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Egyptian Cucumber Germplasm Genetic Diversity as An Approach for Developing Novel Hybrids under Heat Stress Conditions

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ABSTRACT

Climate changes are critical global challenges limiting crop development and productivity. Plant breeding is an exceptional solution for providing thermotolerant genotypes. Plant breeding efficiently is a unique solution for providing food security worldwide. The germplasm genetic diversity of cucumber parental lines should support the release of new hybrids. In this study, A half-diallel design mating was performed with six parental cucumber lines to produce 15 hybrids under heat stress conditions in 2019. In 2020 and 2021, all genotypes were evaluated under heat stress conditions, using a randomized complete block design. The analysis of variances revealed significant differences among all genotypes. The mean performance showed that the hybrid, Parent 1×Parent 2 (P1× P2) was the superior hybrid, followed by Parent 1 (P1) for growth and yield components. The descriptive evaluation adequately demonstrated the greatest variation among all genotypes. The genetic distance between parental lines was divided into two groups based on their genetic bases. General combining ability (GCA), specific combining ability (SCA), and heterosis results revealed that P1 and P2 exhibited the highest effects of GCA in the desirable direction for vegetative, yield, and earliness traits. However, P3 showed the highest effect on most fruit traits. According to SCA effects and heterosis, the hybrids P1×P2, P1×P3, and P2×P5 demonstrated superiority in most traits. The selective parents were the good combiners by accumulative selective genes, which could be valuable in hybridization to produce new various prospective hybrids.

Keywords: Cucumber; Heat stress conditions; GCA, SCA, Morphological characterization, Yield component

INTRODUCTION

The world faces an unprecedented challenge in the aspect of climate change, including rising temperatures. Global warming warns of a serious shortage in the production of crops, especially food (Fischer *et al*., 2002). Therefore, efforts must be made to address this challenge and find alternatives that mitigate these expected losses. The efforts of plant breeders come in an advanced rank in developing high-quality varieties that are tolerant of harsh changes in the environment and capable of continuity and sustainability of production. Plant breeders' goals are no longer limited to breeding high-yielding, high-quality inbred lines; it is now necessary to select tolerant inbred lines for biotic and abiotic conditions (Driedonks *et al*., 2016). Thus, the selection of breeding lines for relatively hot regions takes place under hot conditions (Mickelbart *et al*., 2015). Considering that cultivars from warmer regions are often more heat-tolerant than those from cooler regions, it seems that this technique has been rewarding (Meng *et al*., 2004). Cucumber is one of the most sensitive heat crops. The high temperature is one of the most dangerous, unfavorable conditions for cucumber production in the open field and greenhouses. In summer, the temperature in open fields typically exceeds 38 °C, and in greenhouse exceeds 45 °C which leads to leaves sunburn, growth retardation of stems and roots, fruit malformation, and even plant death, which severely affects cucumber yield and fruit quality (Sun *et al*., 2018). This research presents a breeding program for the development of a number of high-quality, heat stress tolerant cucumber inbred lines and hybrids. Lately, cucumber hybrid production was the development business and seed prices became very high. In Egypt, there is a big gap between the produced cucumber hybrids and the cultivated area needs, which covers by imported seeds (El-Remaly *et al*., 2021). Therefore, plant breeders should intensify efforts toward producing sufficient, cheap, and abiotic-tolerant hybrids (Ilodibia *et al*., 2014). There are many breeding mechanisms that ensure the availability of abundant and good production of the crop (Kohli and Vikram, 2005). The evaluation of lines and their progenies testing by their compatibility and the superiority of their offspring, among these mechanisms are the general and specific combining abilities and heterosis (Mostafa *et al*., 2021). Great progress in classical breeding has been achieved in cucumber for various quantitative and qualitative traits which helped to supply superior varieties suitable for open field and protected cultivation (Jat *et al*., 2021). Genetic improvement of yield and its correlated traits requires the choice of appropriate breeding procedures, which are largely dependent upon the study of the general combining ability (GCA) of parents and the specific combining ability (SCA) of hybrids. Combining ability also indicates the nature and magnitude of gene action involved in the expression of quantitative traits (Kumar *et al*., 2017; Sahoo and Singh, 2017). GCA indicates the common performance of a parental line in hybrid combinations and reflects the additive gene action and frequency of favorable alleles. On the opposite, SCA may be a tool as an example of certain combinations and determine

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which are relatively better or worse than would be expected on the premise of the GCA of the line (Ene *et al*., 2019).

The study aims to develop local climate adapted cucumber inbred lines and hybrids with high production and quality under local climate conditions, which are characterized by a sharp rise in summer temperatures, particularly in conditions in traditional greenhouses used in cucumber production in Egypt. One of the objectives is to release possible hybrids using the half-diallel method. Another point, evaluate the parental lines, and their potential combinations, to identify the best combiners for superior hybrids production. Furthermore, estimate morphological characterization and horticultural evaluation of the produced hybrids compared to the best commercial hybrid.

MATERIALS AND METHODS

Experiments were conducted under non-controlled greenhouse conditions at Vegetable Research Departments, Horticulture Research Institute, Agricultural Research Center during three growing seasons, Fall (2019) and Summer (2020 and 2021). Six adapted inbred lines for heat stress obtained from the inbreeding cucumber program at Cross-Pollinated Vegetable Research Department, Horticulture Research Institute, Agriculture research center, Egypt. Seedlings were transplanted to a greenhouse, on September 9th, 2019. Six inbred lines of landraces were selected from the cucumber populations collection for heat tolerance. Seedlings of all 6 inbred lines were transplanted to a greenhouse, on September 9th, 2019. The gynoecious parents were treated with silver nitrate to induce male flowers (Beyer, 1976). At the flowering stage, crossing using all possible combinations of a half diallel mating design were done, giving 15 F1 hybrids (Griffing, 1956).Fifteen F1 hybrids, six parental lines, and the control F1 hybrid were evaluated where seeds were sown on April 8th, 2020 and 2021. Seedlings were transplanted after a month into the greenhouse in an exceedingly randomized complete block design with five replicates into two rows within the bed (row 10 m long and 1.0 m in width). The space between the plants was 0.5 m. The area of each plot was 90 m^2 (as each plot contained 5 beds at 10 m long × 1.8 m width and number of plants was 200 plants /plot where 2.2 plant/m^2). The plants were exposed to natural thermal stress during May, June, and July (Figure 1). The recommended quality agricultural practices for commercial cucumber production were applied. The averages of temperature degree through the both growing seasons inner and outer the greenhouse were calculated by BST-DL13 (B091BRMT7C) and set in Figure 1. Phenotypic data were recorded on 20 plants to assess 14 horticultural traits under heat stress conditions: Vegetative traits; main stem length (MSL cm) at the end of the season; internode length (IL cm); the number of lateral branches (No. LB) for the primary 50 cm; leaf area (LA cm2) was estimated after 30 days form transplanting on the 10th leaf.; Earliness traits; days to first female flower opening (DFFO); the number of female flowers per node (NFF/N).; Fruit characteristics; average fruit weight (FW g); average fruit length (FL cm); average fruit diameter (FD cm); the ratio between fruit length and fruit diameter (FL/D).Yield traits; the number of early fruits/ plant (NEF/P) and early fruit weight/ plant (EFW/P kg) were measured for three weeks from the primary harvest;; the number of total fruits per plant (NTF/P) and total fruit weight per plant (TFW/P kg) were measured every two days for ten weeks from the primary harvest to the end of the harvest season for each genotype.. Nine importance descriptive traits, nature of growth, leaf color, flowering nature, fruit color, pedicle fruit, fruit ribbed, bitterness, fruit neck, and spines were determinate. Fruit descriptors were evaluated 20 plants per genotype under natural heat stress conditions.

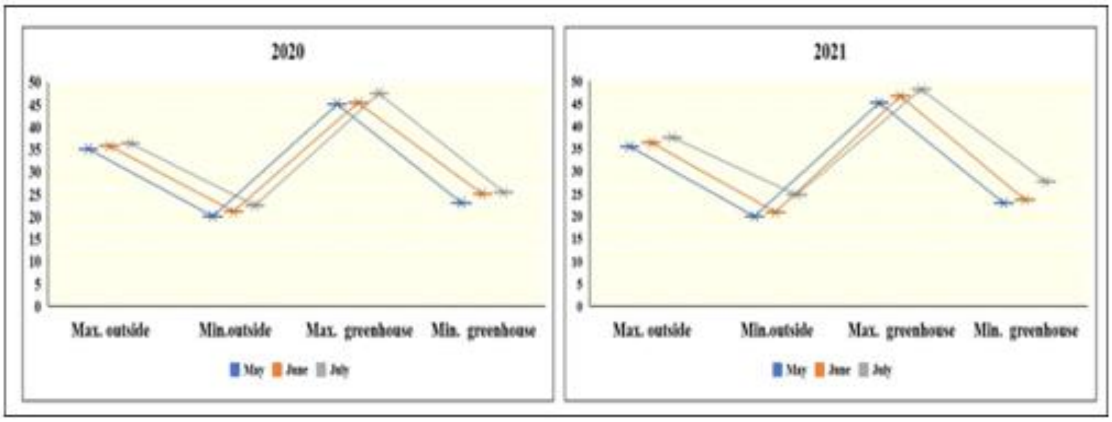

Figure 1. Maximum and minimum means of temperatures degrees during the growing stages in two seasons 2020 and 2021

The effects of general (GCA), specific combining abilities (SCA) values, and variance components for the GCA and SCA effect, for 6 parental lines and their 15 F_1 hybrids, were estimated according to model 2, Method 2, proposed by Griffing (1956) as outlined by Olfati *et al*. (2012).

Two types of heterosis, mid-parent (M.P) and better parent (B.P) heterosis were estimated and expressed as percentages (Mather and Jinks, 1982) as the deviation of F_1 mean over the mid-parent (M.P), and better parent (B.P), in each cross, respectively as follows:

a. mid-parent heterosis (M.P) = [(F_1-M. P)/M. P] x100

b. better parent heterosis (B.P) = [(F_1- B.P)/B. P] x100

The genetic distance between accessions was calculated as, based on the evaluation of the horticultural characteristics, a raw data matrix was created. A pairwise Euclidean distance matrix, the most commonly applied procedure for this kind of traits (Mohammadi and Prasanna, 2003) was analyzed by the UPGMA clustering procedure. A dendrogram was created using past 4.03 software. PCA of the 14 commercial traits was conducted using the PCA method package in R program (Abdi and Williams, 2010).

Statistical analysis

Data were statistically analyzed, using analysis of variance (ANOVA) with the Stat soft statistical package

(MSTATC) software program (Michigan State University, East Lan-sing, MI, U.S.A.). Probabilities of significance among genotypes compared with the least significant difference (LSD) (P≤0.05) according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Results

Morphological assessment

Morphological description deviation for all genotypes was presented in Table 1. The genetic distance between genotypes was measured using a pair-wise Euclidean Distance Matrix. The dendrogram in Figure 2 presents the group of six parental forms based on assessed traits. It can be seen that there are two groups' clusters of genotypes. The UP-GMA analysis of the cucumber inbred lines was classified into two major groups: cluster A and cluster B. Cluster A was divided into two sub-clusters, A-1 included P1 and P2 and A-2 included P4, P5, and P6. However, cluster B contained only P3.

Table 1. List of cucumber genotypes and their morphological characterization

Genotypes	Nature of growth	Leaf color	Flowering nature	Fruit color	Pedicel fruit	Fruit ribbed	Bitterness	Fruit neck	Spain
P1	Indeterminate	Heavily	Gynoecious	Heavily	Long	Slightly	Non	Slightly	Non
P2	Indeterminate	Moderately	Gynoecious	Moderately	Moderately	Slightly	Non	Slightly	Non
P3	Determinate	Heavily	Gynoecious	Heavily	Moderately	Heavily	Non	Heavily	Non
P4	Determinate	Moderately	Gynoecious	Heavily	Long	Moderately	Non	Moderately	Non
P5	Determinate	Slightly	Monoecious	Slightly	Moderately	Moderately	Non	Slightly	Slightly
P6	Indeterminate	Slightly	Monoecious	Slightly	Moderately	Moderately	Non	Moderately	Slightly
P1×P2	Indeterminate	Heavily	Gynoecious	Moderately	Long	Slightly	Non	Slightly	Non
P1×P3	Determinate	Heavily	Gynoecious	Heavily	Moderately	Moderately	Non	Moderately	Non
P1×P4	Indeterminate	Heavily	Gynoecious	Heavily	Long	Moderately	Non	Slightly	Non
P1×P5	Indeterminate	Moderately	Monoecious	Moderately	Moderately	Moderately	Non	Slightly	Slightly
P1×P6	Indeterminate	Moderately	Monoecious	Moderately	Moderately	Moderately	Non	Slightly	Slightly
P2×P3	Determinate	Heavily	Gynoecious	Moderately	Slightly	Moderately	Non	Moderately	Non
P2×P4	Indeterminate	Moderately	Gynoecious	Moderately	Moderately	Moderately	Non	Slightly	Non
P2×P5	Indeterminate	Moderately	Monoecious	Moderately	Moderately	Moderately	Non	Moderately	Slightly
P2×P6	Indeterminate	Moderately	Monoecious	Moderately	Moderately	Moderately	Non	Moderately	Slightly
P3×P4	Determinate	Heavily	Gynoecious	Heavily	Long	Moderately	Non	Moderately	Non
P3×P5	Determinate	Moderately	Monoecious	Moderately	Slightly	Moderately	Non	Moderately	Slightly
P3×P6	Determinate	Moderately	Monoecious	Moderately	Slightly	Moderately	Non	Moderately	Slightly
P4×P5	Determinate	Moderately	Monoecious	Moderately	Moderately	Moderately	Non	Moderately	Slightly
P4×P6	Determinate	Moderately	Monoecious	Moderately	Moderately	Moderately	Non	Moderately	Slightly
P5×P6	Indeterminate	Slightly	Monoecious	Slightly	Moderately	Moderately	Non	Moderately	Slightly

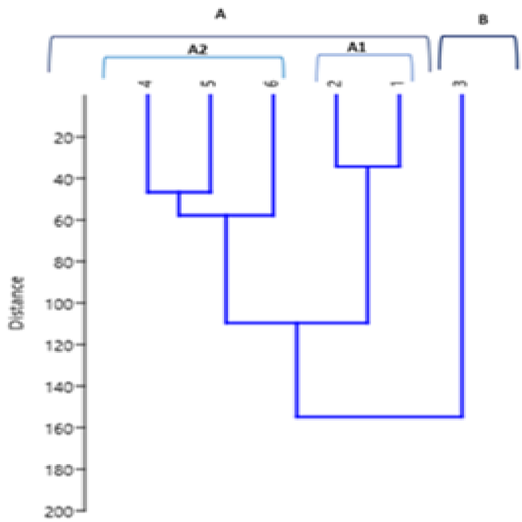

Figure 2. A dendrogram of six parental lines diviation in clusters based on assessed traits.

Correlation assessment

The correlation among vegetative, earliness, and yield traits are presented in Figure 3. Six out of fourteen traits showed a positive and highly significant correlation with yield characters. Days to first female flower to anthesis (earliness) had a negative significant correlation (-0.76 to -0.79) with yield traits under heat stress conditions. Leaf area was positively correlated with the number of early fruits (0.82), early fruit weight (0.81), total fruit number (0.782) and weight (0.783). Fruit diameter had a positive and highly significant correlation (0.84 to 0.94) with yield characters. The number of early and total fruits per plant was highly positive correlated with the early and total yield per plant, which reached 0.99.

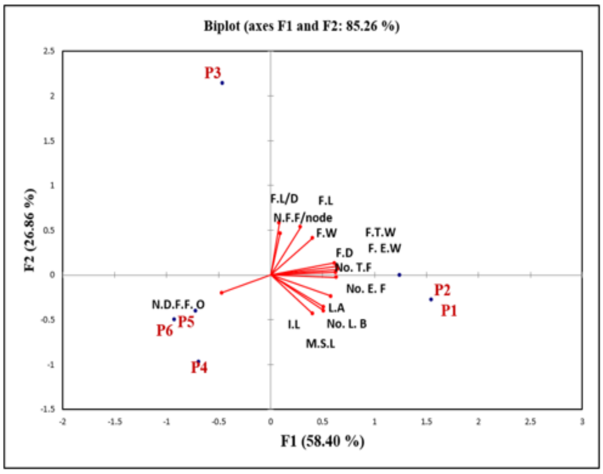

Figure 3. Correlation biplot of all estimated traits under heat stress condition versus six parental lines (parents, red color) and 14 traits (black color).

Mean performance of genotypes

There were vast variations in mean performance across parents, hybrids, and controls for estimated traits under natural heat conditions (Figure 4A-N). For parents, there was a broad variety of genetic backgrounds for the investigated inbred lines alongside their tolerance of heat stress. Parents 1 and 2 were inserted to enhance the vegetative traits, earliness, and yield components, however, parent 3 was used to boost the number of fruits/nodes and fruit length. P4 is characterized by its fruit quality, while P5 and P6 are characterized by strong vegetative growth. There have been quite substantial variations between inbred lines and the control. The parent 1 had the best mean values for vegetative qualities, followed by inbred line 2. These inbred lines have the highest stem length (415.6 and 393.5 cm), the longest node (7.6 and 7 cm), many lateral branches (7.6 and 7,0), and also the biggest leaf area (399.3 and 396,0 cm^2). These inbred lines excel not only in terms of vegetative traits, but also in terms of flowering and yield component features side to side heat tolerance. The inbred line 1 was the earliest blooming inbred line, as evidenced by its early and total yield productivity of 3.14 and 8.15 kg/plant, respectively, when put next to all inbred lines and also the control. The parent 3 has the shortest stem length (228.3 cm) and also the smallest leaf area (298,0 cm^2). When compared to other inbred lines and also the control, parents 4, 5, and 6 demonstrated intermediate values for all vegetative parameters. It had been conceivable to create hybrids with acceptable performance. The main stem length for crossings varied from 143.3 cm (P1×P2) to 430 cm (P2×P3). The cross (P1×P2) surpassed the commercial hybrid's altogether measured attributes, generating 9.922 kg/plant and 88 fruits/plant, compared with 4.37 kg/plant and 38.09 fruits/plant for the control with note clear decrease in productivity under heat stress conditions. The hybrid (P1×P3) also displayed considerable benefit in total yield compared with the control, the fruit numbers were 78.333 and the fruit weight was 9.181 kg/plant.

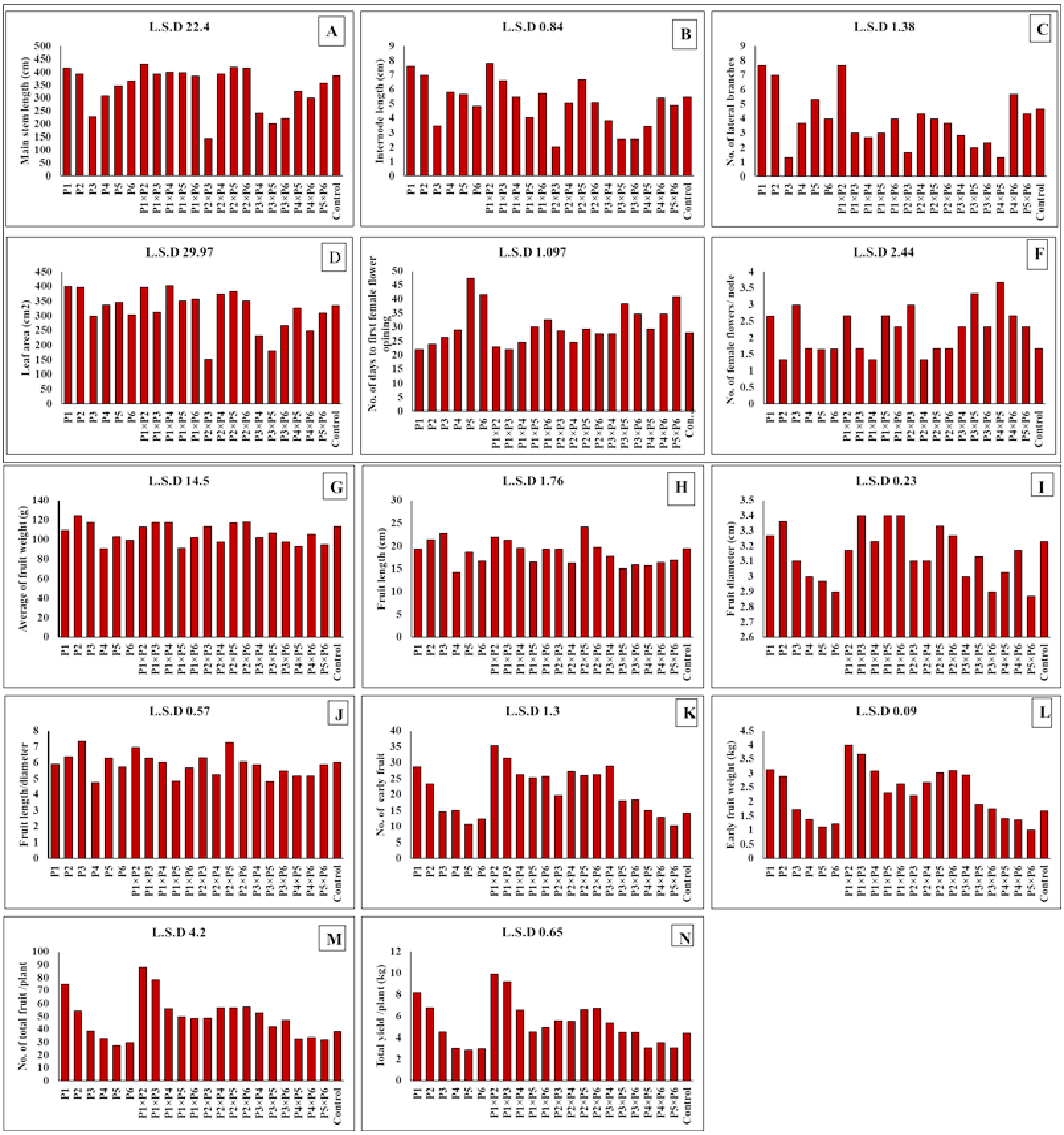

Figure 4A-N. Mean performance of all cucumber genotypes for vegetative traits A, main stem length(cm); B, internode length (cm); C, number of lateral branches; D, leaf area (cm^2), flowering traits E, number of days to first female flower opining, and F, number of female flowers per node, fruits traits, G fruit weight (g); H, fruit length (cm), and I, Fruit diameters(cm) ; J, the ratio between fruit length and diameter and yield component traits, K, number of early fruit; L, early fruit weight (kg); M, number of total fruit, and N, total fruit weight(kg). LSD at *p* ≤0.05.

Combining ability

Analysis of variance for combining ability

Analysis of variance for general combining ability GCA for all estimated traits was calculated and shown in Table 2. High significant SCA variance was also observed for all the traits. The high significant GCA and SCA mean squares were recorded for all traits that suggest the importance of both additive and non-additive components of heritable variance, which are answerable for the variation observed in these traits. Traits with significant variance for SCA are recommended to be improved through hybridization (heterosis) which indicates the pre-dominance of non-additive gene effects, while GCA has been implication selected because the best improvement strategy, hence, the predominance of additive gene effects. The GCA/SCA ratio in Figure 5 showed a smaller amount than one in main stem length, internode length, number of lateral branches, leaf area, number of days to first female flower opening, fruit weight, fruit length, fruit diameter, the ratio of fruit weight to fruit length, and early fruit number. In contrast, the GCA/SCA ratio for the number of female flowers/ nodes, early fruit weight, total fruit number, and weight was higher than unity. These results seek advice from the preponderance of non-additive gene effects in those traits with the ratio of but one and additive effects in over than one. Estimates of GCA effects of individual parental genotypes within the F1 generation were found to be significant or highly significant for the foremost studied traits. P1 showed the highest GCA value, followed by P2 for all studied traits except number of female flowers/nodes. Both parents were good general combiners for all studied characters under natural heat stress conditions. P1 exhibited the very best significant GCA effects within the positive direction in most of the heterotic crosses for all characteristics except flowering traits. Therefore, this parent may be selected as a possible donor for vegetative growth and yield components. Concerning flowering and fruit traits, P3 was a good combiner. P3 showed the longest fruits, but P4 has the shortest fruits.

Table 2. Analysis of variance for combining ability

Sources	Vegetative growth traits				Flowering traits		Fruit traits				Yield component traits			
of variations	MSL	IL	No. LB	LA	DFFO	NFF/node	FW	FL	FD	FL/D	No. EF	EFW	No. TF	TFW
GCA	2444.08	0.76	0.95	1385.20	0.0472	21.0872	25.93	1.91	0.0071	0.1095	18.21	0.29	103.27	1.67
SCA	2822.04	1.45	2.01	2881.38	0.3503	7.7663	38.02	4.41	0.0146	0.4064	22.15	0.26	72.72	1.05
GCA: SCA	0.87	0.52	0.47	0.48	0.1348	2.7152	0.68	0.43	0.4853	0.2694	0.82	1.09	1.42	1.59

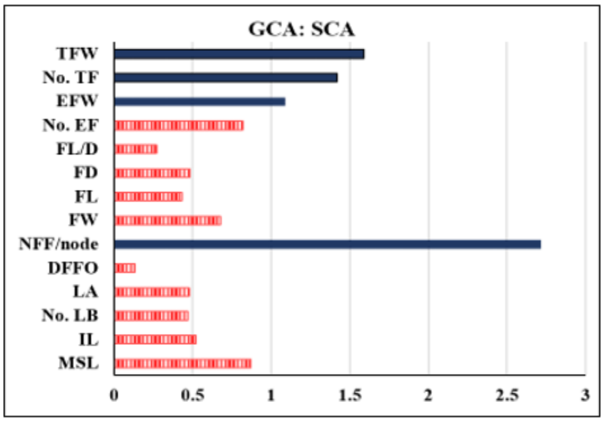

Figure 5. The GCA:SCA ratio for all studied traits, the bar with dark blue color greater than one while the bar with red color smaller than one.

General combining ability (GCA)

Combining ability is the useful in successful prophecy of the genetic capability of parental lines and their crosses to choose the foremost effective donor for a selected trait. Estimates of GCA effects of individual parental genotypes within the F1 generation were found to be highly significant for the foremost studied traits under natural heat stress conditions (Figure 6A-N). During this regard, The GCA of all estimated traits indicated that parents 1 and 2 had a significant positive GCA effect in the traits except flowering traits. Furthermore, it absolutely was observed that the GCA of the number of days to the first female flower opening and the number of female flowers per node showed a negative GCA effect in P1 and P2. Both parents were good general combiners for all studied characters. Therefore, parents 1 and 2 could also be selected as potential donors for all traits. Additionally, the parent 5 showed highly significant effects for female flower numbers/node, while, parent 6 showed significant effects for main stem length and number of female flowers/node.

Specific combining ability (SCA)

Analysis of specific combining ability is an important parameter for judging the specific combinations for exploiting them through heterosis breeding program. The good specific cross combinations are selected based on their SCA effects. SCA effects were estimated for all F1 crosses between specific parents and illustrated in Figure 7A-N. Seven out of fifteen cross-es (P1 x P2), (P1 x P3), (P2×P5), (P2×P6), (P4×P6), (P5×P6), and (P2×P4) exhibited significant positive SCA effects for vegetative growth under heat stress conditions. According to flowering traits, four crosses (P1×P3), (P1×P4), (P2×P4) and (P2×P5) had the highest negative SCA in desirable effect for earliness in the early female flowering. For number of days to first female flower opening, maximum negative SCA effect was recorded in (P1×P3) followed by (P1×P4), (P2×P4) and (P2×P5). Most crosses revealed significant desirable positive SCA for fruit traits, five of them (P1 x P2), (P1 x P3), (P1×P4), (P2×P5) and (P2×P6) exhibited significant desirable positive SCA for, average fruit weight. The utmost SCA effect for fruit length was observed in hybrid (P2×P5), followed by (P1×P4), and(P1×P3). The crosses (P1xP2), (P1 x P3), (P1×P4), (P2×P5), (P2×P6), and (P3×P4) exhibited the highest SCA effects for early and total yield indicating the likelihood of combine both high yield and fruit quality characters. For economic trait early and total yield, the best SCA effect was recorded in hybrids (P1×P2), (P1×P3), (P2×P5), (P2×P6), (P3×P4), and (P3×P5). Likewise, the top heterotic combiners were identified as (P1×P2), (P1×P3), and (P2×P5). The cross combinations, which exhibited significant positive SCA for yield/plant, were also combined with significant/highly significant desirable negative or positive, SCA effects for important yield components particularly fruit weight, fruit length, number of fruits, and fruit diameter.

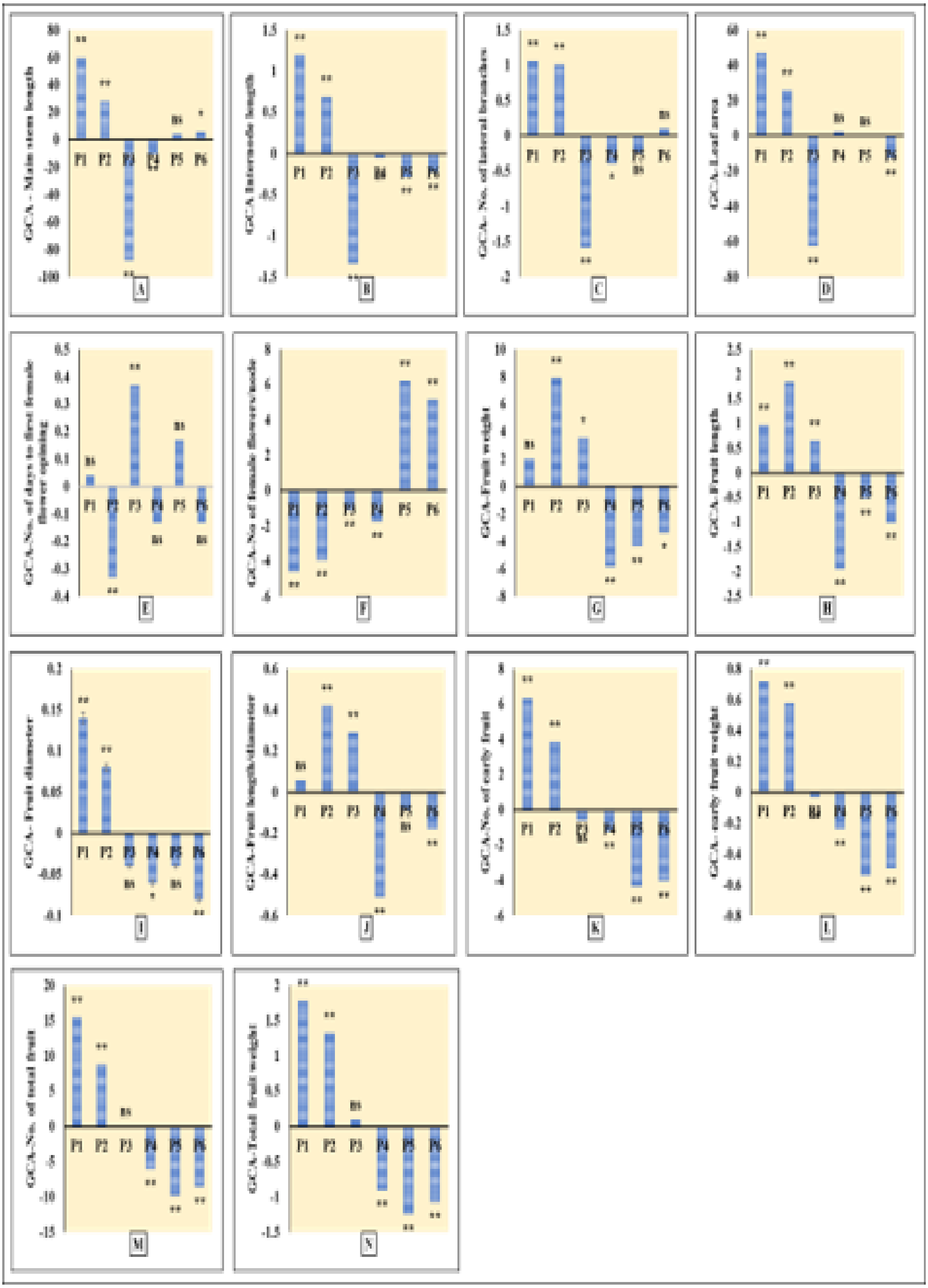

Figure 6A-N Effects of GCA for vegetative traits A, main stem length; B, internode length; C, number of lateral branches; D, leaf area, flowering traits E, number of days to first female flower opining, and F, number of female flowers per node, fruits traits, G fruit weight; H, fruit length, and I, Fruit diameters; J, the ratio between fruit length and diameter and yield component traits, K, number of early fruits; L, early fruit weight; M, number of total fruits, and N, total fruit weight of parental lines.

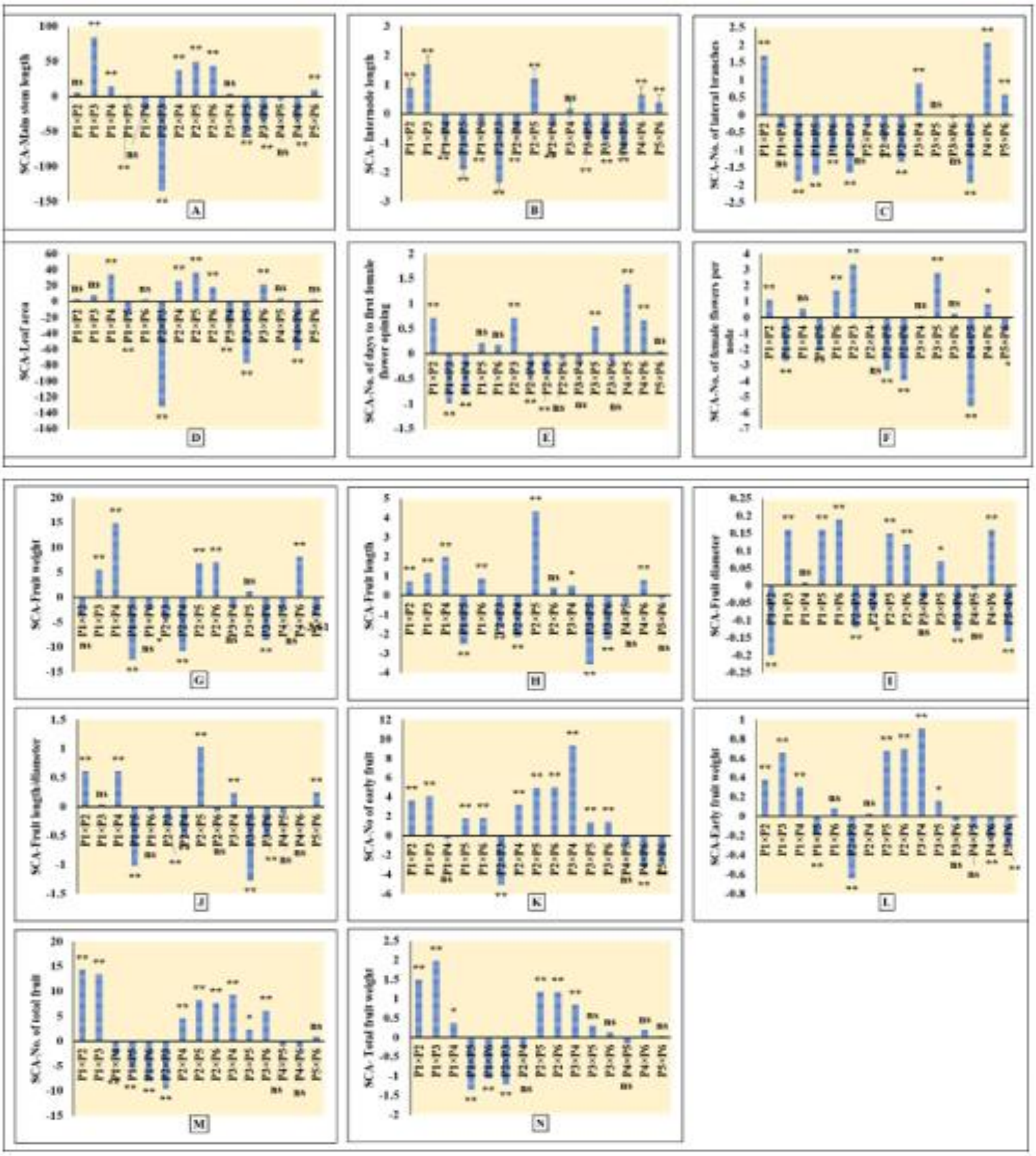

Figure 7A-N Effects of SCA for vegetative traits A, main stem length; B, internode length; C, number of lateral branches; D, leaf area, flowering traits E, number of days to first female flower opining, and F, number of female flowers per node, fruits traits, G fruit weight; H, fruit length, and I, Fruit diameters; J, the ratio between fruit length and diameter and yield component traits, K, number of early fruits; L, early fruit weight; M, number of total fruits, and N, total fruit weight of F1 generation.

Average degree of heterosis (ADH%)

The ADH% was presented in Figure 8A-N. The range of mid-parent heterosis for main stem length in desirable direction was the maximum in seven crosses (P1×P3), (P2×P5), (P2×P4), (P1×P4), (P2×P6), (P1×P2) and (P1×P5) over mid-parent, only two of them (P2×P5) and (P2×P6) exhibited significant increases over better-parent. For internode length only (P1×P3) hybrid showed heterosis over mid-parent in the desirable direction. (P4×P6) hybrid recorded the only significant increases over mid and better-parent for number of lateral branches. For the leaf area also, only one hybrid (P1×P4) exhibited heterosis over mid-parent. The highest significant and negative heterosis for earliness was recorded from (P1×P3) followed by (P1×P4) over mid and better parents. For earliness, hybrid (P1×P3) was identified as the best F1 with respect to heterosis over control. In addition, only hybrid (P2×P3) had the greatest number of female flowers. For fruit weight trait, there is no significant increase in heterosis was recorded, only P2×P5 recorded heterosis over mid and better parent for the fruit length, but heterosis over mid-parent observed with (P1×P2), (P1×P4), and (P1×P6). Three hybrids (P1×P6) followed by (P1×P5) and (P1× P3) exhibited heterosis over mid-parent in fruit diameter. The presence of heterosis over mid and better parents for early yield as fruit numbers was observed in (P1×P2), (P2×P4), (P3×P4), (P3×P 5, and (P3×P6). In addition, (P1×P2), (P1×P3), and (P3 ×P4) exhibited the heterosis over mid and better parents for early yield as fruit weight. For total yield as fruit number and weight, the hybrids (P1×P2), (P1×P3), (P2×P5), and (P2×P6) recorded heterosis over mid and better parents. According to all previous determinate genetics parameters, five hybrids (P1×P2), (P1×P3), (P2×P5), (P2×P6), and (P3 ×P4) revealed the highest significant values for all estimated traits under natural heat stress conditions.

Figure 8A-N Average degree of heterosis (ADH) % based on mid- parent (M.P) and better parent (B.P) of vegetative traits A, main stem length; B, internode length; C, number of lateral branches; D, leaf area, flowering traits E, number of days to first female flower opining, and F, number of female flowers per node, fruits traits, G fruit weight; H, fruit length, and I, Fruit diameters; J, the ratio between fruit length and diameter and yield component traits, K, number of early fruits; L, early fruit weight; M, number of total fruits, and N, total fruit weight of F1 generation.

Discussion

The heat tolerance in cucumber has been become necessary for health life cycle, plant growth and production. So, one in all the foremost important aims for breeding program producing high thermos-tolerant inbred lines and hybrids. There are few reports on the evaluation of heat tolerance in cucumber at different growth stages. Heat stress may be a critical and urgent global concern that's worth investigating because it influences how plants address elevated temperatures (Quint *et al*., 2016; Vihervaara *et al*., 2018). Egypt, in light of the high temperatures, and their harmful effects on cucumber greenhouses in the summer seasons, there are some methods that mitigate high temperatures. One of them includes spray some growth stimulants or spray greenhouses plastic by solution of Cerussite (Lead carbonate, Pb CO_3) or lime (Calcium carbonate, Ca CO_3) to shade and mitigate the damage to plants. Despite the presence of those precautions, they did not prove the effectivity in exceedingly heat percentage and harmful effects. So, the utilization of heat-tolerant plants is the best and safe method included in an integrated program to mitigate the adverse effects of high temperatures on cucumber plants inside greenhouses. Moreover, the study was conducted in plastic greenhouse for two sea-sons, where cucumber grown under natural high temperature around 45°C conditions that cucumber suffered in production. Therefore, the parental lines which success to grow and survival with good yield production as heat tolerant (HT) progeny were selected. These re-sults can be directly served cucumber hybrid production program to solve cucumber production problems in new heat condition seasons. Mean performance revealed highly significant differences among all genotypes for all traits under heat stress conditions (Liu *et al.,* 2021; Yu *et al.,* 2022). Furthermore, the obtained results proved the presence of promising parental lines under natural heat stress condition due to their outstanding traits such as growth, fruit quality, earliness, early and total yield (Kumar *et al.,* 2016). The obtained results indicated that hybrids could significantly enhance growth and yield in cucumber plant production (Ilodibia *et al.,* 2018).

The morphological and genetic variation among genotypes provides evidence of the existence of an adequate amount of genetic variability valid for plant breeding programs (Wei *et al.,* 2019). Genetic variations proved that the wide genetic bases of prenatal lines could be the reason for hybrid heterosis (Ene *et al.,* 2019). A highly significant positive correlation with yield charac-teristics was observed (Sahoo and Singh, 2017). Furthermore, the number of early and total fruits/plant was highly positively correlated with the early and total yield per plant (Kumar *et al.,* 2017). On the other hand, days to first female flower to anthesis (earliness) had a negative significant correlation with yield and its components (Sahoo and Singh, 2017). Therefore, the most enhanced approach to yield breeding may be by selecting other traits that are correlated with yield. The high GCA effects indicate that the parental mean is superior to the overall mean. This illustrates a powerful proof of favorable traits transfer from parents to offspring at high frequency regarding the concentration of preponderantly additive genes (Tak *et al.,* 2017; Malav *et al.,* 2018). The chosen parental lines with high-er performance are crossed in appropriate combination to use heterosis. Combining ability is helpful in eminent the prophecy of genetic capability of parental lines and their crosses. The GCA effects of all calculable traits has positive important results (Tak *et al.,* 2017). Moreover, it had been discovered that the GCA of the range of days to first female flower opening showed negative GCA results. Analysis of specific combining ability is a vital parameter for judgment of the specific combinations for exploiting it through hetero-sis breeding program. The great specific cross combinations are elite supported their SCA effects (Sahoo and Singh, 2017). The cross combinations, that exhibited significant positive SCA for yield/plant, were additionally combined with extremely vital desirable negative SCA effects for two or additional vital yield components (Ilodibia *et al.,* 2018). Regarding, GCA/SCA ratio was less than unity in main stem length, internode length, number of lateral branches, leaf area, number of days to first feminine flower opening, fruit weight, fruit length, fruit diameter, quantitative relation of fruit weight to fruit length, and early fruit number that prove that the predominance of non-additive effect results within the majority of traits (Olfati *et al*., 2012). In distinction, GCA/SCA ratio for number of feminine flowers/nodes, early fruit weight, total fruit number and weight was more than unity (Sahoo and Singh, 2017; Malav *et al*., 2018). The crosses exhibited vital desirable positive SCA for all industrial traits that were effective within the final productivity (Ene *et al*., 2019).

The high-yielding cultivars under natural heat stress conditions were developed from parental lines with high general combining ability. The additive sequence effects were found to be a lot of relevant than non-additive gene effects for each femaleness and yield (Tak *et al*., 2017). The superior genotypes may be well employed in recombination breeding programs to accumulate appropriate genes that area unit answerable for rising yield (Sahoo and Singh, 2017). The high significant GCA and SCA mean squares recorded for all told traits recommend the im-portance of each additive and non-additive elements of inheriting variance and that area unit be blamed for variation ascertained in these traits. The crosses combinations, that exhibited significant positive SCA for many traits, were additionally combined extremely significant desirable negative SCA effects for earliness (Malav *et al*., 2018). As for, the highest significant heterosis over mid-parent for all traits in fascinating direction was exhibited heterosis the prevalence of F_1 over the mid-parents (M.P.) and also the better parent (B.P.) was a result of the accumulation of favorable dominant genes within the F_1 population (Prashant *et al*., 2018). There were significant positive values of heterosis over mid-parent for many traits. The non-additive factor effects check with the dominance that appeared due to heterosis values. Several studies had reported the importance of heterosis in cucumber traits such as yield, fruits, flowering, and growth (Prashant *et al*., 2018). Many studies were conducted to spot the most effective heterotic combination for earliness, yield, and quality traits in cucumber. Considerable heterosis was discovered over higher parent for numerous economic traits. The many negative heteroses for timing were recorded as days to 1st female flower growing (Preethi *et al*., 2019). Vital heterosis had conjointly been reported for timing characters (Jat *et al*., 2021). Therefore, the yield of cucumber could be increased by the exploitation of gynoecious line collectively in future breeding programs. For fruit weight attribute, there was no any important increase in heterosis. Generally, most hybrids had heterotic effects over the center parent.

CONCLUSIONS

In light of the challenge of climatic changes and extreme global warming, it has become necessary for plant breeders to give great efforts to supply cultivars and hybrids that tolerate the high-temperature increase. This study successfully developed a bunch of tolerant inbred lines meeting heat stress. Within the current study, promising parental lines P1, P2, P3, and P5 were identified as useful in hybridization programs to attain the most variability toward changes within the proportion of yield and its components under heat stress conditions. Significant GCA and SCA effects were observed for the studied traits imply that both additive and non-additive components of gene actions were involved within the inheritance. The prevalence of additive gene action in various characteristics indicates that using appropriate methods, like diallel selective mating or cyclic selection, genetic improvement is often achieved through accumulating favorable alleles from parents with high GCA within the target genotype. On the idea of the SCA effects, five cross combinations (P1 × P2), (P1 ×P3), (P2 ×P5), (P2 ×P6), and (P3 ×P4) were found promising F1 hybrids to be used as a source population for further selection. In the current study, promising parental lines such as P1, P2, P3, and P5 were identified as useful lines in hybridization programs to achieve the maximum variability toward changes in the proportion of yield and its components. More interesting, physiological, biochemical and molecular discussion are investigating in the complementary study for the most tolerant prenatal lines for heat stress condition that face cucumber cultivation in Egypt.

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الاستفادة من تنوع المصادر الوراثية للخيار المصري كوسيلة لإنتاج هجن جديدة تحت ظروف الإجهاد الحراري

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الملخص

تعتبر التغيرات المناخية من التحديات العالمية الحاسمة التي تحد من تنمية المحاصيل وإنتاجيتها. كما تعتبر تربية النبات حلاً استثنائيًا لتوفير الطرز الوراثية المتحملة للحرارة. كما تعتبر تربية النباتات حلاً فريدًا لتوفير الأمن الغذائي في جميع أنحاء العالم. يجب أن يدعم التنوع الوراثي في سلالات الخيار الأبوية انتاج هجن جديدة. في هذه الدراسة، تم إجراء التهجين باستخدام التصميم النصف دائري بين ستة سلالات ابوية مرباه داخليا لإنتاج 15 هجينًا تحت ظروف الإجهاد الحراري في عام 2019. أما في عامي 2020 و 2021، تم تقييم جميع الأنماط الوراثية في ظل ظروف الإجهاد الحراري، باستخدام تصميم القطاعات الكاملة العشوائية. أظهر التحليل وجود فروق ذات دلالة إحصائية بين جميع الطرز الوراثية. كما أظهر متوسط الأداء أن الهجين ($P_1 \times P_2$) كان الأعلي تفوقا، يليه الاب (P_1) بالنسبة لصفات النمو الخضري والمحصول. كما أظهر التقييم الوصفي اختلاف كبير بين جميع الأنماط الوراثية. كما انقسمت السلالات الأبوية إلى مجموعتين بناءً على خلفيتها الوراثية. كما كشفت القدرة العامة علي التآلف (GCA)، والقدرة الخاصة علي التآلف (SCA)، وقوة الهجين ان P_1 و P_2 أظهرا أعلى تأثيرات في الاتجاه المرغوب فيه للصفات الخضرية، المحصول وصفات التبكير. ومع ذلك، كان الاب P_3 الأعلى تفوقا في معظم الصفات الثمرية. وفقًا لتأثيرات SCA وقوة الهجين، أظهرت الهجن $P_1 \times P_2$ و $P_1 \times P_3$ و $P_2 \times P_5$ جودة عالية في معظم الصفات. أخيرا فأن الآباء المنتخبة كانوا المعطون الجيدون من خلال تراكم الجينات المنتخبة، والتي يمكن أن تكون ذات قيمة عند انتقالها بالتهجين لإنتاج هجن جديدة ومتنوعة.

الكلمات الدالة: الاجهاد الحراري، القدرة العامة على التآلف، القدرة الخاصة على التآلف، التوصيف الظاهري ومكونات المحصول