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LINE X TESTER MATING DESIGN FOR STUDYING SOME SEED TRAITS OF TOMATO RELEVANT HYBRID SEEDS PRODUCTION

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It is crucial to investigate the traits of tomato (*Solanum lycopersicum* L.) seeds in order to move toward the commercial production of promising hybrid seeds from the Desert Research Center's Plant Breeding and Conservation Program. In the summer months of 2023 and 2024, the research began up. At the greenhouse program at Saint Catherine (28°33` N, 33°56` E, and 1650 m above sea level) of South Sinai, five lines were crossed with three tomato testers using manual pollination to develop hybrid seeds and self-pollination to generate parental seeds. The experimental design was randomized complete block design with three replicates. The results indicated that the sources of variation in line x tester analysis were significantly different for most measured traits in the two seasons. L_3 and L_4 were the best of most of the traits. The cross $L_4 \times T_2$ was the best for the number of seeds per fruit and average seeds weight per fruit. The crosse $L_2 \times T_1$ was positive heterosis and heterobettiosis for all traits. The proportional contribution lines were higher than line × tester interactions and testers for 1000 seeds weight trait, because it basically reflects seeds weight of lines. Heritability estimates in narrow sense were low for all the studied traits.

Keywords: *Solanum lycopersicum*, seeds, performances, heterosis, heritability

INTRODUCTION

In Egypt, tomatoes are one of the major vegetable crops that are widely farmed. Utilizing tomato hybrid seeds is a fundamental component of Egypt's agricultural output. Ganeva (2011) examined the essential characteristics and variability related to seed production in the fruit of tomato intravarietal hybrids and their parent lines. He discovered that the line parents had an average of 65–179.9 seeds per fruit, whereas the hybrids had an average of 90–205 seeds. 1000 seeds weighed between 2.456 to 3.768 g in the lines. The number of seeds in 1 g of fruit in F1 hybrid combinations of tomatoes is significantly larger than those of the parental forms. Gungun and Sumpena (2018) studied yield and seed quality of six tomato cultivars and found that yield and quality of tomato seed production greatly influenced by genotype. Based on the seed quality, all cultivars candidate seeds varieties had good qualities. The average number of seeds per fruit was between 77.25 to 150 seeds. Seeds weight per fruit was 0.075 to 0.325 g. The weight of 1000 seeds was between 2.30 to 3.45 g. Ruiz-Nieves et al. (2021) found that the average number of seeds per fruit is between 120 to 180 seeds. The weight of 1000 seeds was between 2.99 to 3.2 g.

Egyptian agriculture is primarily relay on tomato hybrids imported from overseas, whether for the field or greenhouses. The hybrids are distinguished by their high production quality and resistance to diseases. In the near future, the program aims to produce tomato hybrid seeds that are suitable for the Egyptian desert’s conditions, whether for the field or agricultural greenhouses. The production of tomato hybrid seeds under Egyptian conditions has many economic dimensions. The most important of which is limiting imports from abroad. Also reducing unemployment, as the hybrids production process absorbs a large number of workers. The research aims to study seed traits (number of seeds per fruit, their weight and 1000 seeds weight) of tomato to help in producing hybrid seeds in the future. Also, hybrid vigor and heritability coefficient for those traits were calculated.

MATERIALS AND METHODS

Desert Research Center's (DRC) plant breeding and conservation program provided the plant material used in this investigation. There were five lines: SA1-7/2/3 (L_1), SFla-7/1/3 (L_2), STel-7/1/3 (L_3), $SY_{2,2,1}$-7/1/3 (L_4), and $SH_{3,1}$-5/1/3 (L_5). Together with three testers [$SD_{5,3}$-5/1/3 (T_1), SR_2-7/1/3 (T_2) and $SY_{1,1}$-5/1/3 (T_3)]. The study area: Saint Catherine (28°33` N, 33°56` E and 1650 m above sea level) lies in the arid North African belt; it is characterized by a Sahara-Mediterranean climate. Although the altitude moderates the temperature regime, summers are relatively hot with a mean maximum temperature of 36°C (August), while winters are relatively cool with a mean minimum of -7.8°C (February). Precipitation is less than 50 mm/year. The relative humidity is low, normally between 10 and 20% and rarely exceeding 50% (Grainger, 2003). Soil (Depth 0-30 cm) is sand loamy, salinity is 0.33 dSm^{-1}, pH is 7.90 and organic matter is 1.3%. Irrigation water salinity is 1.02dSm^{-1} and pH is 7.45.

The trial was set up during summer of the two seasons: 2023 and 2024. Five lines were crossed with three testers of tomato by hand pollination to produce hybrid seeds and self-pollination to produce parental seeds at greenhouse program in Saint Catherine, South Sinai. Transplanting was done with the seedlings of 30 days old in the greenhouse on 15th May during the two seasons in Saint Catherine, South Sinai. Tomato genotypes were grown in a randomized complete block design with three replications. Each replication had 8 plots (5 lines + 3 testers). Spacing was 100 cm × 50 cm keeping 20 plants in each plot. A drip irrigation system was used. Normal agricultural treatments were applied. The average number of seeds per fruit, average seeds weight per fruit (g) and average 1000 seeds weight (g) were recorded from five selected plants from each plot (cross pollination and self-pollination), five fruits in ripening phase were randomly selected per each plant.

Analysis of variance was done according to Steel and Torrie (1980). The treatment means were compared using the least significant difference test at 5% and 1% levels of significance. Heterosis was expressed as the percentage deviation of the F_1 hybrids mean ($\overline{F_1}$) from the average of the two parents (M.P.) and better parent (B.P.) as heterobettiosis (Sinha and Khanna, 1975). Line x tester analysis was done as reported by Kempthorne (1957). Heritability estimates were obtained as described by Burton and Devan (1953), heritability in broad and narrow sense were determined as:

$$h^2(b.s) = \frac{\sigma^2 g}{\sigma^2 ph} x100 = \frac{\sigma^2 A + \sigma^2 D}{\sigma^2 A + \sigma^2 D + \sigma^2 e} x100$$

$$h^2(n.s) = \frac{\sigma^2 A}{\sigma^2 ph} x100 = \frac{\sigma^2 A}{\sigma^2 A + \sigma^2 D + \sigma^2 e} x100$$

Where:

h^2 (b.s.): Heritability in broad sense,

h^2 (n.s.): Heritability in narrow sense,

σ^2 g: Genotypic component of variance,

σ^2 ph: Phenotypic component of variance, and

σ^2 A, σ^2 D and σ^2 e are the additive, dominance, and environmental component of variances, respectively.

RESULTS AND DISCUSSION

The results of analysis of variance of all tomato genotypes and their components (parents, crosses, parents vs. crosses, lines, testers and line×tester) are presented in Table (1). Significant tests revealed that the mean squares of genotypes were significant for all tested traits (number of seeds per fruit, seeds weight per fruit and 1000 seeds weight) under Saint Catherine conditions for the two seasons. Also, parents, crosses, lines, testers and line × tester were significant for all traits, except lines for number of seeds per fruit and testers for 1000 seeds weight were non-significant in 2024 season. While parents vs. crosses were significant for the number of seeds per fruit in 2023 season and 1000 seeds weight in 2024 season, only.

The genetic differences in most traits among tomato genotypes have been reported by Adebisi and Ojo (2001), Ganeva (2011), Gungun and Sumpena (2018) and Ruiz-Nieves et al. (2021).

Table (1). Mean squares of line × tester for the number of seeds per fruit, seeds weight per fruit and 1000 seeds weight of tomato genotypes under Saint Catherine conditions in 2023 and 2024 seasons.

Source	df	No. of seeds / fruit		Seeds weight / fruit (g)		1000 seeds weight (g)	
		2023	2024	2023	2024	2023	2024
Replications	2	706.1	506.9	0.012	0.009	0.022	0.072
Genotypes	22	1602.9*	1819.3*	0.023*	0.026*	1.082*	1.013*
Parents	7	1405.8*	1431.0*	0.015*	0.017*	0.829*	0.739*
Par. vs crosses	1	127.9*	598.4n.s	0.003n.s	0.002n.s	0.049n.s	0.524*
Crosses	14	1806.9*	2100.6*	0.028*	0.033*	1.282*	1.185*
Lines	4	919.2*	928.1n.s	0.036*	0.043*	3.264*	3.104*
Tester	2	4788.9*	5865.4*	0.071*	0.084*	0.412*	0.083n.s
Line × tester	8	1505.2*	1745.6*	0.012*	0.015*	0.509*	0.501*
Error	44	18.8	302.5	0.001	0.004	0.025	0.063

NS, **: Nonsignificant, Significant at 0.05 level of probability, respectively.

1. Mean Performance

Mean performances of parents (five lines and three testers) and their fifteen hybrid seeds for number of seeds per fruit, seeds weight per fruit and 1000 seed weight traits of the two seasons. The results presented in Table (2) indicate clearly that significant differences were recorded among the different tomato genotypes in all traits. The mean number of seeds per fruit trait was 97.4, 101.2, 114.4, 113.6, 106.7 and 112 in the lines, testers and crosses, in the two seasons, respectively (Fig. 1). L_3 and $L_4 \times T_2$ gave the highest mean performance of number of seeds per fruit (120.9, 123.9, 139.4 and 148.3) in the two seasons, respectively. While L_5, T_3 and $L_5 \times T_1$ recorded the lowest mean performance of number of seeds per fruit in the two seasons. The genetic differences in the number of seeds per fruit between tomato genotypes have been reported by Ganeva (2011), Gungun and Sumpena (2018) and Ruiz-Nieves et al. (2021).

Concerning the mean seeds weight per fruit trait was 0.32, 0.33, 0.36, 0.39, 0.35 and 0.37 g in the lines, testers and crosses, in the two seasons, respectively (Fig. 2). Mean performance value of seeds weight per fruit was 0.42 and 0.43 g for L_3 and 0.51 and 0.54 g for $L_4 \times T_2$ in the lines and crosses, in the two seasons, respectively. While L_5, T_2 and $L_3 \times T_1$ gave the lowest mean performance of seed weight per fruit in the lines, testers and crosses, in the two seasons, respectively. These results agree with those of Ganeva (2011) and Gungun and Sumpena (2018).

Table (2). Mean performance for number of seeds per fruit, seeds weight per fruit and1000 seeds weight traits of tomato genotypes under Saint Catherine conditions, seasons 2023 and 2024.

Tomato genotype	No. of seeds / fruit		Seeds weight / fruit (g)		1000 seeds weight (g)	
	2023	2024	2023	2024	2023	2024
L_1	100.9	105.6	0.24	0.26	2.53	2.82
L_2	101.9	109.7	0.31	0.34	3.09	3.14
L_3	120.9	123.9	0.42	0.43	3.48	3.50
L_4	100.3	104.0	0.40	0.42	4.09	4.05
L_5	62.9	62.8	0.22	0.22	3.49	3.51
Mean	97.4	101.2	0.32	0.33	3.32	3.40
T_1	103.4	129.5	0.36	0.40	3.39	3.15
T_2	139.6	122.7	0.35	0.37	2.68	3.07
T_3	100.3	88.7	0.37	0.38	3.85	4.25
Mean	114.4	113.6	0.36	0.39	3.31	3.49
$L_1\times T_1$	117.8	123.3	0.30	0.31	2.59	2.73
$L_1\times T_2$	101.7	107.2	0.27	0.28	2.65	2.70
$L_1\times T_3$	127.8	133.3	0.35	0.37	2.76	2.76
$L_2\times T_1$	109.3	117.8	0.37	0.41	3.44	3.46
$L_2\times T_2$	137.2	141.7	0.44	0.46	3.24	3.27
$L_2\times T_3$	91.4	99.3	0.39	0.42	3.97	3.46
$L_3\times T_1$	67.6	67.7	0.13	0.13	1.86	1.88
$L_3\times T_2$	116.9	120.8	0.38	0.39	3.26	3.26
$L_3\times T_3$	135.0	140.0	0.38	0.39	2.78	2.76
$L_4\times T_1$	80.0	82.1	0.34	0.35	4.29	4.41
$L_4\times T_2$	139.4	148.3	0.51	0.54	3.64	3.67
$L_4\times T_3$	106.4	111.1	0.44	0.46	4.16	4.13
$L_5\times T_1$	57.2	56.7	0.20	0.20	3.49	3.54
$L_5\times T_2$	105.1	115.3	0.34	0.37	3.19	3.17
$L_5\times T_3$	106.9	115.7	0.38	0.41	3.57	3.58
Mean	106.7	112.0	0.35	0.37	3.26	3.25
LSD 0.05	7.35	29.11	0.054	0.107	0.268	0.425
LSD 0.01	9.99	39.58	0.073	0.146	0.364	0.578

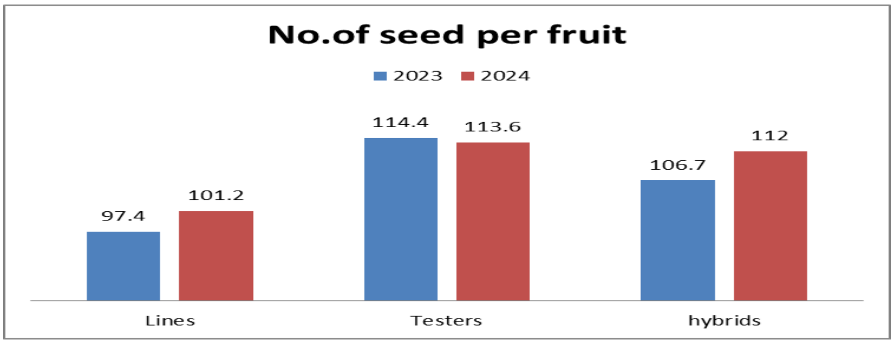

Fig. (1). The mean of no. of seed per fruit trait in tomato lines, testers and hybrids, in the two seasons.

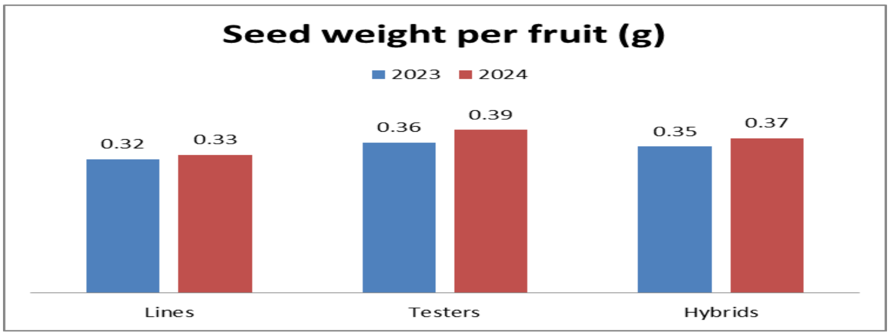

Fig. (2). The mean of seed weight per fruit trait in tomato lines, testers and crosses, in the two seasons.

Regarding the mean 1000 seeds weight trait was 3.32, 3.4, 3.31, 3.49, 3.26 and 3.25 g in the lines, testers and crosses, in the two seasons, respectively (Fig. 3). Mean performance value of 1000 seeds weight was recorded for L_4 (4.02 and 4.05 g) and $L_4 \times T_1$ (4.29 and 4.41 g) in the lines and crosses, in the two seasons, respectively. While L1 and $L_3 \times T_1$ gave the lowest values of 1000 seeds weight in the lines, testers and crosses, in the two seasons, respectively. In this respect, Ganeva (2011), Gungun and Sumpena (2018) and Ruiz-Nieves et al. (2021) found that genotype differences lead to differences in the traits of plant seed. This directly affects the number of seeds produced (Adebisi and Ojo, 2001).

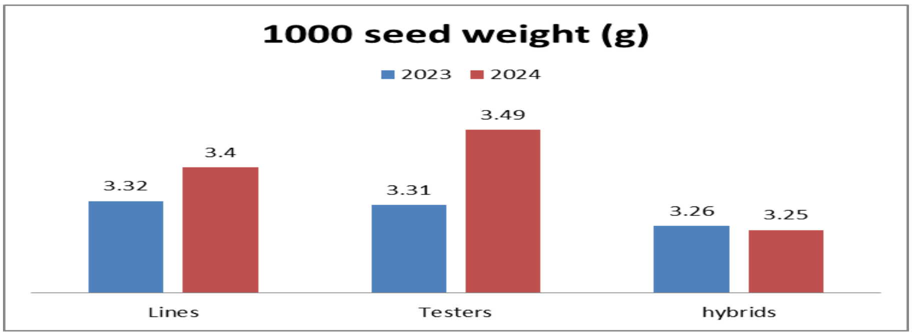

Fig. (3). The mean of 1000 seeds weight trait in tomato lines, testers and crosses, in the two seasons.

2. Heterosis

Table (3) shows heterosis and heterobettiosis effects for some seed traits i.e., number of seeds per fruit, seed weight per fruit and 1000 seeds weight of season 2024. $L_5 \times T_3$ and $L_1 \times T_3$ hybrids expressed significant and highly significant and positive heterosis effect for the number of seeds per fruit (38.72 and 27.25%), respectively. However, the hybrid $L_1 \times T_3$ gave the best heterobettiosis effect. The hybrids $L_2 \times T_1$, $L_2 \times T_2$, $L_2 \times T_3$, $L_4 \times T_2$, $L_4 \times T_3$

and $L_5 \times T_3$ expressed highly significant and positive heterosis and heterobettiosis effects for seeds weight per fruit, respectively. The hybrids $L_2 \times T_1$, $L_2 \times T_2$, $L_4 \times T_1$ and $L_5 \times T_1$ expressed highly significant and positive heterosis and heterobettiosis effect for 1000 seeds weight, respectively. In general, the hybrid $L_2 \times T_1$ had positive heterosis and heterobettiosis effects for all traits. Positive and negative heterosis effects for these traits were detected by Ganeva (2011).

Table (3). Heterosis (M.P.) and heterobettiosis (B.P.) for number of seed per fruit, seed weight per fruit and 1000 seeds weight of tomato genotypes under Saint Catherine conditions in season 2024.

Tomato hybrid	No. of seeds / fruit		Seeds weight / fruit (g)		1000 seeds weight (g)	
	H. (M.P.) %	H. (B.P.) %	H. (M.P.) %	H. (B.P.) %	H. (M.P.) %	H. (B.P.) %
L1× T1	12.68	8.82	-5.05**	-21.67**	-8.48**	-13.32**
L1× T2	-15.69	-27.92	-13.09**	-26.54**	-8.21**	-11.94**
L1× T3	27.25*	26.30	15.63**	-2.63**	-21.98**	-35.09**
L2× T1	5.68	3.97	9.42**	1.67**	10.06**	9.83**
L2× T2	9.68	-4.71	28.70**	23.01**	5.31**	4.14**
L2× T3	-7.02	-9.42	15.21**	9.65**	-6.23**	-18.45**
L3× T1	-42.95**	-45.38**	-69.35**	-70.31**	-43.59**	-46.38**
L3× T2	-11.34	-18.72	-2.07**	-7.81**	-0.76**	-6.86**
L3× T3	22.86	12.99	-4.13**	-9.38**	-28.66	-34.93**
L4× T1	-24.45	-27.56	-14.63**	-16.67**	22.54**	8.97**
L4× T2	17.41	-0.22	36.40**	29.36**	3.09**	-9.38**
L4× T3	6.83	6.83	15.00**	9.52**	-0.36**	-2.67**
L5× T1	-35.57**	-49.94**	-35.83**	-50.00**	6.31**	0.95**
L5× T2	9.09	-22.42	22.22**	-2.65**	-3.59**	-9.60**
L5× T3	38.72**	11.22	37.02**	8.77**	-7.74**	-15.78**

* and **: indicate significant at 0.05 and 0.01, respectively.

3. Contributions

The proportional contributions to the total variance of crosses by lines, testers and their interaction (line × tester) are provided in Fig. (4) for season 2024. The contribution of line × tester interactions towards total variance was higher than testers for number of seeds per fruit trait. The lines contributed were equal with testers contributed than line × tester interactions in the seed weight per fruit trait. Lines contribution was higher than line × tester interactions and testers for 1000 seeds weight trait. Because it basically reflects seed weight of lines. The present results are corroborated with the previous research findings of Manivannan and Sekhar (2005), Kumari and Sharma (2012) and Bayomi (2024), who also found uneven contributions for lines, testers and their interaction (line × tester) of different traits in tomato.

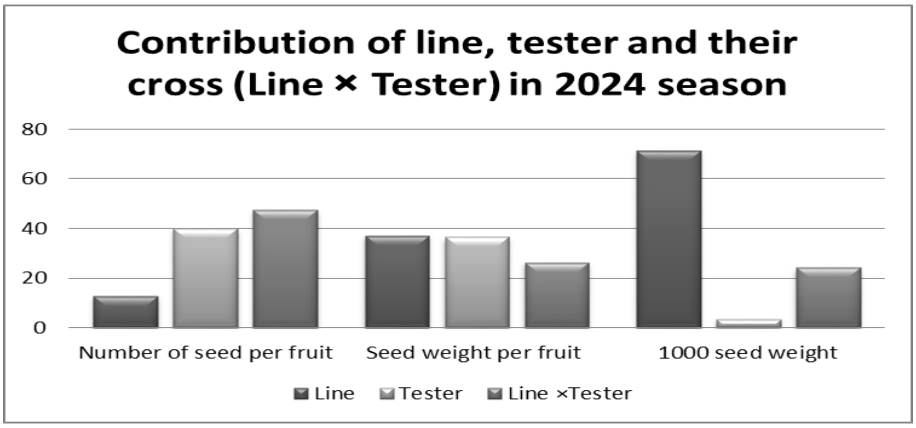

Fig. (4). Contribution of line, tester and their cross (Line × Tester) in the expression of studied traits, season 2024.

4. Heritability

Estimates of heritability in broad and narrow-sense (H^2) of season 2024 are shown in Fig. (5). Heritability estimates in broad sense were moderate for all studied traits. Heritability estimates in narrow sense were low for all studied traits; show that these traits are adopted on the variation available in the tomato genotypes and the effects of environmental conditions. Bicer and Sakar (2010) found that the heritability in lentil (*Lens culinaris*) for 1000 seed weight and number of seeds plant were estimated as 98 and 70%, respectively.

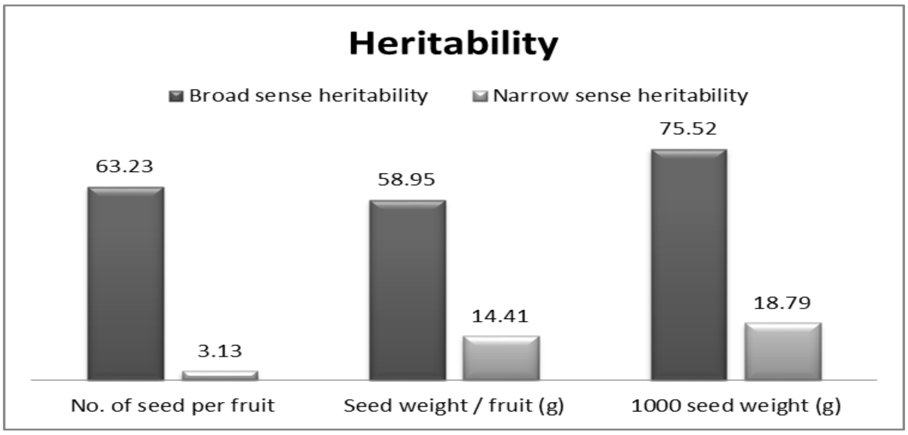

Fig. (5). Heritability in tomato (broad and narrow sense) of studied traits, season 2024.

CONCLUSION

L_3 and L_4 were the best in most of traits. The cross $L_4 \times T_2$ was the best for the number of seeds per fruit and the average seed weight per fruit.

The number of seeds per fruit depends on environmental conditions (temperature and humidity), flower stage during pollination, shape and size of the fruit, fruits contain the mutation high pigment and number of locules per fruit. The crosses $L_{2} \times T_{1}$ had positive heterosis and heterobettiosis effects for all traits. Lines contribution was equal with testers contribution than line × tester interactions in the seed weight per fruit trait. Heritability estimated in broad sense (H^2) was moderate for all traits, Heritability estimation in narrow sense were low for all studied traits.

This study is an important step in the process of producing hybrid tomato seeds in future under Egyptian conditions. It indicates that to produce 1000 hybrid tomato seeds, an average of 12 hybrid fruits are needed. This is the average number of hybrids fruits a plant bear. Consequently, around 600 mother tomato plants must be grown in addition to the father plants, which were planted in two stages to supply pollen throughout the pollination process, in order to generate 1 kilogram of hybrid tomato seeds.

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تصميم تزاوج السلالة × الكشاف لدراسة بعض صفات البذور في الطماطم المتعلقة بإنتاج البذور الهجين

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دراسة صفات بذور الطماطم في غاية الأهمية للتحول للإنتاج التجاري لبذور هجن الطماطم الواعدة والمستخرجة من برنامج تربية وصون النباتات بمركز بحوث الصحراء. اجريت الدراسة خلال فصلي الصيف للعامين ٢٠٢٣ و٢٠٢٤ بصوبة البرنامج بسانت كاترين جنوب سيناء. تم إجراء التلقيح اليدوي بين خمس سلالات وثلاث كشافات وأيضًا التلقيح الذاتي للأباء. التصميم الاحصائي المستخدم هو القطاعات الكاملة العشوائية مع إستخدام ثلاث مكررات. أشارت النتائج أن مصادر التباين في تحليل السلالة × الكشاف كانت ذات فروق معنوية لأغلب الصفات تحت الدراسة في كلا الموسمين. واستنادًا إلى النتائج المتحصل عليها، السلالتين L_3 وL_4 كانا الأفضل لمعظم الصفات. والهجين $L_4 \times T_2$ كان الأفضل لصفتي عدد البذور بالثمرة ووزن البذور بالثمرة. أبدى الهجين $L_2 \times T_1$ قوة هجين موجبة لجميع الصفات. كانت مساهمة السلالة أعلى ثم التفاعل بين السلالة × الكشاف لصفة وزن ١٠٠٠ بذرة لأنه يعكس في الأساس وزن بذورالسلالة. كانت كفاءة التوريث بالمعنى المحدود منخفضة لجميع الصفات.