Study of Tomato Source Material for Breeding Highly Productive Hybrids

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Abstract. In world agriculture, the tomato plays a leading role due to its high nutritional properties, high yields, adaptive abilities and a wide range of uses in fresh, culinary and processing industries. The global tomato market volume is more than 160 million tons. In the ranking of countries, Russia is in 6th place in terms of area and 11th in terms of gross production of tomatoes. Unfortunately, at the moment, a significant part of tomato seed material is imported. The implementation of the import substitution program creates the need to develop domestic breeding and seed production of this crop. The purpose of these studies was to conduct a breeding assessment of parental tomato lines for productivity traits based on statistical analysis methods and to identify promising source material for further breeding work to develop highly productive hybrids. As a result of the research, three best combinations were identified in terms of productivity of hybrids: 2f2-16(8-2) x Veneta, 108t/20 x Victor and 2f2-16(8-2) x Victor, which have a positive effect of specific combining ability, have average and high positive effects of the general combining ability of both maternal and paternal lines. Two maternal lines 108t/20 and 3f-14 showed a positive general combining ability for early and total productivity and its components. therefore, these parents can be successfully used in future breeding programs.

1 Introduction

According to the Food and Agriculture Organization of the United Nations (FAOSTAT), in terms of cultivation area, tomato ranks first in the world among vegetable crops - a total of about 5 million hectares are allocated for it. Today the global tomato market volume is more than 160 million tons [1]. In the ranking of countries, Russia is in 6th place in terms of area and 11th in terms of gross production of this vegetable. Krasnodar region occupies a special place in Russian vegetable growing. The favorable natural and climatic conditions of the south contribute to the cultivation of 40 types of vegetable crops. Tomato is one of the most common vegetable crops in the Krasnodar region. Along with the development of technology, the development of new varieties and hybrids with a complex of economically valuable and adaptively significant traits is a prerequisite for increasing the economic efficiency of the industry. Unfortunately, at the moment, a significant part of tomato seed

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material is imported. The implementation of the import substitution program creates the need to develop domestic breeding and seed production of this crop.

Tomato is a self-pollinating plant. Breeding of F_1 hybrids consists of several stages. First, they search for and develop plant forms with characteristics or mechanisms that prevent self-pollination (dioecy, sterility, self-incompatibility, etc.). At the next stage, through repeated self-pollination of plants, inbred lines that are homozygous for the main economically valuable traits are developed. Next, by crossing with other inbred lines, they are assessed for their combining ability, and the best hybrids and their parental lines are isolated. The final stage is the production of seeds of heterotic hybrids [2]. Obviously, to increase the efficiency of the breeding process, a comprehensive study of the available genetic resources of tomatoes is necessary. Highly productive competitive domestic hybrids and varieties are needed, the development of which is based on the use of a new type of donors obtained from lines with functional male sterility (FMS) and a complex of economically valuable traits. Heterozygous hybrids usually outperform their homozygous parents in yield; quantity, size and quality of fruits; show increased metabolic activity and usually better resistance to insect pests, diseases and extreme temperatures and, ultimately, have better economically valuable characteristics [3]. Currently, the main method for developing heterotic hybrids is combination breeding, which is based on hybridization. An important step in heterotic breeding of tomatoes is the selection of parental pairs based on the combining ability of the parental lines. To this end, parental selection is an important step in facilitating a well-planned hybridization program. Such studies not only provide the necessary information regarding the choice of parents, but also at the same time illustrate the nature and extent of the action of genes involved in the manifestation of desirable traits. An obligatory link in the breeding process is the assessment of combining ability [4]. Determining the state of the combining ability of genotypes and the nature of the action of genes helps to design a future hybrid with given parameters, which puts heterotic breeding at a higher quality level. The efficiency of work in this direction depends, first of all, on the availability of source material with economically valuable traits (early ripeness, large fruit, resistance to diseases, pests, etc.). The value of lines and varieties is determined by their ability to produce progeny with a greater or lesser degree of heterosis when crossed with other lines [5].

Purpose of the study – conduct a breeding assessment of parental tomato lines on productivity traits based on statistical analysis methods. Select promising source material for further breeding work to develop highly productive hybrids.

2 Material and methods of research

The studies were carried out in 2021 - 2023 at the experimental site of the vegetable and potato growing department of FSBSI "FSC of Rice". The plant material used for the study was obtained by crossing seven sterile tomato lines with three tester lines obtained from self-pollination under individual isolators. The hybridization nursery was located in a film spring unheated greenhouse with side ventilation. Sowing of seeds of breeding material for film greenhouses was carried out on February 15, seedlings were obtained on February 21-22. Planting of line seedlings in the breeding greenhouse - early April. Planting pattern – (100+70) x 40. The beginning of flowering in the greenhouse is May 12-15. Hybridization was carried out manually using the castration method using pollen from a freshly picked flower in the early morning hours when the temperature in the greenhouse did not exceed 28 °C. The crossing scheme was carried out in one direction. The maternal lines were those with the trait of functional male sterility, and the paternal lines were fertile. Fruits were harvested in the hybridization nursery in the biological ripeness phase as they ripened. Isolation of seeds - after ripening the fruits for 3-5 days.

Sowing seeds of twenty-one hybrid combinations in cassettes to determine the combining ability of parental lines in open ground was carried out on March 24, seedlings were obtained on April 2-4. Planting cassette tomato seedlings in the field on a breeding plot on April 28-30 according to the scheme (90+50)/2 x 35 cm. The plot area is 10 m^2, the number of plants per plot is 40 pcs. The repetition is threefold, the placement of plots is systematic. The main fertilizer (nitroammophoska) was applied locally into the furrows before planting, at a dose of $N_{60}P_{60}K_{60}$ according to a.i. (350 kg/ha in physical fat). Studies of combining ability based on the characteristics of productivity of parental lines were carried out based on the results of three harvests of hybrids using the method of V.K. Savchenko [9]. Harvesting was carried out manually by piece using the цушпре method as the fruits ripened. Early productivity was calculated based on the results of the first two harvests. During harvesting, the samples were described according to a set of traits, including: general and commercial productivity, the number of fruits on the plant, their average weight, taste, color and shape of the fruit. When harvesting, standard, diseased and non-standard fruits were taken into account separately.

The work was carried out in accordance with the "Methodology of experimental work in vegetable growing" [10] and the "Methodology of state variety testing of agricultural crops" [7]. Agrotechnical work on the experimental field was carried out in accordance with the recommendations for growing tomato [6]. The lack of moisture in the soil was regulated by drip irrigation. Mathematical data processing was carried out using the method of variance analysis [8].

3 Results

The F_1 hybrid nursery was represented by 21 hybrid combinations obtained on a sterile basis. In the present study, all genotypes obtained from crossing seven functionally male sterile lines and three testers differed significantly in both early and overall plant productivity. Among the fertile ones in terms of overall productivity, the line Victor stood out (2.39 kg/plant). Among the sterile ones - line 2f2-16 (2.97 kg/plant). Low rates were observed in the maternal lines SH 12-1-38 and SH 3-1 (2.01 kg/plant and 2.04 kg/plant, respectively) and the pollinator line Veneta (1.90 kg/plant). Along with the yield, weight and shape of the fruit, its color, which determine the commercial qualities of tomato fruits, early ripening is also of great importance. Early productivity of fertile lines varied slightly, ranging from 1.21 kg/plant (Viktor) to 1.39 kg/plant (Kubanets), the total productivity of marketable fruits - from 1.90 kg/plant (Veneta) to 2.39 kg /plant (Victor). In hybrids, variation was observed over a wider range: from 0.77 to 2.58 kg/plant (early yield) and 1.25 to 3.19 kg/plant (general). The highest indicators of both early (2.58 kg/plant) and total yield (3.19 kg/plant) per plant were shown by the combination 108t/20 x Victor. Among the sterile lines, maternal lines 3f-14, 108t/20 and 2f2-16 (2.23 kg/plant, 2.06 kg/plant and 2.00 kg/plant, respectively) showed high early yield returns. Low early productivity was observed in hybrid plants whose maternal lines were sterile lines 3f14-1, SH 12-1-38 and SH 3-1 (1.16 kg/plant, 1.19 kg/plant and 1.22 kg/plant respectively).

Table 1. Early and total productivity of F_1 hybrids

Lines	Paternal (pollinator) tester line						Mean value	
Maternal line	Victor		Kubanets		Veneta			
	Plant productivity, kg							
	Early	Total	Early	Total	Early	Total	Early	Total
	1,21	2,39	1,39	2,06	1,22	1,90		
108t/20	2,58	3,19	2,26	2,84	1,34	2,3	2,06	2,78
2f2-16	2,31	3,05	1,83	2,56	1,85	3,29	2,00	2,97
3f-14	2,16	2,80	2,42	2,5	2,12	2,91	2,23	2,74
3f14-1	1,45	2,01	0,97	1,83	1,07	2,88	1,16	2,24
SH 12-1-38	1,16	1,9	1,62	2,23	0,79	1,91	1,19	2,01
SH 12-1-1	1,57	2,40	1,27	2,14	1,88	2,58	1,57	2,37
SH 3-1	1,35	2,13	0,77	1,25	1,55	2,75	1,22	2,04
Mean value	1,80	2,50	1,59	2,19	1,51	2,66		

Note: by early productivity LSD_{05} =0,13;
by total productivity LSD_{05} =0,17

When developing tomato hybrids based on functional male sterility, the most appropriate method is the method of assessing the combining ability of two genetically different sets of parental lines, proposed by V.K. Savchenko. To study the nature of inheritance of quantitative traits by F_1 hybrids, the combining ability of the parental lines was studied. Assessment of general combining ability (GCA) provides basic and important information for using the genetic potential of parents when developing lines that produce highly productive hybrids when crossed. Since the expression of significant and high effects of GCA of the parental line reflects the presence of favorable additive genes with additive genetic effects. GCA makes it possible to evaluate the components of genotypic variation for a number of traits. An assessment of the GCA effects of lines and testers on productivity and its components showed that only two maternal lines 108t/20 and 3f-14 showed positive general combining ability for all traits (Table 2). Among the lines, the highest values of GCA effects in early productivity (gi = 0.60) and average fruit weight (gi = 7.24) were noted in line 3f-14, in total productivity (g = 0.52) and in the number of fruits per plant (gi =8.78) at line 2f2-16. Lines SH 12-1-38 and SH 3-1 were characterized by low negative effects of general combining ability in terms of productivity and all its components. Among the fertile ones, not a single line showed positive effects of OCS in all respects. High values of GCA effects were shown by the line Victor line for early productivity (gi = 0.16) and fruit weight (gi = 1.57), and the line Veneta for overall productivity (gi = 0.22) and the number of fruits per plant (gi = 4.57). There is a strong connection between the early productivity of hybrids and the GCA effects of their maternal lines (r = 0.81). A close correlation allows us to predict the early yield of hybrids based on the parameters of the parents. Thus, the sterile lines 3f-14 (g = 0.60) and 108t/20 (g = 0.43) had the maximum GCA values for early productivity, and most hybrids involving these lines had high early productivity. The correlation between the early and total productivity of marketable fruits of hybrids is quite close (r = 0.77), and between the total productivity and total productivity of the maternal lines is significant (r = 0.64).

Table 2. GCA effects of lines by productivity and its components

Parental lines		GCA by productivity		GCA by fruit weight	GCA by number of fruits per plant
		early	total		
Maternal lines	108t/20	0,43	0,33	1,24	4,48
	2f2-16(8-2)	0,36	0,52	-1,76	8,78
	3f-14	0,60	0,29	7,24	0,39
	3f14-1	-0,47	-0,21	-7,43	1,83
	SH 12-1-38	-0,44	-0,44	-0,76	-6,97
	SH 12-1-1	-0,06	-0,08	5,90	-3,84
	SH 3-1	-0,41	-0,41	-4,43	-4,66
Testers	Victor	0,16	0,05	1,57	-0,19
	Kubanets	-0,04	-0,26	0,57	-4,38
	Veneta	-0,12	0,21	-2,14	4,57

The nature of the behavior of the lines in individual crossing combinations can be judged by the variations of specific combining ability (SCA) constants. Low variations mean that the line consistently transmits traits to hybrids, and high variations mean that the trait may have a higher value in some combinations than in others [12]. In our experiment, the sterile maternal lines 3f-14 ($\sigma 2 = 0.001$), SH 12-1-1 ($\sigma 2 = 0.013$) and 2f2-16(8-2) ($\sigma 2 = 0.018$) have low variations in the "productivity" trait, and also the fertile line Victor ($\sigma 2 = 0.044$) (Table 3). High variations for this trait are found in the sterile lines 101t/20 ($\sigma 2 = 0.354$) and SH 3-1 ($\sigma 2 = 0.268$) and the pollinator line Veneta ($\sigma 2 = 0.169$). The remaining lines had average variation values.

Specific combining ability effects represent the dominant and epistatic effects of genes, which can be used as an index to determine the utility of a particular combination [11]. SCA is an indicator of the mostly dominant type of gene action. The magnitude of SCA effects is important in selecting combinations with a higher probability of producing desired transgressive phenotypes. The effects of SCA on productivity in crossing combinations ranged from - 0.69 (101t/20 x Veneta) to +0.50 (W 3-1 x Veneta).

Of the twenty-one hybrid combinations, twelve hybrids demonstrated positive SCA effects. The greatest positive effects of SCA (0.32 - 0.50) by plant productivity were shown by five hybrids SH 3-1 x Veneta (0.50), SH 12-1-38 x Kubanets (0.47), 3f14-1 x Veneta (0.43), 101t/20 x Victor (0.37) and 101t/20 x Kubanets (0.32). Hybrids (SH 3-1 x Veneta, SH 12-1-38 x Kubanets, 3f14-1 x Veneta), having the best specific combination for plant productivity, were obtained with the participation of parents with a low GCA effect of maternal line and a high GCA effect of paternal line, or low GCA effects of both parents. This indicates that it is possible to obtain desired transgressive segregants and heterosis from such crosses by applying biparental cyclic selection.

Hybrids exhibit high significant SCA effects in combination (low x high) due to the interaction of dominant alleles from good combinators and recessive alleles from poor combinators. The high SCA effects observed with one parent with good SCA indicate the predominance of additive genetic effects. Hybrids with a significant positive SCA effect, including parents with low general combining ability, show the value of non-additive genetic effects.

Table 3. Results of assessing the productivity of hybrids based on the SCA effects and parental lines based on variations

Parental lines	Paternal (pollinator) tester lines			Variation σ^2
Maternal lines	Victor	Kubanets	Veneta	
101t/20	0,37	0,32	-0,69	0,354
2f2-16(8-2)	0,04	-0,15	0,11	0,018
3f-14	0,02	0,02	0,04	0,001
3f14-1	-0,28	-0,15	0,43	0,143
SH 12-1-38	-0,16	0,47	-0,39	0,174
SH 12-1-1	-0,16	0,02	-0,003	0,013
SH 3-1	0,04	-0,54	0,50	0,268
σ^2	0,044	0,110	0,169	

Having analyzed the most highly productive combinations from the point of view of SCA of the parental lines involved in the crossing and the SCA of the resulting hybrids, we can note the following: the three best combinations in terms of hybrid productivity (2f2-16(8-2) x Veneta, 108t/20 x Victor and 2f2 -16(8-2) x Victor), having a positive SCA effect (Table 4), medium and high positive SCA effects of both maternal and paternal lines (high x high, medium x medium and high x medium) were recorded. Three hybrids with slightly lower productivity indicators (3f-14 x Veneta, 3f 14-1 x Veneta and 108t/20 x Kubanets) had medium and low values of GCA effects by the productivity of maternal lines and high positive and low negative effects of paternal lines (medium x high, low x high, medium x low). This may be due to the additive type of dominance interaction, the action of the epistasis gene and the unfixed genetic component of plant productivity.

Table 4. Results of assessment of GCA of parental lines and SCA of tomato hybrids in highly productive combinations

Hybrid combination	Total productivity, kg/plant	SCA effect of combination	GCA of maternal line	GCA of paternal line
2f2-16(8-2) x Veneta	3,29	0,11	0,52	0,21
108t/20 x Victor	3,19	0,37	0,33	0,05
2f2-16(8-2) x Victor	3,05	0,04	0,52	0,05
3f-14 x Veneta	2,91	0,04	0,29	0,21
3f 14-1 x Veneta	2,88	0,43	-0,21	0,21
108t/20 x Kubanets	2,84	0,32	0,33	-0,26

4 Conclusions

As a result of studying hybrid combinations obtained on the basis of seven lines with traits of functional male sterility and three fertile tester lines, it was found that the highest indicators of both early (2.58 kg/plant) and total yield (3.19 kg/plant) from the plant were shown by the combination 108t/20 x Victor.

There is a strong connection between the early productivity of hybrids and the GCA effects of their maternal lines (r = 0.81), which makes it possible to predict the early productivity of hybrids based on the parameters of the parents. The sterile lines 3f-14 (g =

0.60) and 108t/20 (g = 0.43) had the maximum GCA values for early productivity. Most of the hybrids involving these lines had high early productivity.

Having analyzed the most highly productive combinations from the point of view of GCA of the parental lines involved in crossing and SCA of the resulting hybrids, we can note the following: the three best combinations in terms of hybrid productivity are 2f2-16(8-2) x Veneta, 108t/20 x Victor and 2f2-16 (8-2) x Victor, having a positive SCA effect, recorded medium and high positive GCA effects of both maternal and paternal lines (high x high, medium x medium and high x medium).

Two maternal lines 108t/20 and 3f-14 showed a positive general combining ability for early and total productivity and its components. Among the fertile ones, not a single line showed positive GCA effects in all respects.

According to these results, line 108t/20, 3f-14 and tester CLN-2418A showed the maximum positive GCA effects for most traits, so these parents can be successfully used in future breeding programs to develop highly productive hybrids for cultivation in the South of Russia.

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