EVALUATION OF THE COMBINING ABILITY OF TOMATO GENITORS OBTAINED AT PGRB BUZAU

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Abstract

Hybrid tomatoes are grown in more than 95% of protected areas, rather than varieties. Romania has very few indigenous hybrids of this species, which led PGRB to launch a new tomato breeding program in order to obtain hybrids in accordance with the requirements of growers and consumers, involving in this program the native germplasm collection. PGRB owns a valuable germplasm collection for this species composed of 3084 lines. Of these, 1050 have been identified as genetically stabilized genotypes, 692 as genetically advanced genotypes and 1342 segregants. A number of 33 genitors have been selected after they successfully passed the general combining ability test and showed distinct phenotypic expressiveness. These genitors were involved in specific crosses and 19 of them manifested F1 reproductive heterosis. A number of 9 hybrids outperformed both genitors and genitors mean, from which H 14 recorded the highest percentage of heterobeltiosis of 84.1%. Three hybrids recorded mean values of estimated heterosis with an average of 27.7% (H4) and a number of 7 hybrids were below both the best parent and genitors mean.

Key words*: breeding, germplasm, heterosis, hybrid, selection*

INTRODUCTION

Tomato is one of the most popular vegetable crops grown across the world. Its genetics is much studied among vegetable crops, resulted in the reorganization of its commercial exploitation of hybrid vigour since last hundred years. Tomato has tremendous potential of heterosis for earliness, total yield, resistance attributes and uniformity. Hybrid tomato varieties will continue to predominate high input agricultural systems and may expand under some lower input systems where benefits can be demonstrated (Cheema, D. S., & Dhaliwal, 2005). Therefore, the available germplasm must be replaced with newly evolved hybrids with attractive quality traits to attain high yield potential. Considering the present scenario, development of hybrid is inevitable to enhance the crop yield. For this purpose, choice of parents is an important step that promotes a well-planned hybridization programme (Saeed, A., 2014). In tomato, heterosis has been exploited in F1 hybrids to a great extent for more than 50 years in many developed countries like USA, Europe, and Japan (Islam, M. et.al., 2012).

Although it has only recently arrived in Romania, after 1984, it has become the most used vegetable. Tomatoes have been introduced in numerous research studies. However, Romania is dependent on imports of hybrid tomato seeds for the establishment of crops in protected areas. More than 90% of the hybrid seeds grown in protected areas are of foreign origin and do not always meet the soil and climate requirements and consumer demands.

In Romania, the cultivation of hybrid tomatoes in protected areas shows an upward trend. In this regard, it was necessary to achieve a germplasm collection composed of genotypes with distinct phenotypic expressiveness, suitable for hybrid combinations, which have a genetic heritage of interest that can be inherited and exploited.

It is well known that maintenance or preservation of germplasm involves two principal considerations: avoiding loss of genetic diversity and avoiding costs. Active collections are geared to meet the needs of the

users of germplasm (Evgenidis, G. et.all., 2011). The germplasm collection offers multiple possibilities both for obtaining hybrids with high production potential and for the safe preservation of genes of interest. Hybrids obtained from hybrid combinations must have superior qualities demanded by both consumers and processors.

High yield coupled with good processing qualities are the pre-requisites for the general acceptance of the hybrid by the farmers (Chattopadhyay A., et al., 2013). Breeding for high yield and other desirable traits requires information on the nature and magnitude of variations in the available materials, relationship of yield with other agronomic characters (Akinfasoye, J., 2011).

That progeny derived from commercial parents exhibited improved traits, suggesting that this parent-type is a profitable source for the generation of elite material. Little information exists on breeding potential of commercial tomato varieties for obtaining of new lines via pedigree selection. Given the importance of knowing the breeding value of parents and other important genetic parameters in tomato improvement, it is necessary to investigate the breeding potential of commercial tomato varieties (Hernández-Leal, E., 2019).

The genetic material used to obtain high performance hybrids can come from local populations, established parents, commercial lines, varieties.

The evaluation of combinatorial ability aims to identify potentially valuable and suitable parents to participate in the hybridisation process. Estimation of general combining ability (GCA) provides basic and important information for exploiting genetic potential of parents for development of superior and elite lines (Saeed, A., 2014). Hybrid combinations must exhibit the phenomenon of reproductive heterosis calculated as both estimated and manifested as percentage heterobeltiosis. At the same time a large source of variability within the species studied is obtained.

MATERIALS AND METHODS

The genetic material used in the present experiment comes from the germplasm base held by PGRB Buzau for this species consisting of a total of 3084 genotypes. They were classified according to the degree of genetic stability as follows: 1050 stable, 692 advanced, 1342 segregants (Figure 1).

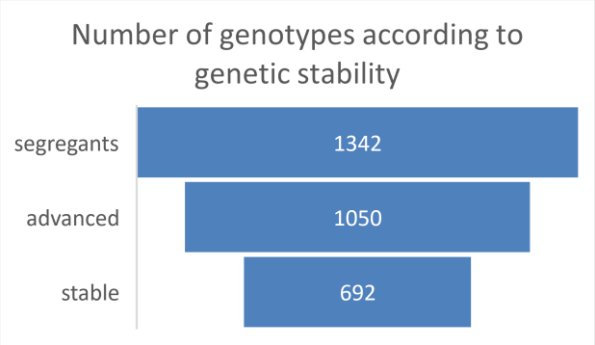


Figure 1. Germplasm collection

Of these, 31 parents have passed the test of general combinatory ability, being subjected in the present work to the test of specific combinatory ability. As a hybridization method, simple hybridization was used, obtaining the following crosses:

L19 ♀ x L10 ♂= **H1**
L22 ♀ x L12 ♂= **H2**
L23 ♀ x L15 ♂= **H3**
L26 ♀ x L10 ♂= **H4**
L311 ♀ x L312 ♂= **H5**
L312 ♀ x L508 A ♂= **H6**
L508 A ♀ x L517 A ♂= **H7**
L517 A ♀ x L522 ♂= **H8**
L12 ♀ x L312 ♂= **H9**
L15 ♀ x L508 A ♂= **H10**
L19 ♀ x L311 ♂= **H11**
L22 ♀ x L312 ♂= **H12**
L709 ♀ x L508 A ♂= **H13**
L724 ♀ x L517 A ♂= **H14**
L2000 ♀ x L522 ♂= **H15**
L709 ♀ x L22 ♂= **H16**
L10 ♀ x L23 ♂= **H17**
L12 ♀ x L26 C ♂= **H18**
L15 ♀ x L311 ♂= **H19**

The hybridization consisted in the castration of the flowers on the maternal parent, which is carried out when the petals begin to open, forming an angle of 25-30° to the vertical axis of the flower, and can continue until the mentioned angle reaches a maximum of 45° and the colour of the stamens is still greenish.

Hand pollination was carried out by inserting the style into the pollen tube in such a way that the pollen grains covered the entire surface of the stigma.

The stamens were harvested and after removing the petals, dried for 15-20 hours at 24°C, after which the pollen was extracted by shaking the stamens vigorously.

The pollen obtained was placed in glass tubes of 3-5 cm length and 2-3 mm inner diameter, fitted at one end with a cotton plug. The pollen was used immediately after extraction. It is important to have plenty of pollen available for

making hybrid crosses. Since tomato vines bloom profusely, a ratio of one male for every four female plants is recommended, as proposed by Opena R.T et al, 2001.

The cultivation technology applied was the classical tomato cultivation in protected areas according to Vinatoru C. et al, 2019.

The experiment was laid out in a randomized complete block design with three replications, similar to the study conducted by Amaefula, C. et.al., 2014. The crop establishment took place by producing seedlings in protected spaces, the planting scheme consisted of strips spaced at 120 cm, with 70 cm between rows and 35 cm between plants/row, in a palisade system.

The estimated heterosis was calculated based on the mean of the parents as follows:

$$[(F1 - MG) / MG] \times 100$$

where MG is the average of the parents and F1 is the resulting hybrid. Heterosis was estimated as better parent heterosis (BPH) as put forth by as follows:

$$BPH = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

where $\overline{F_1}$ is the mean of hybrid, $\overline{BP}$ is the mean of the better parent (Amaefula, C. et.al., 2014).

Measurements were recorded on days to fruiting, fruit weight, fruit length, fruit width, number of fruit per plant and yield per plant according to "descriptors for tomato" proposed by IPGRI, Italy (Saleem, M. Y. et.al., 2009) and UPOV Guidelines for the conduct of tests for Distinctness, Uniformity and Stability.

Test of significance was done as described by Kumar et al., 2011. Components of the generation means were evaluated using Hayman model as explained by Singh & Chaudhary, 1985 as follows:

$$a = \overline{B_1} - \overline{B_2}$$

$$d = \overline{F_1} - 4\overline{F_2} - \left(\frac{1}{2}\right)\overline{P_1} - \left(\frac{1}{2}\right)\overline{P_2} + 2\overline{B_1} + 2\overline{B_2}$$

$$aa = 2\overline{B_1} + 2\overline{B_2} - 4\overline{F_2}$$

$$ad = \overline{B_1} - \left(\frac{1}{2}\right)\overline{P_1} - \overline{B_2} + \left(\frac{1}{2}\right)\overline{P_2}$$

$$dd = \overline{P_1} + \overline{P_2} + 2\overline{F_1} + 4\overline{F_2} - 4\overline{B_1} - 4\overline{B_2}$$

$$t \text{ value of effect} = \frac{\text{effect}}{\text{SE of effect}}$$

a = additive mean; d = dominance effect; aa = additive × additive; ad = additive by dominance; dd = dominance × dominance; B1 = mean of backcross to parent 1; B2 = mean of backcross to parent 2; P1 = mean of parent 1; P2 = mean of parent 2; F1 = mean of First filial generation; F2 = of mean second filial generation; SE = standard error.

Statistical calculations were performed using SPSS software, Pearson correlation coefficients were determined as well as variance analysis by ANOVA test followed by DUNCAN test with 95% confidence interval and p-value < 0.05%.

RESULTS AND DISCUSSIONS

Following the descriptors according to IGPRI and UPOV, the morphological and phenotypical characterization of parents selected from the germplasm collection, parents that have successfully passed the test of general combinatorial ability, was carried out.

Thus, the morphological characters observed and quantified in their case demonstrate a rich phenotypic variability. The availability to crossbreeding as well as the gene pool carried by these parents are the strengths of this parent collection.

The majority of parents showed indeterminate breeding but 2 parents showed semi-determinate breeding. The height of the plant varies between 180-290 cm, the number of leaves under the first inflorescence is on average 6, the type of inflorescence is compound for most parents and the number of inflorescences/plant is 6.4 on average, registering a maximum value of 10 inflorescences/plant in lines L 19, L 80 and L 311 with the specification that these lines present medium size fruits.

Concerning the phenotypic characters of the fruits of the parents selected to participate in the hybridization process and to obtain F1 hybrids, a wide range of variability of the main characters was observed. Different fruit shapes were identified as follows: classic round, flattened, slightly flattened, ovoid, pruniform, cherry type, pomegranate type, banana type, etc.

Fruit colour ranged from shades of yellow, orange yellow, red, burgundy, to indigo black. Fruit weight was recorded as average value at around 157 g, with a minimum at L 10 of 10 g and a maximum of 560 g at L 2000, expressing

a very wide variability of this trait (Table 1 and Table 2) (Figure 2).

Table 1. Morphological characters of genitors

Crt.no.	Genitor	Type of growth	Plant height (cm)	Suckers no.	Fruits no/inflorescence	Total leaves no.	Inflorescence type	Inflorescence no./plant
1.	L10	**SP**$^{+}$	200	18	4	24	biparous	9
2.	L 12	**SP**$^{+}$	200	14	4	28	biparous	5
3.	L 15	**SP**$^{+}$	180	10	6	26	biparous	6
4.	L19	**SP**$^{+}$	200	12	6	24	uniparous	10
5.	L 22	**SP**$^{+}$	180	6	4	25	multiparous	9
6.	L 23	**SP**$^{+}$	200	10	6	24	biparous	6
7.	L 26 C	**SP**$^{+}$	180	12	6	26	multiparous	5
8.	L 27 B	**SP**$^{+}$	180	8	6	20	uniparous	5
9.	L 28	**SP**$^{+}$	180	18	6	22	biparous	5
10.	L 64	SP	60	6	6	50	multiparous	6
11.	L 66	SP	60	6	5	25	biparous	6
12.	L 80	SP+	291	14	5	26	multiparous	10
13.	L 101	SP+	261	17	9	23	multiparous	5
14.	L 150	SP+	215	21	8	27	multiparous	5
15.	L 165	SP+	216	18	7	28	biparous	5
16.	L 306	SP+	268	11	7	26	uniparous	7
17.	L 307	SP+	185	16	7	25	multiparous	6
18.	L 308	SP+	288	10	6	31	multiparous	7
19.	L 309 A	SP+	251	11	7	28	multiparous	8
20.	L 311	SP+	232	9	6	32	uniparous	10
21.	L 312	SP+	281	13	7	30	uniparous	5
22.	L 508 A	SP+	253	11	7	41	multiparous	6
23.	L 517 A	SP+	251	10	7	38	multiparous	5
24.	L 522	SP+	272	13	5	21	multiparous	6
25.	L 524	SP+	268	11	5	27	multiparous	5
26.	L 532	SP+	165	9	6	33	multiparous	5
27.	L 548	SP+	189	10	5	31	multiparous	5
28.	L 631	SP+	271	12	6	36	multiparous	8
29.	L 709	SP+	291	12	5	32	multiparous	5
30.	L 724	SP+	263	13	7	28	biparous	9
31.	L 2000	SP+	250	18	12	35	multiparous	5

Table 2. External fruit characters of parents (mean values)

Crt.no.	Genitors	Fruit shape	Plant height (cm)	Fruit diameter (cm)	Unripe fruit colour	Ripe fruit colour	No. of locules	Fruit weight (g)
1.	L10	rounded	2.0	2.0	Light green shoulder	rosie	2	10
2.	L 12	rounded	2.0	2.0	Light green shoulder	galbena	7	190
3.	L 15	rounded	5.0	5.5	Light green shoulder	rosie	4	40
4.	L19	flattened	4.0	5.2	Light green	visinie	4	300
5.	L 22	flattened	6.3	8.0	Light green	rosie	3	80
6.	L 23	rounded	5.0	5.5	Light green	rosie	6	230
7.	L 26 C	rounded	6.0	6.0	Light green shoulder	rosie	7	150
8.	L 27 B	Slightly flattened	6.0	7.5	Light green shoulder	rosie	5	180
9.	L 28	Slightly flattened	5.5	6.3	Light green shoulder	rosie	5	335
10.	L 64	rounded	6.0	6.0	Light green	rosu inchis	8	165
11.	L 66	Slightly flattened	4.5	5.5	Light green	rosie	6	190
12.	L 80	ovate	3.6	2.1	Medium green	rosie	2	12,1
13.	L 101	rounded	5.2	6.443	Small shoulder	portocaliu	5	128.2
14.	L 150	Bell pepper type	7.365	7.899	Medium green	rosu	4	82.82
15.	L 165	obovate	6.299	6.152	Medium green	rosu	4	142.01
16.	L 306	Cherry type	2.5	2.5	Green shoulder	Rosu cu striatii portocalii	3	160.95
17.	L 307	rounded	4.863	5.423	Medium green	Galben cu striatii verzi	4	86.75
18.	L 308	Bell pepper type	5.5	8.5	Uniform green	Rosu cu striatii portocalii	5	178.9
19.	L 309 A	Rounded Slightly flattened	6.996	9.805	Very light green	Rosu	11	351.6
20.	L 311	rounded	3.563	4.338	Green shoulders	Galben	4	41.94
21.	L 312	Cherry type	3.607	3.599	Uniform green	Rosu cu verde cafeniu	2	27.88
22.	L 508 A	rounded	4.638	4.992	Green shoulders	Rosu cu capac cafeniu	3	65.43
23.	L 517 A	rounded	6.036	9.263	Light green shoulder	Rosu	11	272.97
24.	L 522	Rounded Slightly flattened	5.5	9	Uniform green	Galben portocaliu	16	252.3
25.	L 524	Bell pepper type	8.9	7.4	Medium green	Rosu	4	233.6
26.	L 532	Banana type	7.2	3.9	Striped green	Galben	3	75.6
27.	L 548	rounded	4.278	5.253	Very light green	Portocaliu	3	82.66
28.	L 631	obovate	6.971	4.569	Medium green shoulders	Galben	3	78.24
29.	L 709	obovate	4.709	2.387	Light green	Rosu	2	17.19
30.	L 724	rounded	3.020	3.459	Purple green	Negru indigo cu pata rosie pistilara	2	23.43
31.	L 2000	cordate	9.5	10.3	Medium green	rosu	25	560


L 631


L 522

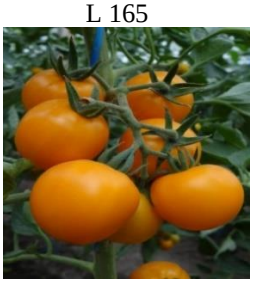

L 312


L 311


L 532


L 165


L 19


L 101


L 80


L724


L 308


H 15


H 18


H 17


H 14


H 13

Figure 2. Fruit details-genitors and hybrids

The aim of the study was to obtain F1 hybrids that visibly show reproductive heterosis. Calculating the estimated heterosis, in relation to the mean of the parents, 7 hybrid combinations were lower than both parents and both parents' mean, 9 combinations exceeded both parents and parents' mean, with a maximum value for estimated heterosis of 55.05% in the hybrid combination L724 ♀ x L517 A ♂= H14. Relative to the best parent, the heterosis, called heterobeltiosis, expresses the percentage by which the hybrid combination is superior to the best parent. Thus, a maximum heterobeltiosis value of 84.1% was recorded for the combination L724 ♀ x L517 A ♂= H14. There is a definite correlation between the two calculated percentages of heterozygosity, with combinations showing both a high percentage of estimated heterozygosity and heterobeltiosis, hybrids H 17 and H 19 with values of 79.4% and 78.3% heterobeltiosis, respectively. The negative values recorded for BPH (heterobeltiosis) show that there may be large distances between the characters recorded by the parents. In terms of yield per plant, high values were recorded by hybrid combinations that had parents with wild

characters that more easily transmit these traits.

Table 3. Parents mean yields, crosses mean yields, estimation of heterosis and heterobeltiosis

Crt.no.	G1 ♀	Yield (kg/plant)	G2 ♂	Yield (kg/plant)	MG	Crosses	Hybrid yield (kg/plant)	Estimated heterosis (%)	BPH-(Heterobeltiosis) (%)
1.	L19	2,4	L10	3,0	2,7	L19 ♀ x L10 ♂= **H1**	2,200	-22.72	-26,6
2.	L 22	3,8	L 12	2,0	2,9	L22 ♀ x L12 ♂= **H2**	3,100	6.45	-18,42
3.	L 23	3,4	L 15	3,7	3,55	L23 ♀ x L15 ♂= **H3**	3,300	-7.57	-10,8
4.	L 26 C	4,5	L10	2,0	3,25	L26 ♀ x L10 ♂= **H4**	4,500	27.77	0
5.	L 311	3,1	L 312	2,7	2,9	L311 ♀ x L312 ♂= **H5**	4,560	36.40	45
6.	L 312	2,7	L 508 A	3,2	2,95	L312 ♀ x L508 A ♂= **H6**	3,396	13.13	6,44
7.	L 508 A	3,2	L 517 A	2,9	3,05	L508 A ♀ x L517 A ♂= **H7**	5,800	47.41	81,25
8.	L 517 A	2,9	L 522	3,2	3,05	L517 A ♀ x L522 ♂= **H8**	3,000	-1.66	-6,25
9.	L 12	2,0	L 312	2,7	2,35	L12 ♀ x L312 ♂= **H9**	4,752	50.54	75,92
10.	L 15	3,7	L 508 A	3,2	3,45	L15 ♀ x L508 A ♂= **H10**	6,150	43.90	66,2
11.	L19	2,4	L 311	3,1	2,75	L19 ♀ x L311 ♂= **H11**	4,200	34.52	35,4
12.	L 22	3,8	L 312	2,7	3,25	L22 ♀ x L312 ♂= **H12**	3,795	14.36	-0.26
13.	L 709	3,2	L 508 A	3,2	3,2	L709 ♀ x L508 A ♂= **H13**	5,270	39.27	64,6
14.	L 724	1,9	L 517 A	2,9	2,4	L724 ♀ x L517 A ♂= **H14**	5,340	55.05	84,1
15.	L 2000	2,5	L 522	3,2	2,85	L2000 ♀ x L522 ♂= **H15**	3,140	9.23	-1,8
16.	L 709	2,7	L 22	3,8	3,25	L709 ♀ x L22 ♂= **H16**	3,500	7.14	-7,8
17.	L10	3,0	L 23	3,4	3,2	L10 ♀ x L23 ♂= **H17**	6,100	47.54	79,41
18.	L 12	2,0	L 26 C	4,5	3,25	L12 ♀ x L26 C ♂= **H18**	6,200	47.58	37,7
19.	L 15	3,7	L 311	3,1	3,4	L15 ♀ x L311 ♂= **H19**	6,600	48.48	78,3

MG- genitors mean; G1-genitor 1,G2-genitor 2

An estimation of the effect of the additive genes according to the desired trait and breeding objective was made by calculation formulas (Table 4). The following quantitative traits were considered: fruit yield/plant, number of fruits/plant and average fruit weight.

The effect of the additive genes was quantified in the average additive value, with a maximum of 2.6% for the yield/plant trait in the case of hybrid H4, for the number of fruits/plant trait, high values were recorded for the hybrid combinations H 16 and H 17 with 159% and 172% respectively and for the average fruit/plant weight trait, H1 showed an additive effect of 278%.

The dominance effect denoted by d recorded a maximum of 1246% for the hybrid combination L2000 ♀ x L522 ♂= H15 for the fruit/plant yield trait. Another high value of the dominant gene effect was observed for fruit weight with 871% at H8. As for the aa effect (additive x additive), also in the case of the hybrid combination H15 it was observed to be the most pronounced, registering 1482% in the case of average fruit weight. The compound effect of additive and dominant (ad) genes recorded a maximum value in the case of the mean fruit weight trait in the H 15 hybrid with 153%. The effect dd (dominance x dominance) recorded a maximum for the hybrid combination H 16 in the case of mean fruit weight. Fruit yield/plant recorded a maximum value of the dd dominance effect in the case of H19 of 20.4%. The recorded percentages show the effect of reproductive heterosis, especially in terms of fruit weight, with a marked increase in this trait in the case of hybrids that showed reproductive dominance.

Heterozygosity values depend on the favourable accumulation of dominant allele genes in the F1 population.

Table 4. Effect of additive genes on the quantitative parameters of the resulting hybrid combinations

Characteristics	Crosses	m (%)	a (%)	d (%)	aa (%)	ad (%)	dd (%)
Fruit yield	L19 ♀ x L10 ♂= **H1**	2 ^{i}	-0,5 ^{abcgh}	1,30 ^{a}	1,8 ^{a}	-0,20 ^{abhi}	-1,8 ^{j}
	L22 ♀ x L12 ♂= **H2**	2,9 ^{h}	1,9 ^{ab}	-0,80 ^{ab}	-1 ^{cd}	1,00 ^{ab}	2,4 ^{gh}
	L23 ♀ x L15 ♂= **H3**	3,1 ^{gh}	-0,2 ^{abce}	0,55 ^{ab}	0,8 ^{ab}	-0,05 ^{abef}	-0,3 ^{ij}
	L26 ♀ x L10 ♂= **H4**	4,3 ^{e}	2,6 ^{a}	-3,95 ^{cd}	-5,2 ^{e}	1,35 ^{a}	8,7 ^{f}

	L311 ♀ x L312 ♂= **H5**	4,36 e	0,5 abc	-5,18 def	-6,84 f	0,30 abd	11,2 e
	L312 ♀ x L508 A ♂= **H6**	3,19 gh	-0,4 abcfg	-1,52 b	-1,96 d	-0,15 abgh	3,8 g
	L508 A ♀ x L517 A ♂= **H7**	5,6-0.5- bc	0,4 abc	-8,45 gh	-11,2 hi	0,25 abd	17,7 bc
	L517 A ♀ x L522 ♂= **H8**	2,8 h	-0,2 abce	-0,05 ab	0 bc	-0,05 abf	0,9 hi
	L12 ♀ x L312 ♂= **H9**	4,55 de	-0,6 di	-7,40 fgh	-9,8 gh	-0,25 abi	15,6 cd
	L15 ♀ x L508 A ♂= **H10**	5,95 ab	0,6 abc	-8,30 gh	-11 hi	0,35 abcd	17,4 bc
	L19 ♀ x L311 ♂= **H11**	4 ef	-0,6 dh	-4,55 de	-6 ef	-0,25 abhi	9,9 ef
	L22 ♀ x L312 ♂= **H12**	3,59 fg	1,2 ab	-1,82 bc	-2,36 d	0,65 abc	4,4 g
	L709 ♀ x L508 A ♂= **H13**	5,07 cd	0,1 abce	-6,41 efg	-8,48 g	0,10 abe	13,6 d
	L724 ♀ x L517 A ♂= **H14**	5,14 cd	-0,9 bcgh	-9,02 h	-11,96 i	-0,40 abi	18,8 ab
	L2000 ♀ x L522 ♂= **H15**	2,94 h	-0,6 abcgh	-1,07 ab	-1,36 cd	-0,25 abi	2,9 gh
	L709 ♀ x L22 ♂= **H16**	3,3 gh	-1 bch	-0,95 ab	-1,2 cd	-0,45 abcd	2,7 gh
	L10 ♀ x L23 ♂= **H17**	5,9 ab	-0,3 abcef	-8,90 h	-11,8 i	-0,10 abg	18,6 ab
	L12 ♀ x L26 C ♂= **H18**	6ab	-2,4 cdh	-9,05 h	-12 i	-1,15 bi	18,9 ab
	L15 ♀ x L311 ♂= **H19**	6,4a	0,7 abc	-9,80 h	-13 i	0,40 abcd	20,4 a
Number of fruits/plant	L19 ♀ x L10 ♂= **H1**	24 e	-170,000 n	265,000 a	356,000 a	-85,000 m	-530,000 s
	L22 ♀ x L12 ♂= **H2**	26 de	-1,000 g	-4,520 m	-10,000 l	-0,504 h	25,000 d
	L23 ♀ x L15 ♂= **H3**	29 c	-5,000 h	-7,540 n	-10,000 l	-2,504 h	19,000 e
	L26 ♀ x L10 ♂= **H4**	38 a	-174,000 o	219,540 c	292,000 c	-86,500 m	-431,000 q
	L311 ♀ x L312 ♂= **H5**	26 de	-23,000 j	178,000 f	238,000 f	-10,000 i	-348,000 n
	L312 ♀ x L508 A ♂= **H6**	25 e	53,000 e	136,000 g	187,000 g	27,000 f	-272,000 m
	L508 A ♀ x L517 A ♂= **H7**	25 de	36,000 f	2,000 l	8,000 k	17,000 g	-8,000 h
	L517 A ♀ x L522 ♂= **H8**	24 e	-2,000 g	-47,500 p	-60,000 n	-1,500 h	95,000 b
	L12 ♀ x L312 ♂= **H9**	18 g	-66,000 l	107,000 i	152,000 h	-28,000 k	-214,000 l
	L15 ♀ x L508 A ♂= **H10**	32 b	-12,000 i	3,502 l	8,000 k	-2,500 h	5,000 f
	L19 ♀ x L311 ♂= **H11**	21 f	-40,000 k	78,500 j	108,000 i	-17,500 j	-149,000 j
	L22 ♀ x L312 ♂= **H12**	33 b	-76,000 m	79,500 j	108,000 i	-37,500 l	-155,000 k
	L709 ♀ x L508 A ♂= **H13**	28 cd	133,000 c	248,500 b	333,600 b	66,500 d	-489,000 r
	L724 ♀ x L517 A ♂= **H14**	41a	69,000 d	8,500 k	10,000 k	33,500 e	-1,040 g
	L2000 ♀ x L522 ♂= **H15**	34 b	-7,000 h	-83,000 q	-110,000 o	-3,000 h	170,000 a
	L709 ♀ x L22 ♂= **H16**	38 a	158,600 b	191,000 e	254,000 e	80,000 c	-374,000 o

	L10 ♀ x L23 ♂= **H17**	39 [a]	172,000 [a]	207,500 [d]	280,000 [d]	84,500 [b]	-411,000 [p]
	L12 ♀ x L26 C ♂= **H18**	38 [a]	-1,000 [g]	-39,000 [o]	-54,000 [m]	-1,000 [h]	86,000 [c]
	L15 ♀ x L311 ♂= **H19**	12 [h]	-40,000 [k]	132,000 [h]	15,000 [j]	150 [a]	-95,000 [i]
Average fruit weight	L19 ♀ x L10 ♂= **H1**	24,2 [e]	278,000 [b]	462,000 [f]	492,000 [f]	133,000 [b]	-520,000 [n]
	L22 ♀ x L12 ♂= **H2**	25,6 [de]	-104,000 [p]	375,000 [k]	400,000 [h]	-48,600 [l]	-414,000 [l]
	L23 ♀ x L15 ♂= **H3**	29,4 [c]	179,000 [d]	397,000 [i]	382,000 [i]	84,000 [d]	-310,000 [j]
	L26 ♀ x L10 ♂= **H4**	38,2 [a]	139,000 [f]	192,000 [n]	158,000 [l]	69,000 [e]	-80,000 [g]
	L311 ♀ x L312 ♂= **H5**	26,4 [de]	14,000 [j]	154,026 [q]	32,000 [q]	7,026 [g]	215,888 [d]
	L312 ♀ x L508 A ♂= **H6**	24,6 [e]	-38,000 [m]	257,562 [l]	72,000 [n]	-19,442 [i]	312,916 [b]
	L508 A ♀ x L517 A ♂= **H7**	25,4 [de]	-207,000 [q]	517,793 [e]	562,000 [d]	-103,223 [m]	-635,634 [p]
	L517 A ♀ x L522 ♂= **H8**	24,400 [e]	20,000 [i]	871,373 [b]	936,000 [b]	9,663 [g]	-1046,686 [r]
	L12 ♀ x L312 ♂= **H9**	17,600 [g]	164,000 [e]	442,000 [g]	348,000 [j]	82,800 [d]	-143,600 [i]
	L15 ♀ x L508 A ♂= **H10**	32,000 [b]	-25,000 [l]	133,500 [r]	66,000 [o]	-12,500 [h]	85,000 [f]
	L19 ♀ x L311 ♂= **H11**	21,400 [f]	248,000 [c]	562,000 [c]	568,000 [c]	119,000 [c]	-548,000 [o]
	L22 ♀ x L312 ♂= **H12**	32,600 [b]	51,000 [g]	179,000 [p]	78,000 [m]	25,400 [f]	130,000 [e]
	L709 ♀ x L508 A ♂= **H13**	27,600 [cd]	-50,000 [n]	184,905 [o]	48,000 [p]	-26,099 [j]	230,238 [c]
	L724 ♀ x L517 A ♂= **H14**	40,600 [a]	-247,000 [s]	389,787 [j]	418,000 [g]	-122,223 [o]	-463,634 [m]
	L2000 ♀ x L522 ♂= **H15**	34,400 [b]	307,000 [a]	1246,000 [a]	1482,000 [a]	153,000 [a]	-1948,000 [s]
	L709 ♀ x L22 ♂= **H16**	38,000 [a]	-65,000 [o]	219,411 [m]	34,000 [q]	-33,599 [k]	345,238 [a]
	L10 ♀ x L23 ♂= **H17**	38,600 [a]	-220,000 [r]	414,000 [h]	316,000 [k]	-110,000 [n]	-112,000 [h]
	L12 ♀ x L26 C ♂= **H18**	38,400 [a]	43,000 [h]	544,000 [d]	502,000 [e]	23,000 [f]	-392,000 [k]
	L15 ♀ x L311 ♂= **H19**	12,400 [h]	-3,000 [k]	-682,000 [s]	20,000 [r]	84,000 [d]	-743,000 [q]

a = additive mean; d = dominance effect; aa = additive × additive; ad = additive by dominance; dd = dominance × dominance.

*letters represent Duncan test results with 95% confidence interval and p<0.05%; CV-coefficient of variation

Taking into account the correlations between the effects of genes calculated according to the formulas mentioned above, it was identified that between the effect of additive genes and the effect of additive x dominance genes there is a positive trend dependence relationship, when one of the effects increases, automatically the other will increase. The R-squared coefficient of determination, calculated by Pearson's correlation of coefficients, was 1 (Figure 2).

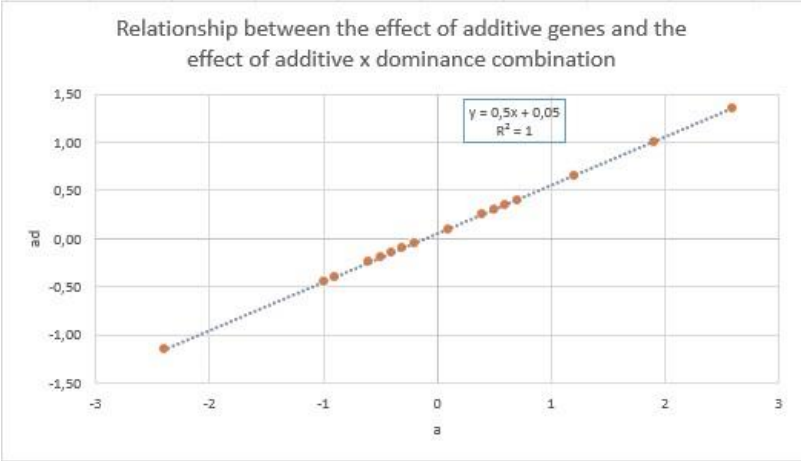


Figure 2. Relationship between the effect of additive genes and the effect of additive x dominance combination

CONCLUSIONS

The germplasm collection of this species has been evaluated for genetic stability. From this germplasm base, 31 parents were selected by the general combinatorial ability test and successfully passed this test. They were then subjected to the specific combining ability test, resulting in 19 hybrid combinations showing reproductive heterosis. Of these, hybrid H 14 recorded the highest percentage of estimated heterosis as well as heterobeltiosis, outperforming both the parent average and the best parent. Calculating the effect of additive genes, it was found that hybrids whose parents possessed wild genes significantly manifested the additive gene effect by recording high values of dominance and additive effect in the F1 population.

The hybrid combinations that demonstrated strong heterosis will be proposed for approval and patenting.

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