

Analysis of tomato lines combining ability by productivity traits for selecting acceptable parents when developing tomato hybrids

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Abstract. The basis of an effective breeding process is the genetic analysis of the inheritance of traits, which makes it possible to select the source material and form the optimal scheme for developing hybrids. The main criterion for assessing the quantitative traits of parental lines is combining ability. In this regard, the aim of the research was to study the combining ability for productivity and its components of 5 maternal lines of tomato with functional male sterility and 6 lines of testers (pollinators) with the subsequent selection of the best parents and their further use in developing heterotic hybrids. Using the methods of traditional breeding, guided by the methodology for assessing two genetically different sets of parental lines proposed by V.K. Savchenko, the results were obtained to determine the combining ability of the lines according to the characteristics: "plant productivity", "average fruit weight" and "number of fruits per plant". The effects of the total and specific combining ability of the material under study have been determined. The most promising lines for further breeding work on the development of new highly productive domestic tomato hybrids have been identified. Maternal line Cu1-36 (8) and testers LG-1212/11 and LG-1174/09 showed the maximum positive effects of TCA in terms of productivity and the number of fruits per plant. The results obtained in 2020 showed that the most productive hybrids (Cu1-36 (8) x LG-1174/09, St543xLG-1174/09, Sf04 (19) x LG-1174/09 and St644xLG-1212/11) were obtained with the participation of paternal lines with a high TCA value. The average weight of the fruit is more influenced by the combining abilities of the maternal lines. The effects of SCA in these combinations are high and medium.

1 Introduction

The main goal of the agricultural development strategy is to ensure the food security of the Russian Federation. In the light of the government's decisions on import substitution, the task is to provide the population with domestic vegetable products by at least 85-90% [1]. Vegetable growing is one of the most important and promising industries in Krasnodar region. Due to political and economic processes in the world over the past five to seven

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years, the introduction of economic sanctions, the program for import substitution in the production of agricultural products, including vegetable growing is being implemented in the region.

Tomato is one of the most common vegetable crops. Globally, tomatoes are grown in 170 countries on an area of 4.7 million hectares with a total production of 159 million tons. Russia currently ranks 8th in the world for tomato production. The yield of this crop is about 1 million tons per year [2]. In Krasnodar region, 0.58 thousand hectares (3.3% of the area) are occupied by open ground tomatoes. The gross harvest is 17.26 thousand tons. This is 1.8% of the total collection in the country [3].

Compared to many vegetable crops, tomato is a relatively new crop for Russia. Tomatoes began to be grown in the southern regions of the country in the 18th century. One of the first publications about this crop in Russia belongs to the founder of Russian agronomy, scientist and researcher Andrei Timofeevich Bolotov. By the middle of the 19th century, the tomato culture began to spread through the vegetable gardens of Russia in the middle regions, and by the end of the 19th century it was widely spread in the northern regions of the country [4].

In recent years, the assortment of tomatoes in Russia has expanded significantly. Difficult modern economic conditions, great competition with imported varieties on the seed market, place new demands on the domestic tomato assortment. New varieties and hybrids with increased potential yield and resistance to stress factors of the environment for various cultivation technologies are required. Hybrids have a significant advantage over linear varieties in terms of plant productivity, uniformity of fruits, marketability, harmonious yield and other characteristics [5]. They are more resistant to unfavorable and stressful weather conditions, better preserve the generative organs in the process of growth and development, and for this reason they have a greater number of fruits, have increased resistance to diseases and viruses [6].

The basis of an effective breeding process is the genetic analysis of the inheritance of traits, which allows you to correctly select the source material and form the optimal scheme for developing hybrids. An obligatory link in the breeding process is the assessment of combining ability [7, 8]. To determine the genotype of the selected lines, a method is used to assess the combining ability, which makes it possible to assess the ability of biotypes to give heterotic progeny when crossed with other individuals or varieties [9].

Seed production of hybrids requires a lot of manual labor to isolate, castrate and mark flowers. In this regard, the prime cost of hybrid seeds is very high. The use of lines with a trait of sterility as mother components can reduce the time for the production of hybrid seeds and halve the labor costs for pollination [10].

Aim of the study. Determine the value of the selected tomato lines by studying their combining ability in terms of productivity. Select promising parental lines for their further use in the development of heterotic hybrids.

2 Methods

The research was carried out in 2020 at the experimental plots of the department of vegetable growing of "Federal Scientific Rice Centre". Hybridization was carried out in 2019. When developing tomato hybrids based on functional male sterility, the most acceptable method for assessing the combinational ability of two genetically different sets of parental lines, is the one proposed by V.K. Savchenko [11]. The crossing scheme is carried out in one direction, when the maternal lines are sterile, and the paternal lines are fertile individuals. This scheme, in contrast to topcross, makes it possible to determine not only the total combining ability of parental lines, but also the effects of the combining ability specific to each combination. 5 sterile maternal tomato lines with the FMS

(functional male sterility) trait bred by "Breeding station named after N.N. Timofeev ", Moscow Agricultural Academy and 6 paternal pollinating varieties bred by "Federal Scientific Rice Centre" were included into hybridization scheme. As a result of crossing, we received 30 hybrids. The work was carried out in accordance with the "Guidelines for breeding tomato varieties and hybrids for open and protected ground" [12]. Accounts and observations - according to the "Methodology of Experimental Method in Vegetable Growing" [13]. The research results were processed by the methods of biometric statistics [14, 15]. Seedlings of hybrids were grown using cassette technology [16]. Sowing seeds in cassettes was carried out on March 19. Planting of seedlings in the field — April 28 according to the scheme (90 + 50) x 35 cm. Allocation of plots is systematic. Repetition 3-fold, the number of plants per plot 20 pcs., The accounting plot area - 7 sq. m. Watering: drip irrigation. The predecessor is pumpkin crops. During the growing season, phenological observations and biometric measurements of plants were carried out. Harvesting is done manually by the weight method as the fruits ripen.

3 Results

To assess the combining ability of 5 sterile and 6 test lines (pollinators) in 2019, we used the crossing scheme of two genetically different sets of parental lines proposed by V.K.Savchenko [11]. As a result, 30 hybrids were obtained, the productive traits of which were assessed in 2020. The productivity of tomato hybrids was determined based on the results of 2 harvests. The variation of this trait was observed in the range from 0.81 kg / plant to 2.26 kg / plant (Table 1). The following hybrids had the highest productivity: Cu1-36 (8) x LG-1174/09 (2.19 kg / plant), St543 x LG-1174/09 (2.26 kg / plant), Sf04 (19) x LG-1174 / 09 (2.21 kg / plant) and St644 x LG-1212/11 (2.19 kg / plant). Among the lines, the highest productivity values were shown by the mother line Cu1-36 (8) and by the tester lines LG-1212/11 and LG-1174/09, the medium values were shown by the lines St543, Sf04 (19) and LG-1213 / 11-2 , low average productivity was shown by the mother line St644 and tester lines Lh-863/09, Vera, 819-341.

Table 1. Productivity of hybrids (kg/plant), 2020.

Lines	Paternal (pollinator) tester lines						Average productivity of maternal line
	LG-1212/11	LG-1213/11-2	LG-1174/09	Lh-863/09	Vera (standard)	819-341	
Cu1-36(8)	1,93	1,78	2,19	1,89	1,56	1,81	1,86
St543	1,75	1,73	2,26	1,67	0,81	1,47	1,61
Cu1-335	2,01	1,89	1,83	1,05	1,20	1,27	1,54
Cf04(19)	2,01	1,35	2,21	1,49	1,28	1,39	1,62
St644	2,19	1,77	1,22	1,26	1,01	1,18	1,44
Average productivity of tester	1,98	1,70	1,94	1,47	1,17	1,43	

LSD_{0,5} – 0,111

3.1 Assessment of general combining ability

The assessment of the total combining ability (TCA) provides important information for using the genetic potential of the parents, since the variance of significant and high effects of the TCA of the parental line reflects the presence of favorable additive genes. This makes it possible to select lines at the initial stage to develop adapted hybrids.

Assessment of the TCA effects by the trait of productivity and its components showed that among the maternal lines, their positive values for all indicators were only in the line Cu 1-36 (8) (Table 2).

In terms of fruit weight, the line Cf04 showed the highest positive TCA value (19). But this line had a negative TCA value for the number of fruits per plant and medium for productivity.

Among the testers, none had positive TCA effects on all counts. In terms of productivity, LG-1212/11 and LG-1174/09 stood out, but they had low indicators in fruit weight and high in their number on the plant. The pollinator line LG-1213 / 11-2 showed high total combining abilities in terms of average fruit weight, medium in productivity and the number of fruits per plant. The tester Vera turned out to be the worst combinator with negative TCA values by all indications.

According to the results, the maternal line Cu 1-36 (8) and testers LG-1212/11 and LG-1174/09 showed the maximum positive effects of TCA in terms of productivity and the number of fruits per plant. These parents can be successfully used in future breeding programs when developing highly productive hybrids with medium fruits. And the lines Cf04 (19) and LG-1213 / 11-2, having the maximum TCA values by fruit weight and positive average indicators of productivity, can be used when developing large-fruited hybrids of average yield.

Table 2. TCA effects of lines by the trait of productivity and its components.

Parental lines		TCA for productivity	TCA for fruit weight	TCA for number of fruits per plant
Maternal lines	Cu 1-36(8)	0,246	1,47	1,73
	St 543	-0,001	-3,86	0,18
	Cu 1-335	-0,074	-9,73	0,01
	Cf04(19)	0,006	11,60	-1,28
	St 644	-0,177	0,51	-1,34
Testers	LG-1212/11	0,361	-7,17	4,13
	LG-1213/11-2	0,089	8,26	-0,19
	LG-1174/09	0,327	-5,84	3,46
	Lh-863/09	-0,146	7,81	-2,07
	Vera	-0,443	-10,29	-2,86
	819-341	-0,189	7,21	-2,47

3.2 Assessment of specific combining ability

The behavior of the lines in individual crossing combinations can be judged by the variance of the SCA constants. Low variances mean that the line consistently conveys traits to hybrids, and high variances mean that a trait may have a higher value in some combinations than in others [18]. In our experiment, in terms of "productivity", maternal lines Cu 1-36 (8), Cu 1-335 and Cf04 (19) have low variances (0.04), as well as testers 819-341 and Vera (0.01 and 0.04 respectively). High variances for this trait are observed in the sterile line St 644 (0.1) and in the pollinator LG-1174/09 (0.12). The rest of the lines had average variance values.

Specific effects of combining ability are dominant and epistatic effects of genes that can be used as an index to determine the usefulness of a particular combination [17]. SCA is an indicator of the dominant type of gene action for the most part. The value of SCA effects is of great importance when selecting cross combinations with higher possibility of obtaining desirable transgression segregants. The SCA effects in terms of productivity in crossing combinations had a large range of variation from -0.54 (St 644 x LG-1174/09) to +0.39 (St 644 x LG-1212/11). Seventeen hybrids showed SCA positive effects. The greatest positive effects of SCA (0.24-0.39) by plant productivity were shown by the five hybrids of thirteen ones, that is combination of St 644 x LG-1212/11(0,39), St 543 x LG-1174/09 (0,32), Cf04(19) x LG-1174/09 (0,26), Cu 1-335 x LG-1213/11-2 (0,26) и St 644 x LG-1213/11-2 (0,24) which were followed by hybrids St 543 x Lh-863/09 (0,20), Cu 1-36(8) x Lh-863/09 (0,17), Cu 1-36(8) x Vera (0,14), Cu 1-36(8) x 819-341 (0,14) (Table 4).

Table 3. Results of assessing the productivity of hybrids by the SCA effects and parental lines by variance, 2020.

Parental lines	Paternal (pollinator) tester lines						Variance
Maternal lines	LG-1212/11	LG-1213/11-2	LG-1174/09	Lh-863/09	Vera	819-341	
Cu 1-36(8)	-0,29	-0,17	-0,01	0,17	0,14	0,14	0,04
St 543	-0,23	0,03	0,32	0,20	-0,37	0,05	0,07
Cu 1-335	0,11	0,26	0,04	-0,34	0,10	-0,08	0,04
Cf 04(19)	0,02	-0,36	0,26	-0,01	0,10	-0,04	0,04
St 644	0,39	0,24	-0,54	-0,04	0,02	-0,07	0,1
variance	0,08	0,07	0,12	0,05	0,04	0,01	

Having analyzed the most highly productive combinations from the point of view of TCA of the parental lines participating in the crossing, and SCA of the obtained hybrids, as well as the average weight of the fruit and their number per plant, the following pattern can be noted: the most productive hybrids were obtained with the participation of paternal individuals with a high TCA value by productivity and the number of fruits per plant. TCA effects of maternal lines have little effect on the productivity of the resulting hybrids. The average weight of the fruit is more influenced by the combining abilities of the maternal lines than of the paternal ones. The SCA effects in these combinations are high and medium.

Table 4. Results of TCA assessment of parental tomato lines by traits in highly productive combinations.

Combination	Productivity, kg/plant	TCA of parental lines		SCA of combination	Fruit weight	TCA of parental lines		Number of fruits per plant, pcs	TCA of parental lines	
		♀	♂			♀	♂		♀	♂
Cu1-36(8)x LG-1174/09	2,19	high	high	-0,01	113,5	medium	low	19,26	high	high
St543xLG-1174/09	2,26	medium	high	0,32	116,0	medium	low	19,51	medium	high

Combination	Productivity, kg/plant	TCA of parental lines		SCA of combination	Fruit weight	TCA of parental lines		Number of fruits per plant, pcs	TCA of parental lines	
		+♀	+♂			+♀	+♂		+♀	+♂
Cf04(19)xLG-1174/09	2,21	medium	high	0,26	126,0	high	low	17,54	low	high
St644xLG-1212/11	2,19	low	high	0,39	96,0	low	low	22,82	low	high
Cu 1-335x1212/11	2,01	low	high	0,11	111,1	low	low	18,07	medium	high
Cf04(19)x1212/11	2,01	medium	high	0,02	123,0	high	low	16,3	low	high
LSD ₀₅	0,111				5,21			1,83		

The hybrids for various purposes grown in the open ground, obtained in the vegetable growing department of the FSBSI "Federal Scientific Rice Centre", correspond to the agro-climatic conditions in the south of Russia. They have a determinant well-leafed bush protecting the fruits from sunburn, and they are resistant to abiotic negative factors.

The department of vegetable growing has started the research linked to the introduction of genetic material in the breeding process from breeding donors containing determinants of resistance to pathogens: late blight (*Ph*) and tobacco mosaic virus (*Tm*) since 2021., Competitive and pathogen-resistant domestic hybrids and varieties developed, using a new type of donors obtained on the basis of lines with functional male sterility (FMS) and a complex of economically valuable traits are necessary for the transition to environmentally-friendly tomato production. The applying DNA- markers makes it possible to accelerate the breeding process and marker - assisted selection (MAS) technologies are one of the priority dynamically developing scientific directions now.

In addition, the use of molecular- genetic methods to identify the target genes determining economically valuable traits as a key breeding "tool" makes it possible to develop varieties with complex resistance to phytopathogens by means of pyramiding several resistance genes (combining in one genotype), that is difficult to achieve when using classical phytopathological testing.

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4 Discussions

The crosses which had the best specific combination in terms of plant productivity were obtained using following parental forms St 644 x LG-1212/11 (low TCA effect x high TCA effect), St 543 x LG-1174/09 (medium TCA x high TCA), Cu 1-335 x LG-1213/11-2 (low TCA x medium TCA), Cf04(19) x 1174/09 (medium TCA x high TCA), St 644 x LG-1213/11-2 (low TCA x medium TCA). The best specific combination in terms of hybrid productivity St 644 x LG-1212/11 retained positive TCA effects of maternal line by mass of fruit and paternal line by fruit amount per plant. The best another cross in terms of SCA productivity St 543 x LG-1174/09 had positive TCA effects values for the trait “amount of fruits per plant” both in maternal and paternal lines. It may be associated with additive interaction type of dominating with epistase gene effect and non-fixable genetic component for plant productivity. The combination St 644 x LG-1174/09 showed the lowest SCA effect on account of non-additive genes interaction and non-fixable genetic components for productivity per plant. It points out the possibility of obtaining the desirable transgressive segregants and heterosis after such crosses by using cycle selection of both parental forms.

5 Conclusions

In the course of research, it was found that the trait "tomato productivity" is controlled by the polygenic system. The following hybrids had the highest productivity: Cu1-36 (8) x LG-1174/09, St543 x LG-1174/09, Cf04 (19) x LG-1174/09 and St644 x LG-1212/11.

Maternal line Cu1-36 (8) and testers LG-1212/11 and LG-1174/09 showed the maximum positive effects of TCA in terms of “productivity” and “number of fruits per plant”. These parents can be successfully used in future breeding programs when developing highly productive hybrids with medium fruits. And the lines Sf04 (19) and LG-1213 / 11-2 can be used when developing large-fruited hybrids of average yield.

The most productive hybrids were obtained with the participation of paternal lines with a high TCA value. The average fruit weight is more influenced by the combining abilities of the maternal lines. The SCA effects in these combinations are high and medium.

When breeding tomatoes for high-yielding large-fruited hybrids for salad purposes, it is advisable to use sterile lines with a high TCA by the trait “fruit weight” as maternal forms, and as pollinators, forms with a high combining ability on the basis of “productivity” and “number of fruits per plant”.

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