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ANALYSIS OF HYBRIDIZATION EFFECT BY THE APPEARANCE OF TARGET TOMATO TRAITS IN F_2, F_3 PROGENIES IN BREEDING FOR MULTI CIRCLE HYDROPONICS

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A b s t r a c t

Classic genetic methods remain actual in practice and study of inheritance and heritability of the main commercial crop traits. *Solanum lycopersicum* L. genetics is well developed, but the special approach is necessary to solve special breeding tasks. Heritability analysis of the main traits in F_1 tomato progeny, which we have been carried out in 2009-2011, revealed some regularity to be further used in breeding practice. We first found that the main fruit yield parameters of *Solanum lycopersicum* L., the average fruit weight ($h^2 = 0.99$) and the average fruit number per plant ($h^2 = 0.96$), are inherited on the maternal side, and dwarfism ($h^2 = 0.83$) and early ripening ($h^2 = 0.73$) are inherited on the paternal side. Effectiveness of the target hybridization method developed earlier has been tested in this paper. Productive maternal plants with larger-sized fruits and early ripening dwarf paternal plants were involved in target crossings. F_1 hybrids and their F_2 progeny resulted from self-pollination of F_1 plants were produced. Analysis of dwarfism inheritance in three F_2 hybrid combinations using χ^2 criterion confirmed recessiveness of *d* gene. The tall plants and the dwarf plants of F_2 population segregated strictly by Mendel's low (3:1). By dispersion analysis of six parental forms and three hybrids, we selected the more productive plants with large fruit size among the dwarf plants, then obtained seed progeny of these plants and studied the heritability of two traits, the dwarfism and large fruit size, in the F_3 hybrids. It was found out that crossing between tall maternal plants with large fruit size and dwarf early ripening paternal plants resulted in lowering the plant height to that of dwarf father. This trait was maintained in F_3 that confirmed the correctness of conclusions have earlier been made by us. Heritability of average fruit weight on the maternal side also has been confirmed in F_3 progeny. In F_3 hybrids derived from crossing maternal plants Vspishka and Krainiy Sever with large fruit size the average fruit weight increased 2 times compared to the parental forms. This trait is maintained in progeny despite negative effects of *d* genes on some quantitative characteristics. Use of high productive maternal forms with small fruits size resulted in lowering average fruit weight in the hybrid progenies. So, dwarfism of *Solanum lycopersicum* L., desirable in multi circle hydroponic technology, is inherited on the parental side, and the fruit weigh is inherited on the maternal side. Thus, to obtain new tomato forms for multi circle hydroponics, the maternal plants with large fruit size and dwarf paternal forms should be crossed.

Keywords: tomato, breeding, heritability, dwarfism, fruit weight

Tomato (*Solanum lycopersicum* L.) is a crop which has been most genetically [1-5]. At the end of the last century, S.D. Tanksley and M.A. Mutschler compiled a classic map of 12 tomato chromosomes where they have indicated several linkage goups [6]. Wide-scale molecular and genetic studies have significantly advanced mapping tomato genome [5, 7-10] and provided for success in solving a number of selection problems, e.g. in mapping the dominant genes at simple trait inheritance [11, 12]. In other cases, traditional genetics is used in dealing with-inheritance of the main valuable traits [13-17].

Dwarfism in *Solanum lycopersicum* L. is controlled by the family of *d* genes located in the long arm of the chromosome 2, which are associated with biosynthesis of brassinosteroids and show 11 alleles [2, 6, 18]. Obtaining dwarf hybrids combining dwarfism and early ripening and high productivity is hindered

due to several characteristics of the *d* genes, i.e., negative effect on the fruit weight and recessiveness (this trait, according to Mendel's second law, is expressed only in a fourth part of F_2 progeny according to 3:1 segregation [2]. Positive characteristics of the *d* genes that can be used in selection are location in chromosome 2 close to the genes controlling early ripening (they can be inherited together due to linkage) [2] and early manifestation during plant development which allows for sporophyte selection, speeding up breeding three-fold [19].

Previously, in analysis of the inheritance of the main economically valuable traits in F_1 generation carried out in 2009 to 2011 based on the collection of tomato marker mutants (maternal forms), it has been shown that the main characteristics of productivity, average fruit weight ($h^2 = 0.99$) and average fruit number per plant ($h^2 = 0.96$) are inherited by maternal line [20],and dwarfism ($h^2 = 0.83$) and early ripening ($h^2 = 0.73$) are inherited by paternal line [21].

In this paper, we have for the first time demonstrated the efficiency of the target hybridization method developed earlier based on the pre-breeding data [15-19].

Our aim was to determine the character of manifestation of dwarfism and average fruit weight in F_2 and F_3 generations in the new forms of *Solanum lycopersicum* L. tomato meant for multi-circle narrow-shelf hydroponics.

Techniques. Basing on the pre-breeding data [19-21], we have carried out a target selection of maternal and paternal forms. The maternal forms were mostly selected by large fruits and productivity; the paternal ones were selected by dwarfism and early ripening. Part of these starting forms was used for target crossings, as a result of which the F_1 hybrids (2011) were obtained. The F_2 generation (2012) was obtained from the self-pollination of the hybrids.

The experimental material in 2013 was three F_2 hybrid combinations of varieties and samples: Mo 411 × Komnatnaya Grusha, Vspyshka × Tiny Team, Krainiy Sever × Komnatnyi, 6 parental forms and 3 F_3 hybrids. Morphological description of plants, biometry of the main parameters, assessment of productivity and average fruit weight were carried out using the weight method. After segregation in height in the F_2 hybrid progeny, the most productive and large-fruit plants from the dwarf ones were selected. In 2014, dwarfism and average fruit weight were determined in the F_3 progenies of three hybrid forms, the parents of which were 2 maternal forms with large fruits, 1 highly productive but small-fruit maternal form and 3 dwarf and early ripening paternal forms.

The studies were carried out in a polycarbonate greenhouse (Richel, France) in planting section (2013) and with the original installation of five-circle narrow-shelf hydroponics with a FITO, Russia medium unit (2014). The repetition of the experiments was 5- (2013) and 10-fold (2014).

The statistical processing of the data was carried out using dispersion analysis according to B.A. Dospekhov [22].

Results. The key characteristics of the starting parental forms used earlier in target hybridization are outlined in Table 1. After their crossings, the F_1 generation was obtained, from which the F_2 generation was obtained from self-pollination. The most large-fruited and productive samples were selected from the dwarf progeny segregated according to the plant height in the 3 (tall plants):1 (dwarf plants). As a result, in the F_2 7 samples were selected from the dwarf plants (Table 2) to obtain seeds.

The progeny of the plants No. 1 from F_2 Mo 411 × Komnatnaya Grusha, No. 8 from F_2 Vspyshka × Tiny Team, No. 1 from F_2 Krainiy Sever × Komnatnyi was used for analysis of the hybridization efficiency in F_3 in studying the degree of manifestation of key traits (dwarfism and average fruit weight). Cross-

ing of the large-fruited and tall maternal form with the dwarf paternal one has led to a decrease in the plant height in all hybrids to the parameters observed in the dwarf father. The trait was maintained in the F_3 generation (Table 3), which confirms the conclusions made in pre-breeding about the inheritance of dwarfism in the paternal line [21]. The inheritance of the fruit weight in the maternal line established in pre-breeding studies [20] was also confirmed in the F_3 generation. An increase in the average fruit weight (almost 2-fold compared to that in the small-fruited paternal form) was observed only in those F_3 hybrids that derived from the large-fruited maternal forms Vspyshka and Krainiy Sever (Table 3). The trait was maintained in the progeny despite the obvious negative effect of the *d* genes on some quantitative traits. The use of the highly productive but small-fruited maternal form Mo 411 has led to a decrease in the fruit weight in the hybrid (see Table 3).

1. Characterization of starting tomato (*Solanum lycopersicum* L.) parental forms resulted from pre-breeding for the multi-circle narrow-shelf hydroponics (Richel polycarbonate greenhouse, All-Russian Research Institute for Breeding and Seed Production of Vegetable Crops, Moscow Province, 2009-2011)

Sample	Plant productivity, g		Fruit weight, g		Number of fruits per plant, psc.		Plant height, cm		Sprouting—ripening, days	
	$\bar{X}$	Δ	$\bar{X}$	Δ	$\bar{X}$	Δ	$\bar{X}$	Δ	$\bar{X}$	Δ
St (Funtik)	221		53		4		46		110	
Maternal forms										
Mo 411	614	+393	16	–37	34	+30	91	+45	106	–4
Vspyshka (1C)	846	+625	79	+26	11	+7	75	+29	96	–14
Krainiy Sever	842	+621	95	+42	9	+5	88	+42	108	–2
	LSD_{05}	129	LSD_{05}	16	LSD_{05}	3	LSD_{05}	16	LSD_{05}	7
Paternal forms										
Komnatnaya Grusha (3C)	248,6	+27,6	11	–42	21	+17	42	–4	103	–7
Tiny Team (11C)	303,8	+82,8	12	–41	21	+17	36	–10	105	–5
Komnatnyi	292,2	+71,2	19	–34	20	+16	33	–13	108	–2
	LSD_{05}	76,0	LSD_{01}	12	LSD_{01}	10	LSD_{01}	16	LSD_{05}	7

Note. X — average trait value, Δ — standard deviation (Funtik variety).

2. Productivity and perspective dwarf tomato (*Solanum lycopersicum* L.) hybrids in F_2 generation (Richel polycarbonate greenhouse, planting section, All-Russian Research Institute for Breeding and Seed Production of Vegetable Crops, Moscow Province, 2013)

Plant No.	Productivity of one plant in repetitions, g					Σ_v	$\bar{X}$	Deviation from St	Group
	1st	2nd	3rd	4th	5th				
St	170	155	165	265	180	935	187		
Dwarf hybrids F_2 Mo 411 × Komnatnaya Grusha									
1[a]	234[a]	150[a]	275[a]	220[a]	285[a]	1164[a]	233[a]	+46[a]	I
2	80	105	75	98	85	43	87	–100	IV
6	15	15	35	15	22	102	20	–167	IV
14	72	86	88	90	60	396	79	–108	IV
21	133	175	185	115	205	813	163	–24	III
30	70	35	25	70	90	290	58	–129	IV
39	152	150	110	150	130	692	138	–49	IV
44	85	100	125	110	90	510	102	–85	IV
46[a]	225[a]	249[a]	200[a]	205[a]	265[a]	1144[a]	229[a]	+42[a]	I
47	50	60	65	110	70	355	71	–116	IV
48	170	128	135	207	125	765	153	–34	III
50	175	139	110	210	164	798	160	–27	III
LSD_{05}								38	
Dwarf hybrids F_2 Vspyshka × Tiny Team									
3	109	186	139	150	118	702	140	–47	III
5	140	134	232	135	190	831	166	–21	III
8[a]	108[a]	295[a]	253[a]	195[a]	190[a]	1041[a]	208[a]	+21[a]	II
10	64	60	65	78	80	341	69	–138	IV
22	150	135	194	140	120	739	148	–39	III
26	35	66	80	60	70	311	62	–125	IV

Continued Table 2

33[a]	255[a]	190[a]	145[a]	205[a]	152[a]	947[a]	189[a]	+2[a]	II
49	32	48	42	45	50	217	43	–144	IV
LSD_{05}								50	
Dwarf hybrids F2 Krainiy Sever × Komnatnyi									
1[a]	227[a]	220[a]	195[a]	250[a]	253[a]	1145[a]	229[a]	+42[a]	I
2	95	54	50	52	60	311	62	–125	IV
4	132	170	145	108	130	685	137	–50	IV
10[a]	175[a]	140[a]	248[a]	195[a]	180[a]	938[a]	188[a]	+1[a]	II
11	145	260	140	158	150	853	171	–16	III
28	125	120	145	130	100	620	124	–63	IV
38	140	130	141	90	120	621	124	–63	IV
46	55	40	35	90	75	295	59	–128	IV
47[a]	210[a]	230[a]	224[a]	190[a]	205[a]	1059[a]	212[a]	+25[a]	II
48	95	85	80	110	90	460	92	–95	IV
49	168	165	110	145	130	718	144	–43	IV
51	95	85	60	74	80	394	79	–108	IV
LSD_{05}								35	

Notes. St — standard (Funtik variety), Σ_v — sum of variants, X — average trait value; [a] — perspective samples selected for seed production. The groups mean deviations of the average square (dispersion) of the set mean value from the average square (dispersion) of the general mean value.

3. Plant height and fruit weight of tomato (*Solanum lycopersicum* L.) parental forms and hybrids in F_3 (Richel polycarbonate greenhouse, five-circle narrow-shelf hydroponics unit, All-Russian Research Institute for Breeding and Seed Production of Vegetable Crops, Moscow Province, 2014

Genotype	Repetition										$\bar{X}$
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	
Average plant height, cm											
Mo 411	95	90	93	90	88	92	90	90	93	95	91.6
Komnatnaya Grusha	38	33	35	35	35	33	35	38	35	37	35.4
F_3 Mo 411 × Komnatnaya Grusha	33	37	33	38	35	32	30	37	35	30	34.0
LSD_{05}											2,5
Vspyshka	53	57	57	55	55	60	50	55	53	53	54.8
Tiny Team	37	35	37	32	38	40	33	37	45	37	37.1
F_3 Vspyshka × Tiny Team	43	40	38	37	42	38	40	38	37	32	38.5
LSD_{05}											4,3
Krainiy Sever	58	50	55	55	58	57	53	57	55	57	55.5
Komnatnyi	32	28	30	27	28	27	28	28	28	28	28.4
F_3 Krainiy Sever × Komnatnyi	18	17	22	15	20	18	22	18	22	17	18.9
LSD_{05}											1.7
Average fruit weight, g											
Mo 411	14	18	12	15	12	15	16	17	13	17	14.9
Komnatnaya Grusha	10	12	8	10	12	9	11	11	8	10	10.1
F_3 Mo 411 × Komnatnaya Grusha	9	10	9	9	9	8	9	7	9	8	8.7
LSD_{05}											1.0
Vspyshka	74	84	77	84	74	71	84	79	88	84	79.9
Tiny Team	9	10	8	10	11	11	8	12	10	9	9.8
F_3 Vspyshka × Tiny Team	18	14	19	16	22	21	18	14	16	18	17.6
LSD_{05}											3.7
Krainiy Sever	27	48	37	46	50	46	38	26	56	50	42.3
Komnatnyi	7	8	7	9	10	7	8	6	10	9	8.1
F_3 Krainiy Sever × Komnatnyi	17	16	14	16	14	18	12	16	14	12	14.9
LSD_{05}											1.5

Note. X — average trait value.

Currently, most genetics papers are dedicated to mapping genes, analysis of their interaction and mapping quantitative trait loci (QTL), whereas in practical selection there is a lack of data about inheritance of selection valuable traits. Despite significant successes of biotechnological approach to realization of genetic information in the progeny [9-12], hybridization remains the key method for production of new forms and is inscribed in the modern organic agriculture concept [13-15]. Data about inheritance and heritability of traits are still required, although today these are few and obtained mostly in diallel crossing. Thus, Serbian scholars, studying the results of diallel crossings of six tomato genotypes, found that genotypes with high number of fruits per plant and high fruit weight can be effectively involved in crossings and selection for high yield

[23]. This corresponds to our data.

Thus, classic genetics is still successfully applicable in selection practice and do not contradict to necessity of genome mapping in the main agricultural crops. In *Solanum lycopersicum* L., dwarfism, a trait that is required for multi-circle narrow-shelf hydroponics technology of tomato growing, is inherited in paternal line, and fruit weight is inherited in maternal line. In order to obtain dwarf forms with 30 to 50 g fruits, the large-fruited tomato forms should be involved in crossings as maternal parents.

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