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Development of Okra (*Abelmoschus esculentus* L. Moench) Hybrids Derived from Selected Inbreds under Drought Stress

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ABSTRACT

Due to the increased water shortage and frequent drought in Egypt, it is essential to develop drought-tolerant plants. Therefore, five drought tolerance lines of okra were used to develop superior hybrids under drought conditions, using a half-diallel mating design to produce fifteen hybrids. There were significant differences among the hybrids and their parents in mean squares for all studied traits. The hybrids (P_2XP_6), (P_2XP_3), (P_1XP_2) and (P_2XP_4) exhibited the maximum mid- parents (MP) and better parent (BP) heterosis for total yield/plant.The mean squares for general (GCA) and specific combining abilities (SCA) were significant for studied traits, which indicates the importance of additive and non-additive gene actions in the inheritance of the studied traits in okra.The magnitudes of additive genetic variance (σ^2A) were larger than their corresponding non-additive genetic variance (σ^2D) for plant height, number of branches per plant, number of days to 50% flowering, pod length and total yield/plant. This revealed the major effect of additive inheritance for these traits.Genetic analysis illustrated that broad sense heritability (h^2_{bs}%) values were larger than their corresponding heritability in narrow sense(h^2_{ns}%) for all studied characters.As for the correlations between yield component traits, there were significant and positive genotypic correlation (r_g) among total yield/plant and plant height, average pod weight and number of pods/plant. Overall, these crosses are promising hybrids with high yielding ability, and could be commercially recommended to improve economical traits in okra under drought conditions.

Keywords: okra, heterosis, combining ability, gene action, heritability, correlation.

INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench) is widely grown in tropical, subtropical and warm regions of the world (Saifullah and Rabbani, 2009; Costa *et al.*, 2018). It is an important vegetable crop, quite popular in Egypt because of the preferable immature fruits, dependable yield and plant adaptability to different environmental conditions and its nutritional value (Priya *et al.*, 2014). It is a major source of vitamins A, B, C and some minerals (Singh *et al.*, 2014 and Gemede *et al.*, 2015).

Due to the lack of water resources, the increased water shortage and frequent drought in agricultural ecosystems in Egypt, it is essential to develop water-saving and drought-tolerant plants to ensure food security. Drought is a serious agricultural stress in arid countries of the world. It has become a serious problem in Egypt due to the lack of water resources, the effects of the desertification and the ecological degradation. Moreover, climate change is expected to increase the occurrence and severity of drought due to higher evapotranspiration and rising temperatures. Drought causes severe reduction in vegetable growth, photosynthetic pigments, physiological properties, minerals uptake and allocation, plant flowering and yield (Romaisa *et al.,* 2015; Deveci *et al.,* 2017; Murat *et al*., 2017). However, plants vary in their qualitative and quantitative responses to water stress. The drought tolerance related traits are complex and not adequately understood (Osmanzni *et al.,* 1987). This complexity arises as a result of number of morphological, physiological and biochemical systems within plant, which are related to drought tolerance.

Scientists, technologists and farmers have pointed out the importance of F1 hybrids. In okra, exploitation of hybrid vigor is an important tool for making genetically improvement of yield and its components. The study of heterosis would help in developing of heterotic crosses for drought tolerance in okra. Moreover, heterosis is an effective mean of combining together the favorable traits of two varieties (Bassey *et al.,* 2010; Wammanda *et al.,* 2010). F1 hybrids have more vigor, better yield and quality (Dahake and Bangar, 2006);Vachhani and Shekhat, 2008; Reddy *et al.,* 2012b). Okra has high chromosome number (2n=72-144).Therefore, the creation of F1 hybrids requires homozygous inbred lines to exploit heterosis in okra (Dias, 2011).

Knowledge on the magnitude of heterosis for various traits is important to locate various interactions to exploit them through heterosis breeding, (Jindal *et al.,* 2009; Singh *et al.,* 2009). Several workers have reported heterosis over their better and mid parents in okra (Singh *et al*, 2009; Reddy *et al.*, 2012_b). These heterotic effects may range from significantly positive to significantly negative depending on genetic makeup of parents (Mehta *et al.,* 2007; Weerasekara *et al.,* 2007; Jindal *et al.,* 2009). The useful heterotic patterns in the development of hybrid varieties of okra, and the use of heterosis gain high yield

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and improved quality were reported and exploited by Reddy *et al.*, (2012 $_b$).

Diallel cross analysis is a powerful tool for characterizing the genetic structure of plant genotypes and estimating the general and specific combining abilities of parents and consequently would help in selecting of desirable parents (El-Gendy *et al.*, 2012). Additive and non-additive genetic variances control total yield and its components traits in okra (Reddy *et al.*, 2011); Reddy *et al.*, 2013); Sawadogo *et al.*, 2014; Kumar and Reddy, 2016$_b$; Priyanka *et al.*, 2018). Selection of okra genotypes with considerable drought tolerance and good economic traits through different breeding strategies is considered to be an economic and efficient mean to alleviate drought problems in water stressed area.

This study was carried out to improve yield of okra hybrids and ensure its sustainability under adverse conditions through breeding drought tolerance okra hybrids.

MATERIALS AND METHODS

Genetic materials and procedures:

The genetic materials used in the current study include six okra inbred lines (P_1, P_2, P_3, P_4, P_5 and P_6) that were obtained from a previous breeding program and were selected according to their potential for drought resistance (Ibrahim *et al.*, 2018). The present study was carried out at El-Baramon Research Station, Horticulture Research Institute, Agricultural Research Center, during the summer seasons of 2017, 2018 and 2019. In the season of 2017, the six advanced inbred lines were sown and selfed to produce adequate quantities of parental seeds. In the season of 2018, the parental inbreds were sown and crosses among lines were made in all possible combinations, excluding reciprocals (in a half-diallel mating design), to produce fifteen F_1 hybrids. Afterwards, all okra genotypes, including 6 parental inbred lines and 15 F_1 hybrids, were sown in 20th March, 2019 in an evaluation experiment. The experiment comprised of three replications and each plot was 4 rows, 3 m. long and 0.6 m width and a plant-to-plant spacing of 0.3 m was adopted, a plant population of 10 plants per row. As for irrigation regime, okra plants were exposed to 50 % of field capacity. Agricultural practices were applied as recommended for the commercial okra production.

Data record and measurements:

Measurements were recorded on randomly chosen five plants from each plot for the following traits: Plant height (P.H cm), Number of branches/plant (No. B/P), Number of days to 50% flowering (No. D.F), Pod Length (P.L cm), Pod Diameter (P.D cm), Average pod weight (A.P.W g), Number of pods /plant (No. P. /P) and Total yield/plant (T.Y./P g).

Genetical analyses:

Data were subjected to statistical analysis of variance and the F-test according to Snedecor and Cochran (1982). For the comparison among the various genotypic means, LSD test was used. Half diallel analysis was carried out to provide information on general (GCA) and specific (SCA) combining abilities, and to indicate the different types of gene action. Sum squares of the investigated genotypes was partitioned into sources of variations due to general combining ability (GCA) and specific combining ability (SCA) according to Griffing's Method-II-Model-I (Griffing, 1956).

The heterotic effects were computed as a deviation of the mid- parents (MP) and the better parent (BP) for all the characters , following the standard formula according to Fehr, 1987.

$$\mathbf{H\ \%\ (M.P) = F1 - M.P / M.P\ X100} \quad \textbf{and}$$
$$\mathbf{H\ \%\ (B.P) = F1- B.P / B.P\ X100.}$$

The variances of GCA (σ^2g) and SCA (σ^2s) were obtained on the basis of the expected mean squares for all studied traits.

$$\mathbf{GCA\ effect\ (g_i) = 1/\ n+2\ [(\Sigma(Yi. +Yii) - 2 / n\ Y..)]}$$
$$\mathbf{SCA\ effect\ (S_{ij}) = Yij- 1 / n+2\ (Yi. + Yii + Y.j + Yjj) + 2 / (n+1)\ (n+2)\ Y..}$$

Additive (σ^2A) and non-additive (σ^2D) genetic variances were estimated according to Matzinger and Kempthorne (1956) as follows:

$$\sigma^2 A = 2\ \sigma^2 g \qquad \sigma^2 D = \sigma^2 s$$

Estimates of heritability in broad sense ($h^2_{b \cdot s}$) and narrow sense ($h^2_{n \cdot s}$) were measured according to the following equations:

$$h^2_{b \cdot s}\ \% = (2\ \sigma^2 g + \sigma^2 s / 2\ \sigma^2 g + \sigma^2 s + \sigma^2 e)\ x\ 100$$
$$h^2_{n \cdot s}\ \% = (2\ \sigma^2 g / 2\ \sigma^2 g + \sigma^2 s + \sigma^2 e)\ x\ 100$$

Phenotypic (r_{ph}) and genotypic (r_g) correlations among pairs of the studied characters were calculated as outlined by Singh and Chaudhary, 1985.

$$r_g = cov.g_{1.2} / (\sigma^2_{g1} \cdot \sigma^2_{g2})^{1/2}$$
$$r_{ph} = cov.ph_{1.2} / (\sigma^2_{ph1} \cdot \sigma^2_{ph2})^{1/2}$$

RESULTS AND DISCUSSION

Analysis of variance:

The analysis of variance and the mean squares for plant height, number of branches per plant, number of days to 50% flowering; pod length, pod diameter, average pod weight, number of pods per plant and total yield per plant are shown in Table (1).

Table 1. Analysis of variance and mean squares of all genotypes for studied traits in okra.

S.O.V	d.f	P.H (cm)	No. B./P	No. D.F	P.L (cm)	P.D (cm)	A.P.W(g)	No. P./P	T.Y./P (g)
Replication	2	12.64	0.43	5.44	0.02	0.01	0.03	2.21	666.92
Genotypes	20	1249.19**	3.08**	74.79**	3.52**	0.05**	2.72**	232.56**	25169.74**
Error	40	15.21	0.51	3.51	0.008	0.005	0.026	5.09	536.16

P.H: plant height, No. B. / P: number of branches per plant, No. D. F: number of days to 50% flowering, P.L: Pod Length, P.D: pod diameter, A.P.W: average pod weight, No. P. /P: number of pods per plant and T.Y./P: total yield per plant. **: significant at 0.01 level of probability.

The results of the analysis of variance reveal that the mean squares of genotypes were highly significant for all studied traits. Furthermore, the genotypic mean squares were larger than error mean squares. These results reflect that the genotypes were the major component variance in the overall phenotypic variance. The significant differences between genotypes are attributed to the different genetic sources utilized in the present study. Generally, half diallel crossing mating design could be exploited in order to partition of the genetic variance to its components . Similar results were reported by (El-Gendy *et al*., 2012; Reddy *et al.*, 2013; Shwetha *et al.*, 2018).

Mean performance and heterosis

Ranges of the means of parents, F_1 hybrids and heterosis over mid- parents (M.P) and better parent (B.P) with the best four hybrids are shown in Table (2). The okra hybrids exhibit the positive or negative heterotic effects over mid-parents and better-parent. The positive heterosis may be attributed to the varying extent of genetic diversity among parental inbred lines of different crosses combinations. Meanwhile, the negative heterosis may be attributed to the combination of unfavorable genes of the parents into the new crosses. For plant height, parents varied widely from 124.11 to 208.22 cm while, F_1 hybrids was varied from 163.89 to 212.78 cm and heterosis values ranged from – 7.41 to 20.22 % and from -13.71 to 6.49 % over M.P and B.P, respectively. The present results are in agreement with those reported by Kumar and Reddy (2016a) and Jindal *et al*., (2009) on okra. The hybrids (P_1XP_3), (P_2XP_3), (P_3XP_6), (P_1XP_5) were taller than their mid – parental values by 15.31 to 20.22 %, while the hybrids (P_1XP_3); (P_1XP_2); (P_2XP_3) and (P_1XP_4) were taller than their respective tallest parent by 2.52 to 6.49 %.Regarding number of branches/plant, the mean performances of parents varied from 1.00 to 4.33 while, F_1 hybrids ranged from 1.67 to 4.33 and the estimates of heterosis varied from – 17.45 to 73.32 % and from – 53.03 to 85.84 % over mid parents and better parent, respectively. Additionally, heterosis over mid parents in the best four hybrids ranged from 39.99 % for the cross (P_2XP_3) to 73.32 % for (P_5XP_6), while the estimated values of heterosis over better parents varied from 17.98 % for the hybrid (P_5XP_6), to 85.84 % for the hybrid (P_2XP_5). As for the number of days to 50% flowering, the results in Table (2) elucidate that parents varied widely ranging from 49.33 to 65.00, while range was observed in the F_1 hybrids from 50.00 to 67.00 and heterosis estimates ranged from -14.66 to 11.36 % and from -12.83 to 21.09 % over mid parents and better parent, respectively. The cross (P_1XP_5) had the highest heterosis over both mid parents (11.36%) and better parent (21.09%). Such results reflect a general agreement with the findings of El- Gendy *et al.* (2012) and El- Gendy *et al.* (2013) on okra.

Table 2. Range, mean values of parents, F_1 hybrid and heterosis over mid parents and better parent with the best four hybrids among okra crosses.

Traits	Range				The best four hybrids (heterosis %) over	
	Mean performance		Heterosis			
	Parents	F_1s	M.P	B.P	M.P	B.P
P. H (cm)	124.11 -208.22	163.89 -212.78	-7.41 - 20.22	-13.71- 6.49	20.22(P_1XP_3), 17.70(P_2XP_3), 15.41(P_3XP_6), 15.31(P_1XP_5)	6.49(P_1XP_3), 5.49(P_1XP_2), 2.78(P_2XP_3), 2.52(P_1XP_4)
No. B. / P	1.00 - 4.33	1.67 - 4.33	-17.45 -73.32	-53.03 -85.84	73.32(P_5XP_6), 71.46(P_3XP_6), 44.44(P_2XP_5), 39.99(P_2XP_3)	85.84(P_2XP_5), 50.38(P_3XP_6), 18.00(P_1XP_5), 17.98(P_5XP_6)
No. D. F	49.33 - 65.00	50.00 - 67.00	-14.66 -11.36	-12.83 -21.09	11.36(P_1XP_5), 11.26(P_1XP_2), 7.64(P_1XP_3), 4.75(P_1XP_4)	21.09(P_1XP_5), 16.89(P_3XP_5), 14.19(P_1XP_3), 13.27(P_1XP_2)
P. L (cm)	3.82 - 7.05	3.99 - 6.90	-3.81 - 22.09	-13.48 -11.41	22.09(P_3XP_4), 15.98(P_2XP_3), 15.70(P_3XP_5), 14.33(P_2XP_4)	11.41(P_2XP_4), 3.06(P_4XP_5), 1.06(P_1XP_2), 0.85(P_1XP_6)
P. D (cm)	1.48 - 1.93	1.52 - 1.94	-9.55 - 12.70	-15.03 -12.12	12.70(P_1XP_2), 8.46(P_2XP_5), 6.62(P_2XP_3), 6.57(P_3XP_5)	12.12(P_1XP_2), 1.23(P_1XP_3), 1.21(P_2XP_3), 1.18(P_1XP_4)
A. P.W (g)	3.64 - 6.15	5.05 - 6.83	8.66 - 50.04	6.35 - 35.06	50.04(P_3XP_6), 45.64(P_4XP_6), 40.42(P_3XP_4), 37.75(P_1XP_3)	35.06(P_4XP_6), 26.34(P_2XP_4), 25.32(P_1XP_3), 25.14(P_3XP_6)
No. P. / P	58.00 - 84.00	75.00 - 95.33	2.69 - 26.14	-10.71 -18.17	26.14(P_2XP_3), 22.73(P_2XP_6), 22.57(P_3XP_4),1 19.75(P_1XP_2)	18.17(P_2XP_6), 13.10(P_1XP_2), 12.05(P_2XP_3), 11.60(P_2XP_4)
T.Y./P (g)	293.00 - 418.13	322.00 -552.27	3.56 – 69.46	1.96 -58.49	69.46(P_2XP_6), 66.24(P_2XP_3), 50.30(P_2XP_4), 49.89(P_1XP_2)	58.49(P_2XP_3), 56.00(P_2XP_6), 44.54(P_1XP_2), 41.19(P_2XP_4)

(P.H): Plant height; (No. B. / P): Number of branches per plant; (No. D. F): Number of days to 50% flowering; (P.L): Pod Length; (P.D): Pod Diameter; (A.P.W): Average Pod weight; (No. P. /P): Number of Pods per plant and (T.Y./P): Total yield per plant. F_{1s}: First hybrids

Concerning pod characteristics, the performance of inbred lines and their F_1 hybrids for pod length ranged from 3.82 to 7.05 cm for parents and 3.99 to 6.90 cm for F_{1S}, while heterosis estimates varied from - 3.81 to 22.09 % and from - 13.48 to 11.41 % over mid parents and better parent, respectively. Furthermore, heterosis over mid parents for the best four hybrids varied from 14.33 % for the cross (P_2 X P_4) to 22.09 % for the hybrid (P_3 X P_4). In the same manner, heterosis over better parent for the best four cross ranged from 0.85 % for the hybrid (P_1 X P_6) to 11.41 % for the cross (P_2 X P_4). Also, for pod diameter mean performances ranged from 1.48 to 1.93 cm for parents and 1.52 to 1.94 cm for F_1 hybrids, heterosis estimates ranged from - 9.55 to 12.70 % and from - 15.03 to 12.12 % over mid parents and better parent, respectively. It is evident that, heterosis over mid parents for the best four crosses varied from 6.57 % for the cross (P_3XP_5) to 12.70 % for the cross (P_1 X P_2). Heterosis percentages over the better parent for the best four crosses varied from 1.18 % for the cross (P_1 X P_4) to 12.12 % for the cross (P_1 X P_2). Such results are in harmony with those reported by Sawadogo *et al.* (2014) on okra and Abd El-Hadi *et al.* (2014) on summer squash.

For average pod weight, parents ranged from 3.64 to 6.15 g, while F_1 hybrids ranged from 5.05 to 6.83 g. Heterosis estimates over mid parents ranged from 8.66 to 50.04 %, while those over better parent ranged from 6.35 to 35.06 %. Heterosis of mid parents for the best four crosses ranged from 37.75 % (P_1 X P_3) to 50.04 % (P_3 X P_6). Heterosis over better parent for the best four crosses ranged from 25.14 (P_3 X P_6) to 35.06 % for the cross (P_4 X P_6). For number of pods/ plant trait, data show that the mean performance values for parents and their F_1 hybrids ranged from 58.00 to 84.00 and from 75.0 to 95.33%, respectively, while the detected heterosis varied from 2.69 to 26.14 % and from -10.71 to 18.17 % over mid parents and better parents, respectively. For the cross (P_2 X P_3) heterosis over mid parents for the best four crosses ranged from 19.75 for the hybrid (P_1 X P_2) to 26.14 %, while heterosis over the better parents in the best four crosses varied from 11.60 for cross (P_2 X P_4) to 18.17 % for the cross (P_2 X P_6). For total yield/ plant, the calculated values of mean performance for both parents and their F_1 hybrids were ranged from 293.00 to 418.13 and 322.00 to 552.27, respectively. While, heterosis ranged from 3.56 to 69.46 % and 1.96 to 58.49 % over mid parents and better parents, respectively. In the best four crosses, heterosis estimates varied from 49.89 to 69.46 % and from 41.19 to 58.49 % over mid-parents and better parents, respectively. The heterosis observed for total yield per plant was attributed to the heterosis exhibited for growth and yield parameters. As there is a significant genotypic association between yield and yield parameters like pod length, average pod weight and number of pods/ plant. Heterosis observed for these component characters have greatly contributed for higher magnitude of heterosis observed for total yield. Heterosis is believed to arise from the combined action and interaction of allelic and non-allelic factors and is usually correlated with heterozygousity. Similar findings were illustrated by Falconer and Mackay, (1996) and Assar *et al.*, (2010) on tomato. However, for exploitation of heterosis, the information on general combining ability should be supplemented with specific combing ability and hybrid performance.

These trends indicate that F_1's produced higher yield than their respective parents under drought stress. These findings were reinforced by Weerasekara *et al.*, 2007; Reddy *et al.*, 2012; Kumar and Reddy, 2016a.

Analysis of combining ability variances:

The results in Table (3) represent the analysis of variance of the half-diallel mating scheme for the various recorded traits. The mean squares for GCA and SCA were significant or highly significant for all investigated characters. These findings indicate the importance of additive and non-additive gene actions in the inheritance of the studied traits in okra. With respect to GCA / SCA ratio, it is clearly that general combining ability mean squares were larger than their corresponding mean squares of specific combining ability for No. B / P ,P.L and T.Y./P, indicating that the additive effects were more important than non additive action for the studied traits. Otherwise, the SCA means squares were larger for No. D. F,P. D., A. P.W. and No. P. / P . This suggests that the major contribution of non-additive effects in the inheritance of these traits. As the results of the ratio of δ^2gca / δ^2sca was greater than one for No. B. / P, P. L. and T.Y. / P. On the other hand, less one for No. D.F.; P.D.; A. P.W. and No. P. /P. traits. These results are consistent with the findings of Obiadalla- Ali (2006) on summer squash and Sanin *et al* (2014) on pumpkin.

Table 3. Analysis of variance and mean squares for combining ability analysis in okra crosses.

S.O.V	d.f	P.H(cm)	No. B/P	No. D.F	P.L (cm)	P.D (cm)	A.P.W (g)	No. P./P	T.Y./P (g)
δ^2 gca	5	414.9**	1.10**	15.61**	1.53*	0.01*	0.23*	46.76**	1250.70**
δ^2sca	14	415.1**	0.36*	40.07*	0.45*	0.02*	2.24**	133.90**	22.13**
Error	40	15.21	0.51	3.51	0.01	0.01	0.03	5.09	5.16
δ^2gca/δ^2sca		1.00	3.06	0.39	3.40	0.50	0.10	0.35	56.52

(P.H): Plant height; (No. B. / P): Number of branches per plant; (No. D. F): Number of days to 50% flowering; (P.L): Pod Length; (P.D): Pod Diameter; (A.P.W): Average Pod weight; (No. P. /P): Number of Pods per plant and (T.Y./P): Total yield per plant. *, **: significant at 0.05 and 0.01 levels of probability, respectively.

General Combining ability effects (g_i):

Information on general combining ability effects of six parental lines together with high mean performance increases the chance of getting suitable hybrids. Magnitudes of general combing ability effects (g_i) of six parental lines for the examined characterss are given in Table (4). The obtained data show positive and significant estimations for all studied characterss. In the same time, the results elucidate that the GCA effects had undesirable negative and highly significant values for some parents. As for plant height, (P_5) surpassed it is rivals by attaining value of (14.76 ± 0.73) followed by (P_2) (11.69 ± 0.73) and (P_4) (1.72 ± 0.73). Concerning number of branches/ plant, the parental inbred line (P_5) expressed its superiority with GCA value of (0.83 ± 0.33), followed by (P_4) (0.50 ±0.33) and (P_1) (0.25 ± 0.33). In case of number of days to 50% flowering, the parent (P_5) gave higher magnitude of GCA (2.90 ± 0.35) followed by P_4 (1.70 ± 0.35), P_1 (1.07 ± 0.35) and P_2 (0.32 ± 0.35). Regarding pod length, parents P_3 and P_4 were the best combiners with (1.45 ± 0.02) and (0.26 ± 0.02) GCA value among parents for pod length. The best combiner for average pod weight trait was shown by P_5

(0.52±0.30). The same data illustrated that, P_1 gave the highest value of GCA for No.P./P (4.35 ± 0.42) followed by (P_6) (4.06 ± 0.42) and P_2 (3.18 ± 0.42) . About the total yield/ plant, the estimation of GCA effects show that P_2 gave the greatest value (35.42 ± 4.32) followed by P_5 (35.38 ± 4.32) while, P_1 had the lowest GCA effects (28.10 ± 4.32). Al-Ballat, (2008) reported that, none of the parents was the best general combiner for all studied traits. Also, Pradip *et al.*, (2013) suggested that the high GCA effects are attributed to additive gene effects or additive X additive interaction effects and represent a fixable portion of genetic variation.

It could be suggested that parents with positive GCA effects were considered to be better combiners. The estimated general combining ability and heterosis effect were influenced by dominant gene action types. Therefore, general combining ability and heterosis effect are positively associated (Yustiana, 2013). These findings could be used to select parents in the hybrids breeding program to gain more heterotic effects.

Table 4. Estimations of general combining ability (GCA) effects of parental inbreds for different traits of okra.

Parents	P.H.(cm)	No. B/P	No. D.F	P.L (cm)	P.D (cm)	A.P.W (g)	No. P./P	T.Y./P (g)
P_1	-0.88*	0.25	1.07*	-0.07*	0.02*	-0.20	4.35**	28.09**
P_2	11.69**	-0.20	0.32	-0.20*	0.31**	-0.09	3.18**	35.48**
P_3	-18.20**	-0.79**	-4.51**	1.45**	-0.08*	0.51**	-6.36**	-23.45**
P_4	1.71**	0.50**	1.69**	0.26**	-0.04*	-0.29	-0.69*	-45.07**
P_5	14.75**	0.83**	2.90**	-0.35**	0.12**	0.52**	-4.53**	35.38**
P_6	-9.07**	-0.58**	-1.47**	-0.57**	-0.06*	-0.45*	4.06**	-30.44**
S.E. (gi)	0.72	0.33	0.35	0.02	0.01	0.30	0.42	4.31

(P.H): Plant height; (No. B. / P): Number of branches per plant; (No. D. F): Number of days to 50% flowering; (P.L): Pod Length; (P.D): Pod Diameter; (A.P.W): Average Pod weight; (No. P. /P): Number of Pods per plant and (T.Y./P): Total yield per plant. *, **: significant at 0.05 and 0.01 levels of probability, respectively.

Specific combining ability effects (s_{ij}):

The results in Table (5) illustrate the estimates of specific combing ability effects (s_{ij}) of 15 F_1 hybrids. For plant height, the F_1 hybrids P_1 X P_5 showed largest value of SCA effects (17.63 ±1.65) followed by P_3 X P_6 (11.58 ±1.65), P_2 X P_3 (11.44 ±1.65) and P_1 X P_2 (10.80 ±1.65).

While, the F_1 hybrid P_5 X P_6 , P_2 X P_5, P_3 X P_6 and P_2 X P_3 showed highly significant effects (1.33± 0.30, 0.76 ± 0.30; 0.42 ± 0.30 and 0.38 ± 0.30), respectively for number of branches/plant. For number of days to 50% flowering, P_1 X P_5 showed highly significant effects and highly value of specific combining ability effects (5.20 ± 0.79) followed by the cross P_5 X P_6 (4.93 ± 0.79), P_1 X P_2 (3.46 ± 0.79) and P_1X P_4 (2.08 ± 0.79). Otherwise, The F_1 hybrid P_3 X P_4 and P_2 X P_4 were at the greatest SCA values of (0.65 ± 0.04) and (0.38 ± 0.04), respectively for pod length traits, (0.12 ± 0.03) P_1 X P_2 and (0.11 ± 0.03) P_2 X P_5 for pod diameter traits. For average pod weight, the SCA effects of F_1 hybrid P_3 X P_6 was the greatest (0.94 ± 0.07) as concerns P_3 X P_4 (0.78 ± 0.07); P_1 X P_3 (0.71 ± 0.07) and (P_1 X P_5 and P_4 X P_6)(0.67± 0.07), respectively.

Table 5. Estimates of specific combining ability (SCA) effects of cross combinations for different characters of okra

Crosses	P.H(cm)	No. B./P	No. D.F	P.L (cm)	P.D (cm)	A.P.W (g)	No. P./P	T.Y./P (g)
P_1 X P_2	10.80**	-0.33*	3.46**	-0.02	0.12*	0.18*	7.06**	36.86**
P_1 X P_3	9.10**	-0.08	1.95**	0.29*	0.03	0.71**	-3.40**	65.90**
P_1 X P_4	7.17**	0.30	2.08**	-0.32**	0.06*	0.43**	2.27**	72.41**
P_1 X P_5	17.63**	0.30	5.20**	0.11*	-0.05*	0.67**	1.44*	47.06**
P_1 X P_6	-7.44**	0.05	-3.42**	0.34**	0.01	-0.12*	2.85**	23.48**
P_2 X P_3	11.44**	0.38*	1.04*	0.37**	0.03	0.37**	6.44**	98.21**
P_2 X P_4	3.00**	-0.24	1.16**	0.38**	-0.09**	0.47**	0.43	59.62**
P_2 X P_5	1.46	0.76**	-2.05**	-0.03	0.11*	0.50**	2.60**	37.57**
P_2 X P_6	-1.92*	-0.16	-1.34**	-0.31**	0.01	0.42**	7.68**	96.60**
P_3 X P_4	7.60**	0.01	-3.68**	0.65**	-0.03	0.78**	6.31**	-51.24**
P_3 X P_5	1.86*	0.01	1.46*	0.34**	0.09*	0.05	5.48**	54.81**
P_3 X P_6	11.58**	0.42**	-1.84**	0.16*	-0.02	0.94**	4.56**	-9.57
P_4 X P_5	-15.87**	-0.29	-2.42**	-0.08*	-0.12**	-0.39**	0.81*	-2.73
P_4 X P_6	-1.84*	-0.54**	-3.38**	-0.03	-0.01	0.67**	4.23**	13.05**
P_5 X P_6	0.12	1.13**	4.93**	0.05	0.07*	0.66**	-3.61**	52.20**
S.E.(ij)	1.65	0.30	0.79	0.04	0.03	0.07	0.95	11.85

(P.H): Plant height; (No. B. / P): Number of branches per plant; (No. D. F): Number of days to 50% flowering; (P.L): Pod Length; (P.D): Pod Diameter; (A.P.W): Average Pod weight; (No. P. /P): Number of Pods per plant and (T.Y./P): Total yield per plant. *, **: significant at 0.05 and 0.01 levels of probability, respectively.

In addition, five of the F_1 hybrids (P_2 X P_6; P_1 X P_2; P_2 X P_3; P_3 X P_4 and P_3 X P_5) indicated positive significant values of specific combining ability effects for number of pods per plant. Moreover, the positive significant values of specific combining ability effects were found in seven F_1 hybrids (P_2 X P_3 (98.21± 11.85), P_2 X P_6 (96.60 ± 11.85), P_1 X P_4 (72.41 ± 11.85), P_1 X P_3 (65.90 ± 11.85), P_2 X $P_4$59.62 ± 11.85), P_3 X P_5 (54.81 ± 11.85 and P_5 X P_6 (52.20± 11.85) for total yield per plant trait. The same finding was reported by Assar *et al.* (2010) on tomato and Kumar and Reddy (2016_b) on okra. In general, high specific combining ability effects manifestation by hybrids where both the parents were good, general combiner might be attributed to upper- case additive X additive gene action. At the same time, the high X low interaction, besides expressing the favorable additive effect of the large parent, manifested some complementary gene interaction effects with a larger SCA. However, the biggest part of the heterosis displayed by suchlike crosses may be attributed to additive X dominance type of gene action. The best crosses involved at least one parent with high general combining ability effects can be used as a selection criteria for the identification of superior genotypes. Parents with high GCA did not essential produce hybrids with high SCA, but interaction of parents with average or low GCS usually produce hybrids with high SCA. The results come with an agreement with previous ones reported by other investigators, on ridge gourd, Pradip *et al.* (2013), and on pumpkin Sanin *et al.* (2014). Furthermore, most of the other hybrids exhibited positive and relatively high estimated for this trait. Hybrids elucidate the positive and high specific combining ability (SCA) effects suggested the non-additive gene action in the inheritance of traits under this study. These results were in conformity to the reports of Medagam *et al.,* (2013).

Genetic parameters and heritability:

The genetic parameters, i.e. phenotypic (σ^2 *Ph*), genotypic ($\sigma^2 g$), additive ($\sigma^2 A$) and non-additive ($\sigma^2 D$) , degree of dominance (*D. d*) in addition to heritability in broad sense (h^2_{bs} *%*) and narrow sense (h^2_{ns}*%*) are presented in Table (6). The genetic analysis reflects that the genotypic variance contributed a big portion in the phenotypic variance for all the various studied traits, revealing that these traits were affected by genetic factors to express the phenotypic variance. Both additive ($\sigma^2 A$) and non–additive genetic variances including dominance ($\sigma^2 D$) genetic variance were found to be positive for all studied traits.

This observation revealed the importance of additive and non- additive gene actions in controlling the inheritance of the studied traits. The dominance ($\sigma^2 D$) variance was larger than the corresponding values of additive variance ($\sigma^2 A$) for A.P.W and No. P. / P traits, which suggests that the dominance genetic exhibited the major influence in the genetic expression of these characters. In this respect, on okra plant, Solanky and Singh (2010); El- Gendy *et al.* (2012) and El- Gendy *and* El- Sherbeny (2013), found that non additive genetic variance was larger than the additive genetic variance for plant height, number of branches, number of pods/plant and pod yield/plant in okra plants. Coversely, the additive variance were smaller than non-additive ($\sigma^2 D$) for P.H; No. B/P; No. D.F. and T.Y. / P traits. This suggests that the additive genetic variances showed a minor role in the genetic expression of such charactes.

The degree of dominance estimations of P.H. (0.71), No. B/P (0.41), P.L. (0.38) and P.D. (0.76) indicate that partial dominance influences the inheritance of these traits, whereas the corresponding values of degree of dominance for No. D. F (1.13), A.P.W (2.21), No. P. / P (1.20) and T.Y. / P (2.98) reflect the over dominance gene action in the inheritance of mentioned characters. These could be varied by the degree of dominance (*D.d*) which were less than one, revealing the importance of partial dominance and that the additive effects largely contributed in the inheritance of such traits. Whereas the traits which the degree of dominance were higher than one, revealing the importance of dominance in the genetic control of these traits. These results are on agreement of Obiadall (2006) on summer squash and Assar *et al.* (2010) on tomato.

In general, the heritability in broad sense (h^2_{bs}) was higher than the corresponding heritability in narrow sense (h^2_{ns}) for all recorded characters. The estimates values of heritability in broad sense (h^2_{bs}%) which gave the values 98.78 % for P.H, 83.36 % for No. B/ P, 95.30 % for No. D. F; 99.76 % for P.L, 90.06 % for P.D, 99.05 % for A.P.W, 97.81 % for No. P. / P and 97.87 % for T. Y. / P. In the same data, the highest values of (h^2_{ns}%) were 65.54 % for P.H, 71.63 % for No. B. / P, 41.75 % for No. D. F, 87.06 % for P.L, 57.45 % for P.D, 16.79 % for A.P.W, 40.22 % for No. P. / P and 9.94 % for T. Y. / P. These results illustrate that the importance of additive and non – additive gene effects in the inheritance of those characters. These finding are supported by the results of Salameh and Kasrawi (2007) on okra; Assar *et al.,* (2010) on tomato; Abd El-Hadi *et al*., (2014) on squash; Sanin *et al*., (2014) on pumpkin.

Regarding heritability percentage, it is likely noticeable that broad sense heritabilities ($h^2_{b.s}$%) were high and exceeded 90 % for all investigated trais. These suggest that all traits were highly heritable. Moreover, heritability in narrow sense ($h^2_{n.s}$%) values indicate the relative importance of additive gene action in the inheritance of the studied traits. Heritability estimates give an insight into the degree of gene action to express a certain trait and phenotypic reliability in predicting its breeding value (Ndukauba *et al*., 2015).

Table 6. Estimates of genetic parameters and heritability in broad (h^2_{bs}%) and narrow sense (h^2_{ns}%) for all studied traits of okra.

S.O.V	P.H. (cm)	No. B/P	No. D.F	P.L (cm)	P.D (cm)	A.P.W (g)	No. P./P	T.Y./P (g)
δ^2ph	416.39	1.03	24.92	1.17	0.02	0.91	77.52	8389.90
δ^2G	411.32	0.85	23.75	1.17	0.01	0.90	75.82	8211.00
δ^2A	829.8	2.20	31.22	3.06	0.02	0.46	93.52	2501.40
δ^2D	415.1	0.36	4.07	0.45	0.02	2.24	133.90	22.13
D.d	0.71	0.41	1.13	0.38	0.76	2.21	1.20	2.98
$h^2_{b.s}$%	98.78	83.36	95.30	99.76	90.06	99.05	97.81	97.87
$h^2_{n.s}$%	65.54	71.63	41.75	87.06	57.45	16.79	40.22	9.94

(PH): Plant height; (No. B / P): Number of branches per plant; (No. D. F): Number of days to 50% flowering; (P.L): Pod Length; (P.D): Pod Diameter; (APW): Average Pod weight; (No. P. /P): Number of Pods per plant and (TY/P): Total yield per plant.

Correlation among studied traits:

The results of the correlation coefficient among some agronomic traits of okra studied are shown in Table (7). Phenotypic (r_{ph}) and genotypic (r_g) correlations among the pairs of traits were calculated. Regarding genotypic correlation (r_g) results show that P.H. was positively correlated with No. B. / P (r_g = 0.74), No. D. F. (r_g = 0.73); P.D. (r_g = 0.81) and T.Y. / P (r_g = 0.43). Regarding pod traits, P. L. positively associated to A.P.W. (r_g = 0.51). Whereas, P. D. showed positive and significant correlation with P. H (r_g = 0.81) and No. B. /P (r_g = 0.67). In addition, A. P.W. exhibited the positive and significant correlation with P.L. (r_g = 0.51). With respect to yield component traits, there were significant and positive genotypic correlation among N.P. / P and No. B. / P (r_g = 0.46), A. P. W (r_g = 0.99) and T.Y. / P (r_g = 0.80). The positive and significant correlations among yield component traits make it easier and effective for plant breeder to make indirect selection for high yielding hybrids.

Phenotypic correlation (r_{ph}) among studied traits indicated significant and positive correlation between P.H and No. B. / P (r_{ph} = 67); No. D. F. (r_{ph} = 0.71) and T.Y. / P (r_{ph} = 0.43). Moreover, Pod traits elucidate significant and positive correlation between P.L and A.P.W. (r_{ph} = 0.51). Similarly, positive and significant phenotypic correlation was found between P.D and P.H. (r_{ph} = 0.76); No. B. / P (r_{ph} = 0.60), No. D. F. (r_{ph} = 0.64) and A.P.W. (r_{ph} = 0. 51). In the same manner, A.P.W. was correlated with P.L. (r_{ph} = 0.51). As for yield components, No. P. / P was positively correlated with T.Y. / P (r_{ph} = 0.55), whereas T.Y. /P was associated with P.H. (r_{ph} = 0.43), A. P.W. (r_{ph} = 0.84) and No. P. / P (r_{ph} = 0.55). These results are in accordance with the findings of Ibrahim *et al* (2013) and Simon *et al.* (2013) on okra.

Table 7. Genotypic r_{ph} (above diagonal) and phenotypic r_g (below diagonal) correlation for all studied traits in okra

Traits	P.H.(cm)	No. B/P	No. D.F	P.L (cm)	P.D (cm)	A.P.W (g)	No. P./P	T.Y./P (g)
P.H.(cm)		0.74**	0.73**	-0.44*	0.81**	0.31	0.30	0.43*
No. B/P	0.67**		0.63**	-0.44*	0.67**	0.23	0.46**	0.19
No. D.F	0.71**	0.55**		-0.58**	0.68	-0.20	0.06	- 0.14
P.L (cm)	-0.43*	-0.40*	-0.56**		-0.35**	0.51**	- 0.34*	0.24
P.D (cm)	0.76**	0.60**	0.64**	-0.33*		0.24	0.08	0.24
A. P.W (g)	0.31	0.21	-0.20	0.51**	0.23		0.99**	0.95**
No. P./P	0.29	0.01	0.06	-0.34*	0.09	-0.04		0.80**
T.Y./P (g)	0.43*	0.18	-0.14	0.25	0.23	0.84**	0.55**	

(PH): Plant height; (No. B / P): Number of branches per plant; (No. D. F): Number of days to 50% flowering; (P.L): Pod Length; (P.D): Pod Diameter; (APW): Average Pod weight; (No. P. /P): Number of Pods per plant and (TY/P): Total yield per plant. *, **: significant at 0.05 and 0.01 levels of probability, respectively.

CONCLUSION

The main aim of the breeding program is to develop okra varieties with desirable agronomic traits, high yielding and tolerance to environmental stress such as drought stress. So, breeding programme should be efficiently being planned with prior knowledge of genetic parameters of complex traits, i.e., yield and its components. Desirable inbred lines with good crosses and general and specific combining abilities identified in this study could be exploited in future breeding programme. Estimations of GCA and SCA were highly significant, indicating the importance of additive (σ^2A) and non-additive genetic variance (σ^2D) in the inheritance of characters. Heritability in broad sense ($h^2_{b.s}$%) was high for all studied traits, emphasizes the high proportion of genetic variation in the whole phenotypic variation. The results showed that the parents (P_2), (P_5) were best general combiners and the best specific combiners for P_3 X P_4 for Number of days to 50% flowering, pod length and average pod weight, P_2 X P_3 for total yield per plant. These crosses are promising hybrids with high yielding potential under drought conditions and could be commercially recommended to improvement economical traits in okra under drought conditions.

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أنتاج هجن من الباميا مستنبطة من سلالات منتخبة تحت ظروف الجفاف.

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بسبب نقص الموارد المائية وكذلك نقص المياه المتزايد والجفاف المتكرر في النظم الزراعية المصرية، كان من الضروري انتاج هجن موفرة للماء وتتحمل الجفاف لضمان الأمن الغذائي. لذلك تم استخدام خمسة سلالات من الباميا متحملة للجفاف لتطوير هجن متفوقة من الباميا تحت ظروف الجفاف. وذلك باستخدام نظام التهجين النصف دائري لانتاج خمس عشرة هجين. أوضحت النتائج وجود فروق معنوية عالية في متوسط المربعات الوراثية بين الهجن والآباء لجميع الصفات المدروسة. لم يظهر أي من الهجن تفوق كامل في قوة الهجين لجميع الصفات المدروسة، ولكن وجد أن كل من الهجين P_2 X P_3 وP_2 X P_6 قد أعطى أعلى قوة هجين لصفة المحصول الكلى للنبات سواء المحسوبة بالنسبة الى متوسط الآباء او أفضل الأباء. كذلك أظهرت النتائج وجود فروق معنوية عالية عند تقدير القدرة العامة والقردة الخاصة على الخلط لكل الصفات المدروسة. مما يشير إلى أهمية التباين الوراثى الاضافى وغير الإضافي في وراثة تلك الصفات المدروسة في الباميا. كذلك أظهرت النتائج أن القيم المقدرة للقدرة العامة على الخلط كانت أكبر من القيم المقدرة للقدرة الخاصة على الخلط لصفتى عدد الأفرع للنبات وطول القرن. مما يشير إلى أن التأثيرات المضافة كانت أكثر أهمية من العمل غير الإضافي لكلا الصفتين. على العكس من ذلك، كانت القيم المقدرة للقدرة الخاصة على الخلط كانت أكبر من نظيرتها للقدرة العامة على الخلط لصفات أرتفاع النبات وعدد الأيام حتى تفتح 50 % من الازهار ومتوسط وزن القرن وعدد القرون للنبات والمحصول الكلى للنبات مما يشير إلى المساهمة الكبيرة لتأثيرات التباين الوراثى غيرالمضيف في وراثة هذه الصفات. كذلك أشارت النتائج إلى أن الأباء P_2 ، P_5 كانت لهما قدرة عامة عالية على الخلط لصفة ارتفاع النبات وقطر القرن ومتوسط وزن القرن والمحصول الكلى للنبات. كان للهجين (P_3 X P_4) قدرة خاصة على الخلط لصفات عدد الأيام حتى تفتح 50٪ من الازهار وطول القرن ومتوسط وزن القرن، بينما كان للهجين (P_2 X P_3) قدرة خاصة على الخلط لصفات المحصول الكلى للنبات. كذلك أشارت النتائج إلى أن التباين الإضافي كان أعلى من التباين الغير اضافى (التباين السيادى) لصفات طول االنبات وعدد الأفرع للنبات وعدد الأيام حتى تفتح 50 % من الأزهار وطول القرن وقطر القرن والمحصول الكلى للنبات. ومن ناحية أخرى كان التباين الغير إضافي أعلى من التباين الإضافي لصفة متوسط وزن القرن وعدد القرون للنبات وهذا يدل على الدور الكبير للتباين الغير إضافي في وراثة تلك الصفات. كانت قيم معامل التوريث في المدى المعنى الواسع أكبر من نظيرتها لمعامل التوريث في المدى الضيق لجميع الصفات المدروسة. وكانت قيم معامل التوريث فى المدى الواسع قد تراوحت بين 83.36٪ إلى 99.76٪ لصفة طول القرن وعدد الفروع لكل نبات على التوالي، في حين تراوحت القيم المقدرة لمعامل التوريث فى المدى الضيق بين 9.94٪ إلى 87.06٪ لصفتى المحصول الكلى للنبات وطول القرن على التوالي. أظهر معامل الارتباط بين كل زوج من الصفات قيماً موجبة ومعنوية لبعض الصفات، مما يشير الى ان الانتخاب لصفة واحدة من تلك الصفات سيكون مرتبطًا بتحسين الصفات الأخرى. وبذلك فقد اظهرت هذه الهجن التحمل لظروف الجفاف وقوة الهجين لصفات المحصول و مكوناته ، ويمكن التوصية بها تجارياً لتحسين الصفات الاقتصادية في الباميا تحت ظروف الجفاف.