49.67	-15.75 - 2.05	00	13
Days to first picking	E_1	41.00 - 47.67	-13.99 - 0.00	00	10
	E_2	40.00 - 48.33	-10.45 - 8.21	02	01
	E_3	48.00 - 57.00	-2.70 - 15.54	05	00

	E_4	47.00 - 57.00	-14.02 - 4.27	00	06
Days to last picking	E_1	78.00 - 89.67	-3.70 - 10.70	01	00
	E_2	57.67 - 69.67	-18.40 - -1.42	00	11
	E_3	84.33 - 102.67	0.00 - 21.74	11	00
	E_4	71.00 - 84.67	-13.06 - 3.67	00	03
Average fruit length	E_1	7.35 - 9.91	-1.34 - 33.12	10	00
	E_2	8.01 - 10.35	-8.67 - 18.02	01	00
	E_3	9.76 - 13.92	0.62 - 43.51	07	00
	E_4	8.38 - 12.80	-12.47 - 33.80	08	00
Average fruit girth	E_1	1.25 - 1.64	-4.59 - 25.51	07	00
	E_2	1.26 - 1.55	-16.00 - 3.11	00	03
	E_3	1.24 - 2.99	-0.53 - 140.11	12	00
	E_4	1.16 - 2.93	-5.43 - 139.13	10	00
Average fruit weight	E_1	7.55 - 10.96	-4.95 - 38.04	11	00
	E_2	8.24 - 10.49	-8.44 - 16.59	03	00
	E_3	9.86 - 14.72	8.59 - 16.59	18	00
	E_4	9.08 - 13.59	-9.44 - 35.37	06	00
Plant height at final harvest	E_1	65.30 - 85.43	-6.85 - 21.87	08	00
	E_2	54.87 - 70.80	-2.49 - 25.83	09	00
	E_3	127.20 - 166.47	-2.60 - 27.46	09	00
	E_4	73.00 - 94.07	-22.31- 0.11	00	05
Branches/plant at final harvest	E_1	0.13 - 1.47	-93.75 - 31.25	00	24
	E_2	0.40 - 1.80	-81.25 - -15.63	00	24
	E_3	1.07 - 3.27	-40.74 - 81.48	06	03
	E_4	0.83 - 2.73	-64.29 - 17.14	01	19
Internodes/ plant at final harvest	E_1	11.33 - 13.80	-8.60 - 11.29	00	00
	E_2	10.07 - 14.27	-12.21 - 24.42	04	00
	E_3	18.87 - 23.13	0.35 - 23.05	05	00
	E_4	13.33 - 16.40	-4.31 - 17.70	04	00
Internodal length at final harvest	E_1	4.13 - 7.20	-18.42 - 42.11	04	00
	E_2	3.00 - 5.37	-28.00 - 28.80	01	01
	E_3	5.97 - 8.12	-15.17 - 15.40	00	00
	E_4	4.03 - 6.70	-32.78 - 11.67	00	04
Fruits/plant	E_1	10.33 - 13.13	-6.63 - 18.67	02	00
	E_2	8.80 - 12.67	-31.61 - -1.55	00	21
	E_3	17.80 - 23.33	5.95- 38.89	08	00
	E_4	11.93 - 15.20	-12.25 - 11.76	00	00
Fruit yield/plant	E_1	108.21 - 154.69	-4.47 - 36.27	07	00
	E_2	98.12 - 147.58	-12.44 - 31.70	02	00
	E_3	201.72 - 334.06	18.90 - 96.91	23	00
	E_4	127.97 - 196.11	-17.86 - 25.87	02	00
Fiber content	E_1	4.13 - 5.17	-11.62 - 10.55	01	02
	E_2	3.89 - 4.92	-12.53 - 10.80	04	01
	E_3	4.08 - 5.03	-8.45 - 12.94	03	00
	E_4	4.19 - 4.92	0.32 - 17.81	16	00

Table 2: Promising hybrids for standard heterosis for fruit yield/plant and its component traits over environments in okra

S. No.	Hybrid	Fruit yield/plant (g)	Standard heterosis (%)	Useful and significant standard heterosis (%) for component traits
		E_1		
1	AOL-16-04 x Arka Anamika	154.69	36.27**	Days to first picking, average fruit length, average fruit weight, plant height at final harvest,
2	NOL 17-09 x Arka Anamika	150.27	32.37**	Days to first picking, days to last picking. average fruit length, average fruit weight, fruits/ plant
3	AOL-16-04 x Parbhani Kranti	145.55	28.40**	Days to 50% flowering, days to first picking, average fruit length, average fruit girth, average fruit weight
		E_2		
1	AOL-16-04 x Parbhani Kranti	147.58	31.70**	Plant height at final harvest, internodes/plant at final harvest
2	AOL-16-04 x Arka Anamika	134.71	20.22*	Plant height at final harvest, internodes/plant at final harvest
		E_3		
1	NOL 17-09 x Arka Anamika	334.06	96.91**	Days to last picking, average fruit length, average fruit girth, average fruit weight, branches/plant at final harvest fruits/ plant
2	AOL-16-04 x Arka Anamika	303.92	79.14**	Days to last picking, average fruit girth , average fruit weight, plant height at final harvest, branches/plant at final harvest, fruits/ plant
3	NOL 17-09 x Arka Abhay	286.62	68.94**	Average fruit length , average fruit girth, average fruit weight, branches/plant at final harvest

4	AOL-16-04 x Parbhani Kranti	195.01	67.55**	Days to last picking, average fruit length, average fruit girth, average fruit weight, plant height at final harvest, branches/plant at final harvest, fruits/ plant
E_4				
1	NOL 17-09 x Arka Anamika	196.11	25.87*	Days to 50% flowering, average fruit length, average fruit girth, average fruit weight, internodes/plant at final harvest
2	AOL-16-04 x Parbhani Kranti	195.01	25.16*	Average fruit length, average fruit girth, average fruit weight



Photograph 1: Photograph of fresh marketable fruits of top ranking hybrids with their parents

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