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Gene action and hybrid vigour for yield, yield components and tolerance to the Two-Spotted Spider mite in summer squash

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Abstract

An investigation was conducted at Kaha Vegetable Research Farm in the Kaliobia Governorate from 2021 to 2023 with an aim to evaluate the performance of six inbred lines of *summer squash* and their fifteen crosses in both open field and plastic greenhouse conditions. The study spanned two successive summer seasons (2022 and 2023) and focused on assessing horticultural traits and resistance levels to the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). Significant variations were observed in the mean performance of all traits among different genotypes. Analysis revealed significant differences in both general (GCA) and specific (SCA) combining abilities for all studied traits, except for the number of days to anthesis of the first female flower, indicating the presence of both additive and non-additive gene effects in traits inheritance. In the plastic greenhouse, genotype P3 exhibited the highest resistance with an average of 10.6 mites per 2 inches^2, while the cross P2 × P6 showed tolerance with an average of 4.4 mites per 2 inches^2. This study highlights the potential of new *summer squash* hybrids with desirable horticultural traits and resistance to the two-spotted spider mite. Additionally, parent 222/2 (P1) demonstrated the best combining ability for all traits, while parents 264 (P5) and 240/3 (P4) were the most effective combiners for total yield. Breeders may leverage these parents for genetic enhancement and the production of hybrids with superior horticultural qualities. Overall, this research provides valuable insights for researchers, breeders and farmers involved in the cultivation, breeding and utilization of *summer squash* in Egypt.

Key words: Summer squash, heterosis, *Tetranychus urticae*, tolerant, two-spotted spider mite.

Introduction

Summer squash, scientifically known as *Cucurbita pepo* L., stands as a cornerstone in the realm of warm-season crops within the Cucurbitaceae family, celebrated for its nutritional richness and its pivotal role in supporting metabolic health. Its adaptability to diverse climates, from temperate to subtropical, has cemented its status as a staple in tropical regions, thereby wielding considerable influence in global agricultural economies (Paris, 1996).

Delving into the intricate interplay of genetic factors shaping key traits in cucurbits, researchers have scrutinized the roles of general combining ability (GCA) and specific combining ability (SCA) in the context of female flower anthesis duration. Abd El-Hadi *et al.* (2005) provided seminal insights into this arena, revealing the dominance of non-additive genetic variance over additive genetic variance in squash traits, particularly in relation to early and total yield per plant.

Moreover, recent investigations by El-Shoura and Diab (2022) have unveiled promising combinations for various squash traits, pinpointing specific crosses—such as P1 × P3, P1 × P4 and P3 × P4—that exhibit the highest SCA values. Soliman (2022) further underscored the significance of genetic diversity in breeding programs by identifying desirable negative heterosis for earliness in select F_1 crosses. Notably, El-Shoura and Diab (2022) shed light on the phenomenon of heterosis surpassing both mid and better parental values for early and total yield in summer squash.

However, amidst these strides in genetic enhancement and trait optimization, challenges persist in the form of agricultural pests, chief among them being *Tetranychus urticae* Koch, commonly known as the two-spotted spider mite. These minuscule pests pose a formidable threat to squash plants, inflicting damage upon leaves, stems and branches. The symptoms of their insidious infestation manifest as distinctive white or yellow spots on the lower leaf surface (Faris *et al.*, 2004; Abdallah *et al.*, 2009; Mutthuraju, 2013). In light of escalating concerns regarding pesticide reliance and environmental sustainability, identifying squash varieties endowed with resilience to *T. urticae* assumes paramount importance.

In response to this imperative, the current study endeavors to unravel the intricacies of heterosis and combining ability in fifteen squash crosses and their parental lines, with a specific focus on elucidating the tolerance of squash varieties and hybrids to spider mite infestation. By scrutinizing the intricate genetic interplay and discerning patterns of resilience, this research seeks to furnish breeders, researchers and farmers with invaluable insights to bolster the conservation, breeding and utilization of summer squash in Egypt and beyond.

Materials and methods

The study was conducted at Kaha Vegetable Research Farm over the period of 2021 to 2023. Six inbred lines of summer squash (*Cucurbita pepo* L.) were utilized as parental lines in a half diallel cross-mating design. These inbred lines, namely 222/2 (P1), 280/9 (P2), 270/5 (P3), 264 (P4), 240/3 (P5) and 207/5 (P6), were developed by the first author.

Genetic materials were maintained for homozygosity and seed yield enhancement in the summer season of 2021 by cultivating the six chosen inbred lines in an unheated plastic greenhouse. In the fall of 2021, these parental lines were planted in an unheated plastic house and all potential crosses were made without reciprocals to produce F_1 seeds. Seeds of the parents and their resulting fifteen crosses were sown in seedling trays in the unheated plastic house on February 27th, 2022 and 2023.

For the open field experiment, a randomized complete block design with three replicates was employed. Each plot consisted of three rows, each one meter wide and four meters long, with a spacing of 50 centimeters between rows. Agricultural practices followed the recommendations of the Ministry of Agriculture in Egypt. Ten plants of each parent and F_1 cross were assessed for various characteristics including days to female flower anthesis, days to male flower anthesis, fruit number per plant, fruit length and diameter (cm), fruit weight (g), early yield per plant and overall yield per plant (kg).

To evaluate horticulture traits and tolerance to *Tetranychus urticae* infestation, seedlings of parents and crosses were transplanted into the open field on March 15th, 2022 and 2023, and also under an unheated plastic house. A complete randomized block design with three replicates, each containing 15 plants, was implemented in the greenhouse. Sampling for spider mite infestation involved randomly selecting five leaves from various parts of the plants in each replicate. These samples were placed in closed paper bags and taken to the Labouratory for analysis. Movable stages of *T. urticae* were counted under a stereomicroscope on the lower leaf surface in two randomly chosen square inches. This sampling was repeated weekly over a span of 10 weeks, covering the vegetative, fruiting and flowering stages.

Statistical analysis involved comparing means using the New L.S.D. technique as outlined by Snedecor and Cochran (1990). For *T. urticae* infestation, a two-factor ANOVA with replications was conducted using Microsoft Excel 2010. General and specific combining abilities (GCA and SCA) were computed using Griffing's (1956) method 2 model 1. Additionally, the average degree of heterosis (ADH%) was calculated following the approach suggested by Sinha and Khanna (1975), representing the percentage change in F_1 performance over both the mid-parent (MP) and better parent (BP).

Results and discussion

Open field experiment

Mean performance for the studied traits: The mean performance of fifteen summer squash crosses alongside six parental lines, assessed and combined across the years 2022 and 2023, is detailed in Table 1. Notably, significant differences were observed across genotypes for all evaluated traits. The number of days until the first female flower anthesis varied among parental lines, ranging from 26.45 (P2) to 31.95 (P5). In contrast, the fifteen F_1 crosses displayed a range of 22.1 (P1 × P2) to 29.30 (P2 × P3) days, with the Tabarak control hybrid registering 31.15 days. Similarly, for the duration until the first male flower anthesis, parental values spanned from 23.80 (P1) to 30.80 days (P4), while F_1 crosses ranged from 20.80 (P4 × P5) to 29.30 (P1× P4 and P3× P6) days, with the Tabarak hybrid at 29.15 days. These observations corroborate the findings of Badr *et al.* (2021), who noted significant relationships across variations, particularly with the number of days until the first female flower anthesis.

In terms of fruit weight, parental values ranged from 74.86 (P4) to 86.41 g (P1), while their crosses varied from 80.05 (P1 × P3) to 109.85 g (P1 × P5), with the Tabarak hybrid at 86.60 g. Fruits per plant exhibited parental values ranging from 7.95 (P6) to 12.25 (P4) fruits per plant, whereas F_1 crosses ranged from 8.80 (P2 × P6) to 14.80 (P3 × P6) fruits per plant, with the Tabarak hybrid at 11.15 fruits per plant.

Regarding average fruit length, the lowest parental value was 11.30 cm (P4), while the highest was 12.90 cm (P1). F_1 crosses ranged from 12.25 (P3 × P6) to 14.85 cm (P5 × P6), with the Tabarak hybrid at 15.55 cm. These findings correspond with Soliman (2022), who reported parental fruit length ranging from 10.76 (P6) to 14.95 cm (P3) and F_1 crosses ranging from 11.15 (P1 × P2) to 16.75 cm (P1 × P3).

Regarding early yield per plant, parental genotypes exhibited a range from 0.108 kg (P6) to 0.185 kg (P1), while crosses ranged from 0.102 kg (P2 × P6) to 0.302 kg (P5 × P6), with the Tabarak hybrid at 0.178 kg. These results align with those of Hussien (2015), who reported early yield per plant ranging from 0.13 kg (P5) to 0.28 kg (P4) for inbred lines and from 0.14 kg (P1 × P5) to 0.5 kg (P4 × P6) for their crosses.

Significant variation was also observed in total yield per plant among parental values, ranging from 0.56 kg (P6) to 0.89 kg (P1). Crosses between parental values exhibited even greater diversity, ranging from 0.83 kg (P4 × P6) to 1.20 kg (P1 × P2).

Combining ability: Tables 2 display the variance analysis for combining ability across different traits investigated in the study. Significantly, there were notable differences observed in both general and specific combining abilities for all traits examined. This underscores the substantial influence of both additive and non-additive genetic factors on the heritability of the traits under study.

These findings are consistent with those of Hussien *et al.* (2013), who reported similar results, noting significant mean squares for both general combining ability (GCA) and specific combining ability (SCA) concerning the same traits.

The inheritance patterns of traits such as days to anthesis of the first female flower and average fruit diameter were predominantly associated with additive genetic variance, as evidenced by the GCA/SCA mean squares ratio. Conversely, traits including days to anthesis of the first male flower, fruit weight, number of fruits per plant, average fruit length and early and total yield per plant exhibited a GCA/SCA ratio below unity, indicating the predominance of non-additive gene action for these variables. These observations align with the findings reported by Hussien *et al.* (2013).

The estimated values for the studied traits are illustrated in Tables 3and 4, showcasing the influence of general combining ability (GCA) for parental lines and specific combining ability (SCA) for crosses. Notably, certain parental lines exhibited significant GCA effects across multiple traits. Specifically, P1 displayed significant effects for all studied traits, P2 for all traits except the number of fruits per plant and early yield, P3 for the number of fruits per plant and average fruit length, P4 for all traits except the number of days to anthesis of the first female flower, fruit weight

Table 1. Mean performance of the six parents, their fifteen crosses and Tabarak hybrid of summer squash for yield and some fruit traits, in open field, combined across two seasons (2022 and 2023)

Genotypes	Days to anthesis of first female flower	Days to anthesis of first male flower	Fruit weight (g)	No. of fruits /plant	Fruit length (cm)	Fruit diameter (cm)	Early yield/ plant (kg)	Total yield/ plant (kg)
222/2 (P1)	28.30de	23.80fg	86.41g	10.65ghi	12.90jk	2.95a	0.185efg	0.89g
280/9 (P2)	26.45efg	25.95cde	82.16hi	10.80fghi	12.50kl	2.15hi	0.149ghi	0.87g
270/5 (P3)	30.30abc	30.45ab	75.95kl	9.45jk	13.15ij	2.10i	0.168efgh	0.67h
264 (P4)	31.30a	30.80a	74.86l	12.25d	11.30m	2.25hi	0.163fgh	0.88g
240/3 (P5)	31.95a	29.65ab	76.06kl	9.55jk	12.75jkl	2.60def	0.147ghi	0.69h
207/5(P6)	26.6efg	29.30ab	77.81jk	7.95l	12.20l	2.90ab	0.108i	0.56i
P1 × P2	22.1h	26.00cdef	91.88f	14.50ab	13.90efgh	2.30ghi	0.163fgh	1.20a
P1 × P3	28.15de	22.50gh	80.05ij	14.15abc	14.30bcde	2.25hi	0.216cde	0.92cd
P1 × P4	28.15de	29.30ab	95.70e	13.40c	14.20cdef	2.65cde	0.280ab	1.12a
P1 × P5	27.45def	25.95c	109.85a	11.15fgh	13.20ij	2.25chi	0.210cdef	1.06b
P1 × P6	25.45g	23.65cdefg	90.36f	10.40hij	14.55bc	2.25chi	0.183efg	0.90g
P2 × P3	29.30bcd	27.b95	100.65cd	10.60ghi	14.70bc	2.10i	0.243bcd	0.95de
P2 × P4	25.30g	25.4cdef5	102.21c	12.20de	13.35ghij	2.80abc	0.294ab	1.13ab
P2 × P5	25.30g	26.15cd	105.81b	11.15efgh	13.25hij	2.75abcd	0.195defg	0.97bc
P2 × P6	26.65efg	23.80efg	108.53ab	8.80kl	13.90defg	2.75abcd	0.102i	0.90fg
P3 × P4	25.80fg	21.30hi	89.15fg	11.55defg	13.60fghi	2.50efc	0.104i	0.92ef
P3 × P5	28.65cd	25.50cdef	81.96hi	11.85def	14.55bcd	2.10i	0.122hi	0.90fg
P3 × P6	27.80de	29.30ab	89.70f	14.80a	12.25kl	2.40fgh	0.248bc	1.18a
P4 × P5	28.65cd	20.80i	96.41e	13.60bc	12.50kl	2.60def	0.212cdef	1.11a
P4 × P6	27.50def	24.30defg	98.08de	9.80ijk	13.20ij	2.70bcde	0.188efg	0.83fg
P5 × P6	27.80de	23.15gh	83.03h	14.15abc	14.85b	2.60def	0.302a	0.97bc
Tabarak	31.15ab	29.15ab	86.60g	11.15efgh	15.55a	2.80abcd	0.176efg	0.97fg

Table 2. Mean squares for combining ability (GCA and SCA) for some characters in summer squash during season 2023 on open field.

Source of variation		GCA	SCA	GCA/SCA
Days to anthesis of first female flower	MS	23.26	14.77	1.57
	F	18.55**	11.78**	
Days to anthesis of first male flower	MS	3.85	35.66	0.11
	F	1.67**	15.48	
Fruit weight	MS	23.26	14.77	0.51
	F	18.55**	11.78**	
No. of fruits /plant	MS	3.85	35.66	0.34
	F	1.67**	15.48	
Fruit length	MS	2.44	2.71	0.90
	F	20.83**	23.11**	
Fruit diameter	MS	0.432	0.233	1.85
	F	30.83**	16.62**	
Early yield/ plant	MS	0.00264	0.01391	0.19
	F	467.15**	2460.7**	
Total yield/ plant	MS	0.06	0.17	0.36
	F	17.01**	46.45**	

*Significant at 0.05 level of probability, **Significant at 0.01 level of probability.

and fruit length, P5 for the number of days to anthesis of the first male flower, fruit length, fruit diameter, and early and total yield per plant, and P6 for the number of days to anthesis of the first female flower and fruit diameter. These parental lines, given their substantial GCA effects across various traits, hold promise as valuable combiners for breeding purposes. These findings are consistent with the conclusions drawn by El-Shoura and Diab (2022), Hamadan and Al-Zubaae (2023) and Soliman (2022), who emphasized the potential for creating superior hybrids using high GCA parents.

Optimal combinations were observed for the specific combining ability effects of the crosses, including P1 × P2, P1 × P5, P1 × P6, P2 × P4, P2 × P5 and P4 × P5 (for number of days until anthesis of the first female flower); P1 × P3, P2 × P6, P3 × P4, P3 × P5, P4 × P5, P4 × P6 and P5 × P6 (for number of days until anthesis of the first male flower). These combinations exhibited considerable and advantageous negative SCA effects on the duration of flowering (for both female and male flowers), suggesting the potential to simultaneously increase yield and promote early flowering.

Furthermore, several cross combinations showed significant SCA effects for important traits such as fruit weight, number of fruits per plant, fruit length, fruit diameter, early yield per plant and total yield per plant. These findings align with those reported by Hussien *et al.* (2013) and Soliman (2022), indicating the potential for achieving significant improvements through the selection of appropriate cross combinations with favorable SCA effects.

Heterosis effects: Tables 5 and 6 display the mid-parent (MP) and better-parent (BP) heterosis values for each trait under study. Notably, the trait of earliness showed a desirable and significant negative MP heterosis in the case of days until anthesis of the first female flower. This negative MP heterosis was observed in six F_1 crosses, with three F_1 crosses exhibiting favorable significant negative BP values—specifically, P3 × P4, P1 × P2 and P2 × P5 with percentages of (-17.58%, -15.00% and -10.00%, respectively).

Similarly, for the trait of earliness regarding days until anthesis of the first male flower, seven F_1 crosses displayed a significant negative MP heterosis. Additionally, five F_1 crosses revealed favorable significant negative BP values—namely, P3 × P4, P4 × P5, P5 × P6, P4 × P6 and P3 × P5 with percentages of -29.67%, -28.89%, -22.47%, -20.22% and -16.67%, respectively.

These findings align with those of El-Shoura and Diab (2022), who reported significant negative (MP) heterosis ranging from -8.11% (P3 × P4) to 9.98% (P1 × P4) for days to anthesis of the first female flower (day).

All crosses, except for P1 × P2 and P1 × P3, exhibited favorable and significant positive mid-parent (MP) heterosis for fruit weight. Eleven crosses demonstrated favorable significant positive better-parent (BP) values for fruit weight, ranging from 6.10% (P3 × P5) to 33.87% (P2 × P6). For the number of fruits per plant, eight crosses displayed favorable significant positive BP values, ranging from 12.73% (P4 × P5) to 63.86% (P3 × P6).

Nine crosses showed desirable positive BP heterosis for fruit length, ranging from 7.42% (P1 × P2) to 16.88% (P5

Table 3. General combining ability effects (gi) of parental lines for studied traits of summer squash during season 2023 in open field

Parents	Days until anthesis of first female flower	Days until anthesis of first male flower	Fruits weight	No. of fruits / plant	Fruit length	Fruit diameter	Early yield/ plant	Total yield/ plant
222/2 (P1)	-1.29**	-1.62**	4.11**	1.12**	0.81**	0.05**	0.042**	0.13**
280/9 (P2)	-4.41**	-0.25**	13.00**	-0.51**	0.07**	-0.06**	-0.026**	0.099**
270/5 (P3)	3.08**	2.00**	-14.15**	0.60**	0.89**	-0.67**	-0.008**	-0.101**
264 (P4)	1.45**	-0.13*	-0.76**	1.40**	-1.76**	0.03**	0.030**	0.115**
240/3 (P5)	2.83**	-0.50**	-2.22**	0.15*	0.11**	0.05**	0.001*	0.009**
207/5(P6)	-1.66**	0.50**	0.02	-2.76**	-0.12**	0.60**	-0.038**	-0.252**
S.E(gi)	0.36	0.48	0.43	0.21	0.11	0.03	0.0007	0.019

*Significant at 0.05 level of probability. **Significant at 0.01 level of probability.

Table 4. Specific combining ability effects (Si) of crosses for studied traits of summer squash during season 2023 in open field.

Crosses[Z]	Days until anthesis of first female flower	Days until anthesis of first male flower	Fruit weight	No. of fruits / plant	Fruit length	Fruit diameter	Early yield/ plant	Total yield/ plant
P1×P2	-9.05**	0.02	-26.22**	10.64**	0.65**	-0.49**	-0.126**	0.62**
P1×P3	2.45*	-8.23**	-18.28**	6.33**	0.84**	-0.18**	0.068**	0.27**
P1×P4	1.07	13.89***	14.43**	1.93**	2.99**	0.02*	0.216**	0.39**
P1×P5	-2.30*	5.27**	57.79**	-4.02**	-1.28**	-0.70**	0.010**	0.27**
P1×P6	-5.80**	-1.73	-1.45	-2.30**	2.75**	-1.24**	-0.030**	-0.20**
P2×P3	7.57**	6.39**	35.43**	-2.43**	2.68**	-0.86**	0.189**	0.17**
P2×P4	-5.80**	-1.48	23.04**	0.07	1.33**	0.93**	0.290**	0.35**
P2×P5	-9.18**	-0.11	31.21**	-0.08	-0.64**	1.11**	0.030**	0.37**
P2×P6	4.321**	-6.11**	41.96**	-5.77**	1.19**	0.87**	-0.211**	-0.15**
P3×P4	-12.30**	-16.73**	7.79**	-0.44	1.21**	0.85**	-0.260**	0.03**
P3×P5	-1.68	-5.36**	-9.94**	0.31	2.64**	-0.48**	-0.178**	-0.12**
P3×P6	-0.18	7.64**	12.81**	13.12**	-3.52**	0.18**	0.253**	1.31**
P4×P5	0.95	-14.23**	15.57**	5.21**	-0.91**	0.12**	0.059**	0.66**
P4×P6	1.45	-8.23**	29.72**	-5.08**	1.83**	0.18**	-0.009**	-0.17**
P5×P6	-0.93	-9.86**	-23.11**	12.87**	4.55**	-0.24**	0.368**	0.79**
SE(Sij)	0.98	1.34	1.18	0.59	0.30	0.10	0.002	0.05

Table 5. Relative heterosis (MP) and (BP) for studied traits of summer squash during season 2023

Crosses[Z]	Days until anthesis of first female flower		Days until anthesis of first male flower		Fruit weight		No. of Fruits /plant	
	MP %	BP %	MP %	BP %	MP %	BP %	MP %	BP %
P1×P2	-18.56**	-15.00**	2.67	8.45	2.65	-1.60	44.17**	48.26**
P1×P3	-2.25	0.00	-12.34*	0.00	-1.94	-8.90**	45.51**	38.17**
P1×P4	-6.67	-3.45	11.65*	28.17**	18.03**	8.63**	15.85*	26.81**
P1×P5	-9.89*	-5.75	1.86	15.49*	33.52**	24.56**	8.91	4.10
P1×P6	-11.38*	-7.50	-5.00	7.042	8.024**	2.89	14.59*	0.31
P2×P3	4.09	11.25*	2.35	10.13	29.45**	25.29**	7.74	17.19*
P2×P4	-14.45**	-7.50	-9.94	-2.53	31.17**	25.70**	3.09	-2.65
P2×P5	-17.71**	-10.00*	-7.69	-1.26	32.18**	28.48**	13.14*	5.37
P2×P6	1.25	1.25	-13.09*	-7.59	34.77**	33.87**	-6.80	-20.30*
P3×P4	-18.48**	-17.58**	-30.05**	-29.67**	16.74**	15.55**	12.69*	30.87**
P3×P5	-6.45	-4.39	-17.13**	-16.67**	6.57**	6.10**	28.22**	29.12**
P3×P6	-1.75	5.00	-1.11	0.00	14.99**	12.02**	78.58**	63.86**
P4×P5	-6.38	-5.37	-29.67**	-28.89**	25.00**	23.19**	27.62**	12.73*
P4×P6	-2.89	5.00	-21.55**	-20.22**	29.34**	24.75**	-4.71	-22.28**
P5×P6	-5.14	3.75	-22.90**	-22.47**	4.19*	1.93	74.57**	59.17**

Z: 222/2 (P1) 280/9 (P2), 270/5 (P3), 264 (P4) 240/3 (P5) and 207/5(P6).*Significant at 0.05 level of probability. **Significant at 0.01 level of probability.

× P6), including P1 × P2, P1 × P3, P1 × P4, P1 × P6, P2 × P3, P2 × P6, P3 × P5, P4 × P6 and P5 × P6, with percentages of (7.42, 6.70, 8.65, 12.27, 9.43, 9.47, 9.43, 9.75 and 16.88%, respectively). Only two crosses indicated desirable significant positive BP heterosis for fruit diameter, namely P2 × P4 and P3 × P4, with percentages of (26.47 and 17.91%, respectively).

Regarding early yield per plant, eleven crosses demonstrated favorable significant positive MP heterosis, ranging from 21.36% (P1 × P3) to 142.90% (P5 × P6). Ten crosses showed favorable significant positive BP heterosis, ranging from 6.44% (P1 × P5) to 108.75% (P5 × P6).

For total yield per plant, all crosses exhibited preferred and exceptionally significant positive MP heterosis, ranging from 22.91% (P1 × P6) to 109.44% (P3 × P6). All crosses displayed favorable significant positive BP heterosis, except for three crosses: P1 × P6, P2 × P6 and P4 × P6. BP heterosis ranged from 16.55% (P3 × P4) to 93.02% (P3 × P6). These findings are consistent with those reported by Hussien *et al.* (2013 and 2015).

Green house experiment

Susceptibility of different squash varieties to *T. urticae* infestation: The resistance of *T. urticae* was investigated over two consecutive seasons, 2022 and 2023, as well as combined across both seasons. The ranks of resistance are presented in Table 7 for six parents and their 15 crosses, alongside Tabark as a standard hybrid. The mean performance for the average number of *T. urticae* movable stages (per two square inches) varied significantly among the genotypes.

Among the parents, P3 displayed the highest resistance with an average of 10.6 mites per two square inches, followed by P1, P4, P2, P6 and P5, with average numbers of 14.7, 16.8, 20.7, 23.8 and 33.8, respectively.

The cross P2 × P6 exhibited the highest resistance with an average of 4.4 mites per two square inches, significantly surpassing the next most resistant crosses, P2 × P3 and P5 × P6, with mite averages ranging between 13.6 and 15.6. Conversely, the cross P1 × P4 showed the highest susceptibility with an average of 44.8 mites per two square inches, followed by P4 × P6 with 35.6 mites. Both of these crosses were significantly more

Table 6. Relative heterosis (MP) and (BP) for studied traits of summer squash during season 2023

Crosses[Z]	Fruit length		Fruit diameter		Early yield/plant		Total yield/plant	
	MP %	BP %	MP %	BP %	MP %	BP %	MP %	BP %
P1×P2	8.95**	7.42*	-9.43*	-20.88**	-9.55**	-21.35**	47.81**	45.68**
P1×P3	8.31**	6.70*	-12.10*	-24.17**	21.36**	14.57**	41.99**	25.90**
P1×P4	16.76**	8.69*	-1.26	-14.28**	59.81**	46.27**	37.77**	37.77**
P1×P5	3.35	2.55	-16.47**	-21.98**	22.66**	6.44**	44.58**	29.49**
P1×P6	15.68**	12.27**	-21.54**	-21.98**	21.73**	-6.95**	22.91**	3.24
P2×P3	12.64**	9.43**	-8.95	-10.29	51.66**	38.93**	38.55**	24.44**
P2×P4	11.85**	5.52	27.41**	26.47**	87.04**	76.73**	37.22**	35.25**
P2×P5	4.57	3.90	19.73**	11.39	32.87**	32.56**	49.38**	35.55**
P2×P6	11.23**	9.47**	15.19**	1.11	-20.05**	-31.42**	25.92**	7.04
P3×P4	10.27**	1.24	18.79*	17.91*	-34.52**	-36.64**	31.44**	16.55*
P3×P5	11.93**	9.43**	-8.96	-16.45**	-18.79**	-25.76**	36.55**	35.00**
P3×P6	-2.20	-6.45*	0.00	-13.33	86.84**	49.04**	105.44**	93.02**
P4×P5	4.99	-1.56	8.22	0.00	43.94**	35.71**	59.43**	42.80**
P4×P6	14.60**	9.78**	8.28	-5.55	38.90**	13.67**	23.77**	3.95
P5×P6	19.52**	16.88**	-4.14	-10.00**	142.90**	108.75**	82.39**	69.54**

Z,222/2 (P1), 280/9 (P2), 270/5 (P3), 264 (P4) 240/3 (P5) and 207/5(P6).(parents name)
*Significant at 0.05 level of probability. **Significant at 0.01 level of probability.

susceptible compared to the standard hybrid Tabark, which had an average of 36.2 mites per two square inches and did not show significant differences in susceptibility.

Table 7. Mean performance of *T. urticae* movable stages on tested summer squash parents and their crosses in plastic house across two seasons

Genotypes	Number of *T. urticae* Koch movable stages (two inches^2)	Resist Rank
222/2 (P1)	14.7cdefgh	4
270/5 (P2)	20.7ijklm	11
280/ 9(P3)	10.6 b	2
240/3(P4)	16.8defghi	6
264 (P5)	33.8rstu	19
207/5(P6)	23.8imno	14
P1 × P2	28.2pq	16
P1 × P3	20.0hijkl	10
P1 × P4	44.8v	22
P1 × P5	17.1defghi	7
P1 × P6	17.4defghij	8
P2 × P3	13.6 cde	3
P2 × P4	29.5pq	17
P2 × P5	33.5rstu	18
P2 × P6	4.4 a	1
P3 × P4	21.0ijklmn	12
P3 × P5	23.2klmno	13
P3 × P6	19.1fghijkl	9
P4 × P5	25.3mno	15
P4 × P6	35.6rstu	20
P5 × P6	15.6cdefgh	5
Tabarak	36.2rstu	21

Our findings revealed varying degrees of infestation by *T. urticae* across different squash varieties. These results align with those of Abdallah *et al.* (2018), who conducted a two-year investigation to assess the suitability of three squash cultivars—Mabroka, Brencesa and Eskandarani—for egg and motile stages of *T. urticae* in Balaktar and Om Saber villages, Behera Governorate. They found no significant differences in infestation levels among the three cultivars (LSD; $P > 0.05$). However, Mabroka exhibited the highest resistance to *T. urticae* in both villages, surpassing Eskandarani in terms of average output, followed by Brencessa, which showed higher total yield production despite a moderate mean number of spider mite infestations. Eskandarani was the most susceptible, resulting in very weak fruit yield production during both seasons.

Furthermore, Abdallah *et al.* (2009) observed significant differences in *T. urticae* infestation among three squash cultivars. Eskandarani was the most sensitive, Hytech was intermediate and the American cultivar had the lowest average number of spider mite infestations. Additionally, Abou-Zaid *et al.* (2019) reported that the most resistant varieties throughout the study period were Sama 740 and Arkam, while the most susceptible variety was Andro 174. Moreover, Rasha *et al.* (2020) investigated the vulnerabilities of three squash varieties to *T. urticae* infestation and its population over two consecutive seasons, 2017 and 2018. They found Eskandarani to be the most susceptible, followed by Hytech and Milet. In the 2017 season, Eskandarani and Milet experienced population peaks in the second week of May and June, while in 2018, peaks occurred in the fourth week of April and May. Hytech exhibited peaks in the third and first weeks of May and June in 2017, shifting to the first and fourth weeks of May and June in 2018. These findings were consistent with those of Gamila *et al.* (2016), who also observed two peaks of *T. urticae* activity in the second and fourth weeks of April.

Based on the findings of our study, it is evident that parent 222/2 (P1) emerged as the most favorable combiner across all traits. Additionally, parents 264 (P5) and 240/3 (P4) displayed superior combining abilities for total yield, suggesting their potential utility for genetic enhancement by squash breeders to develop hybrids with desirable horticultural qualities. Conversely, the specific combination P2 × P4 demonstrated the highest combining ability for all traits. Moreover, crosses such as P1 × P2, P3 × P6 and P4 × P5 exhibited highly desirable heterosis for total yield, indicating their promise for yield improvement. In terms of resistance to *T. urticae*, parent P3 (280/9) showed the highest level of resistance, with an average of 10.6 mites per 2 square inches. Additionally, the cross P2 × P6 displayed notable resistance, with an average of 4.4 mites per 2 square inches. These findings suggest the potential of these genotypes for use in breeding programs aimed at developing squash varieties with enhanced resistance to *T. urticae*.

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