

# Features of heterosis manifestation in interlinear hybrids of sweet pepper in unheated film greenhouses

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**Abstract.** The dynamics of changes in an important economic trait of sweet pepper "average fruit weight" and the manifestation of heterosis have been studied on the example of 10 hybrids and their parental lines with multiple harvests in an unheated film greenhouse. It was found that the average weight, regardless of its value, was maximum and relatively stable during the first 5 harvests, which corresponds to the return of an early yield in the first month of fruiting. At the last collection, there was a decrease in the average weight of the fruit by 1.3-2.5 times. It has been established that a decrease in fruit weight with late harvests in hybrids occurs at a later date and is less pronounced than in parental lines, which indicates their higher adaptive ability. With an early harvest in 3 combinations, the level of true heterosis was 5.4-19.7%, a hypothetical heterosis at the level of 5.4-24.4% was found in 7 hybrids. At an early harvest and a late harvest in 50% of sweet pepper hybrids, the value of heterosis varied, but had the same character; in 50% of hybrids, a change in the sign of heterosis to the opposite was noted. 2 hybrid combinations with a more stable average fruit weight were identified with multiple harvests - (Bs1xF46Kt22706) and (San1xF46Kt2181) with varying traits within 77-99 g and 81-123 g. the effect in 80% of large-fruited (17.6-27.3%) and medium-fruited hybrids (8.5-49.3%) was noted after the early harvest on July 21. The maximum effect of heterosis does not correspond to the maximum value of fruit weight in the experiment and is associated with a more pronounced reaction of the parental lines compared to hybrids to extreme temperatures during the period of fruit formation.

## 1 Introduction

In modern vegetable breeding, preference for many crops is given to F1 hybrids, which are superior to traditional varieties in terms of economically valuable traits, and have a higher adaptive ability to biotic and abiotic factors. Hybrid breeding is based on the phenomenon of heterosis, known as the superiority of hybrids over parents. Initially, the interpretation of heterosis assumed an increase in the value of the trait in hybrids in relation to the average of the parents. [1]. The classic definition in Russian biology is the definition: heterosis is a phenomenon noted in some F1 hybrids, expressed in their superiority in one or several traits

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over the best parental form [2]. Researchers who touch upon the topic of heterosis in their works give preference to one or another definition or both at once, while superiority over the best parent is considered true heterosis, over the value of the average of parents - hypothetical [3]. Despite the fact that heterosis has been used in breeding for 100 years [4], its genetic causes are interpreted ambiguously and are based on three hypotheses: overdominance, dominance, and epistasis. All three hypotheses are not mutually exclusive, and depending on the trait or crop, either one or another explanation of heterosis is used [1]. Studies conducted over the years have confirmed that all three types of gene action jointly govern the final expression of the heterotic effect, and heterosis cannot be explained from the point of any separate theoretical hypothesis [2,5]. Since heterosis manifests itself in specific environmental conditions, it is necessary to take into account the interaction "genotype - environment". In different environmental conditions, the type of inheritance in a particular hybrid combination can vary widely [5,6]. According to the theory of ecological and genetic control of quantitative traits, environmental conditions affect not only the change in the severity of traits, but their redefinition due to a change in the gene set that determines the trait [7,8]. Moreover, according to Bulgarian scientists, in crops with a long fruiting period (tomato, pepper, etc.), the effect of heterosis manifests itself unevenly during the fruiting period - most strongly at the beginning and weaker - at the end of the period [9].

Heterosis, as a rule, is the higher, the more complex the trait is, or in other words, the more genes are involved in the control of the trait. So, for example, in sweet pepper, heterosis on the basis of "yield" will be higher than on the yield components: fruit weight and number of fruits. Some authors suggest that 5 genes control the "average fruit weight" trait in pepper. On the other hand, the weight of the fruit is also a resultant trait, depending on the thickness of the wall of the fruit, the length and diameter of the fruit and therefore, it is possible, according to other authors, that specific genes, both of the fruit weight and the yield do not exist [6]. Many researchers point to the fact that hybrids with a high percentage of heterosis are not always the best in terms of economically valuable traits [10, 11], therefore, it is advisable in practical breeding to use the criterion "hybrid strength", as the sum of the average parents and heterosis [1].

Numerous studies using molecular genetic methods aimed at establishing DNA polymorphism in breeding material, as a criterion for the selection of divergent genotypes for hybridization and obtaining guaranteed heterosis, have not yet been called so successful that they could replace traditional methods based on determining the combining ability of lines [1, 12].

According to many researchers, sweet pepper has a strong heterosis effect in terms of: duration of the growing season, yield, the number of fruits per plant, the fruit weight, the plant height [6,10,13,14].

The requirements of producers for F1 sweet pepper hybrids are quite high, this applies to yield, marketability of fruits, uniformity of fruits during the growing season. The most popular are hybrids with large fruits weighing 150-200 g. In addition, fruits with a light green or yellowish color with a thick pericarp wall, thin skin and juicy tender pulp without bitterness, herbaceous aftertaste, with an ascorbic acid content of at least 100- 120 mg / 100 g are preferable [2].

Spring film greenhouses occupy a significant sector in the production of early pepper. It is the early maturing heterotic hybrids, due to the higher stress resistance in the initial period of growth to low temperatures, and in the summer to high temperatures, that are economically more profitable and are in demand in protected ground. The experience of growing sweet pepper hybrids in a film greenhouse and in the open field has shown that in an isolated greenhouse, products have higher commercial qualities and productivity. No less important is the high ecological value of fruits in the greenhouse, due to a decrease in

pesticide load on plants or, at best, the implementation of a program for the integrated use of biological means of protection against pests and diseases. The quality of greenhouse fruits during the growing season depends on the cultivated hybrid, the level of its response to growing conditions.

Aim of the study: to study the manifestation of heterosis by the average fruit weight in sweet pepper hybrids in the process of regular harvesting of fruits in technical ripeness and to identify the most stable combinations by the weight of the fruit when grown in a spring film greenhouse.

## 2 Materials and methods

Experimental work was carried out at the experimental breeding site of the vegetable growing department and in a spring film greenhouse with side and ridge ventilation in 2020. Breeding material for research - 10 hybrid combinations based on 4 lines with nuclear-cytoplasmic male sterility and 6 lines of pollinators homozygous for many traits, 10 parental lines, including 4 lines - fertile analogs of male-sterile lines. Seedlings were grown in an artificial climate chamber and in a seedling greenhouse. Planting in the greenhouse on April 15. The number of accounting plants on the plot is 10 pieces, 2-fold repetition. Planting scheme: (80 + 50) x30 cm. When preparing the soil and planting, fertilizers were applied at a dose of N120P120K120, during the growing season, fertilization was carried out with nitrogen fertilizer at a dose of N20 and 5 foliar dressings (fertilizer polydon + albite) in combination with calbit C (during fruiting). Irrigation method - drip irrigation. The harvesting of fruits in technical ripeness was carried out once every seven days, from June 16 to August 31, taking into account the total number of fruits from the plot and the weight of the fruits. Early yield was calculated based on the results of 5 harvests during the 1st month of fruiting. During the growing season, phenological observations were carried out; during the first harvest, biometric measurements of fruits were carried out [16]. The degree of heterosis by fruit weight was assessed according to Kh. Daskalov [9].

## 3 Results of study

The size of the early yield of fruits in the greenhouse largely determines the profitability of the pepper crop and is one of the important traits that is closely related to heterosis in terms of early maturity and productivity traits.

From the results presented in Table 1, it follows that heterosis in the weight of the fruit based on the early yield (on average for 5 harvests) did not manifest itself in all hybrids. In 3 combinations, the excess over the best parent was 5.4%, 11.1% and 19.7%, the excess to the average indicator of parents varied within 3.5-24.4% already in 7 hybrids out of 10 that passed the test. It should be noted that positive heterosis in fruit weight, both true and hypothetical, is characteristic of parental couples with medium-sized fruits in the range of 75-105.7 g, and the differences in this trait within one pair of crosses did not exceed 14 g (comb. No. 13). When crossing the msEn57 line with large-fruited peppers with smaller-fruited lines, the mass of the fruit is inherited either by an intermediate type (No. 15) or heterosis is observed in relation to the middle parent (No. 14). If, as the maternal form, lines with smaller fruits than in the paternal lines were used, then at best, only hypothetical heterosis was observed (No. 17.18), in other combinations (No. 12.19) - negative heterosis.

The manifestation of true and hypothetical heterosis according to the results of the next 4 collections, including up to August 21, only in 50% of the hybrids had the same character as in the early collection (Tables 1, 2). In 50% of hybrids, a change in the sign of heterosis

to the opposite was noted. The value of true heterosis was maximum in hybrid No. 1 - 15.3%. Hybrids No. 12,14,15 were characterized by insignificant true heterosis in the range of 1.3-7.3% and a higher hypothetical - 8.5-15.7%. The rest of the hybrids, as a rule, had an average fruit weight, more or less approaching the average of the parents.

**Table 1.** Heterosis by mass of the fruit when obtaining an early yield

№	Hybrid	Mass of the fruit, g			True heterosis, %	Hypothetical heterosis, %
		F1	♀	♂		
11	msSan1xF46Kt21-81	111,4	105,7	94,0	5,4	11,5
12	msSan1xSamf 325	98,0	105,7	111,0	-12,0	-9,5
13	msSan1xNad1	91,0	105,7	70,0	-13,9	3,5
14	msEn57xF46Kt227-06	137,0	158,0	83,3	-13,3	13,5
15	msEn57xSamf322	130,1	158,0	107,5	-17,6	-2,0
16	S5xSamf325	97,0	75,0	81,0	19,7	24,4
17	S5xSamf322	100,0	75,0	107,5	-7,0	9,6
18	msBs1xSamf322	107,2	85,5	107,5	-0,3	11,1
19	msBs1xL307	92,1	85,5	118,0	-22,0	-9,5
20	msBs1xF46Kt227-06	95,0	85,5	83,3	11,1	12,5

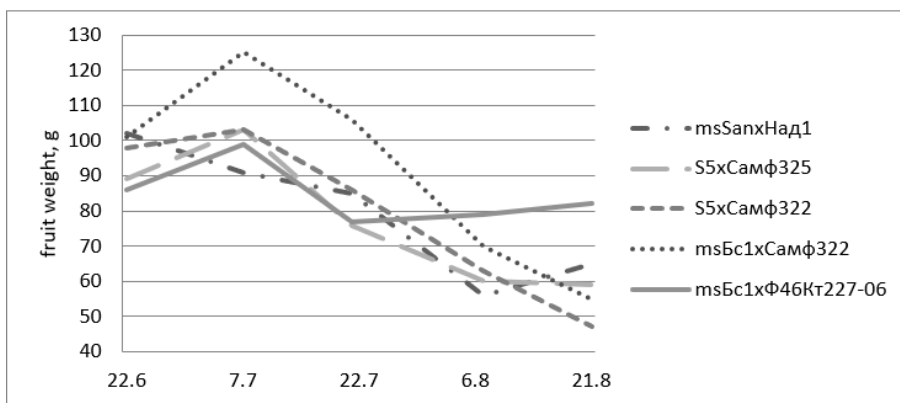
If we compare the data on the fruit mass in hybrids and parents with an early yield and a late yield, it should be noted that for almost all samples there is a significant decrease in this indicator. The exception was the F46Kt227-06 line, in which the weight loss was minimal and amounted to only 2.3 g. The maximum fruit mass decrease was observed in the large-fruited En57 line - from 158 g to 93.4 g, at the same time it should be noted that for hybrids on their basis (No. 14,15), the decrease in weight was not so strong - from 137 g to 94.6 g and from 130.1 g to 98.8 g. It follows from this that the reaction of hybrids to a change in growing conditions, which manifests itself in an increase in daytime temperature to an extreme one for a pepper crop, is less pronounced than in lines.

**Table 2.** Heterosis by mass of the fruit after early harvest

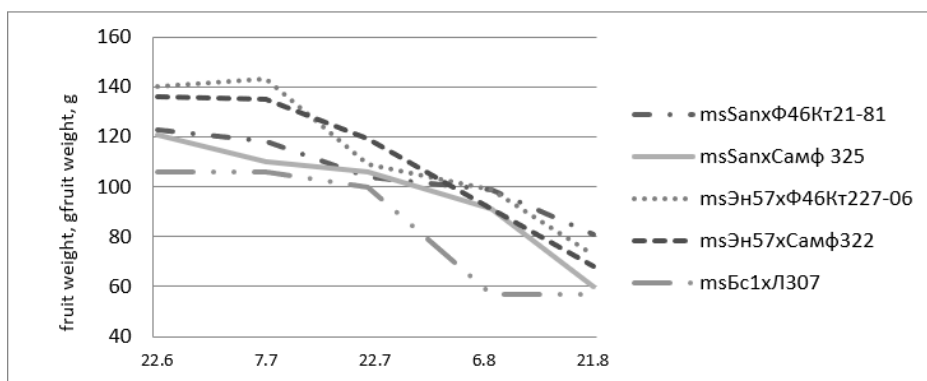
№	Hybrid	Mass of the fruit, g			True heterosis, %	Hypothetical heterosis, %
		F1	♀	♂		
11	msSanxF46Kt21-81	93,6	81,2	71,6	15,3	22,5
12	msSanxSamf 325	87,0	81,2	78,4	7,3	9,0
13	msSanxNad1	71,8	81,2	59,2	-11,6	2,3
14	msEn57xF46Kt227-06	94,6	93,4	81,0	1,3	8,5
15	msEn57xSamf322	98,8	93,4	77,4	5,8	15,7
16	S5xSamf325	65,8	64,6	71,4	-7,8	-3,2
17	S5xSamf322	69,6	64,6	77,4	-10,1	-2,0
18	msBs1xSamf322	77,6	77,4	77,4	0,3	0,3
19	msBs1xL307	74,8	77,4	78,4	-4,6	-4,0
20	msBs1xF46Kt227-06	78,0	77,4	81,0	-3,7	-1,5

For producers of pepper products in a greenhouse, it is necessary to know how the weight of the fruit changes during cultivation, how much the fruit is "growing smaller" in dynamics, in order to provide for a set of agrotechnical measures that can prevent or even out this process. To identify patterns and determine more stable genotypes based on "mass of the fruit", we analyzed the change in fruit weight of hybrids and parents with an interval of 2 weeks, i.e. through harvesting, and the level of hypothetical heterosis was calculated for these harvest dates. If we trace the change in the weight of the fruit during the fruiting

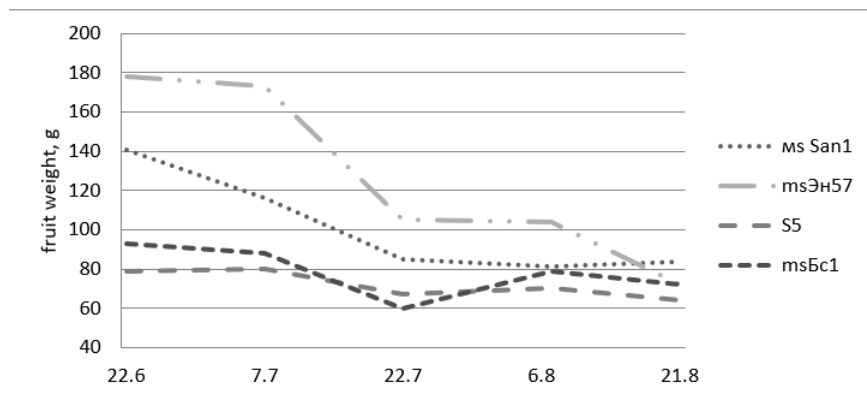
period in medium-fruited and large-fruited hybrids (Figures 1, 2), then the following tendency can be noted: after the early harvest, from July 21 (6th harvest), the fruit weight significantly decreases, namely, by 15,2-26,2% and 12,4-23,8%, respectively. The exception is the hybrid (Bs1xL307), in which a sharp decrease in mass of the fruit is noted only on August 7 - by 46.2%. The minimum average weight of the fruit is observed on August 7-21, moreover, it decreased in comparison with the maximum indicator in the experiment by 1.7-2.3 times, less pronounced shrinking of the fruits was manifested in 2 combinations - (Bs1xF46Kt22706) and (San1xF46Kt2181) - 1.3 and 1.5 times, respectively. The parental lines have also shown a decrease in fruit weight in the last collection by 1.3-2.5 times, this was more pronounced in large-fruited lines, for example, msEn57 and msSan1, L307 (Figures 3.4). It should be noted that, like hybrids, a decrease in mass of the fruit was also noted on the date of July 21, but for some lines, one might say, less adapted to high temperatures, this was more pronounced; for others, more hardy, it happened more smoothly, without sharp jumps and was typical, as a rule, for small-fruited lines, for example, S5, Nad1, Samf325-11, Samf325-12.



**Fig. 1.** Average fruit weight by harvest dates in medium-fruited hybrid



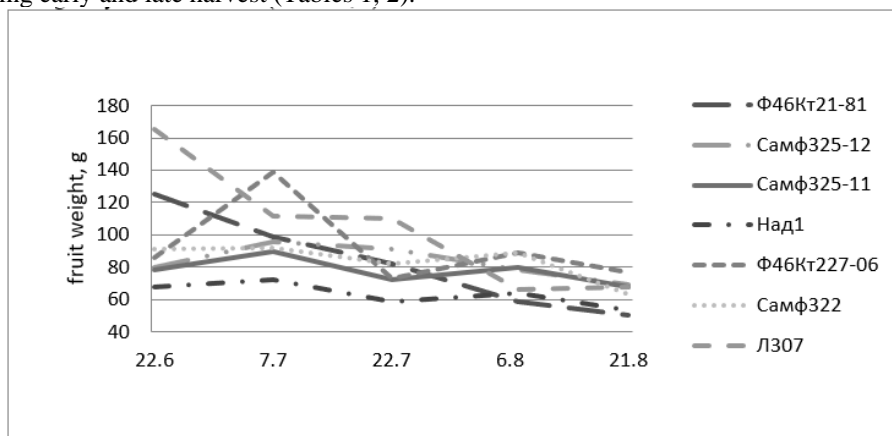
**Fig. 2.** Average fruit weight by harvest dates in large-fruited hybrids



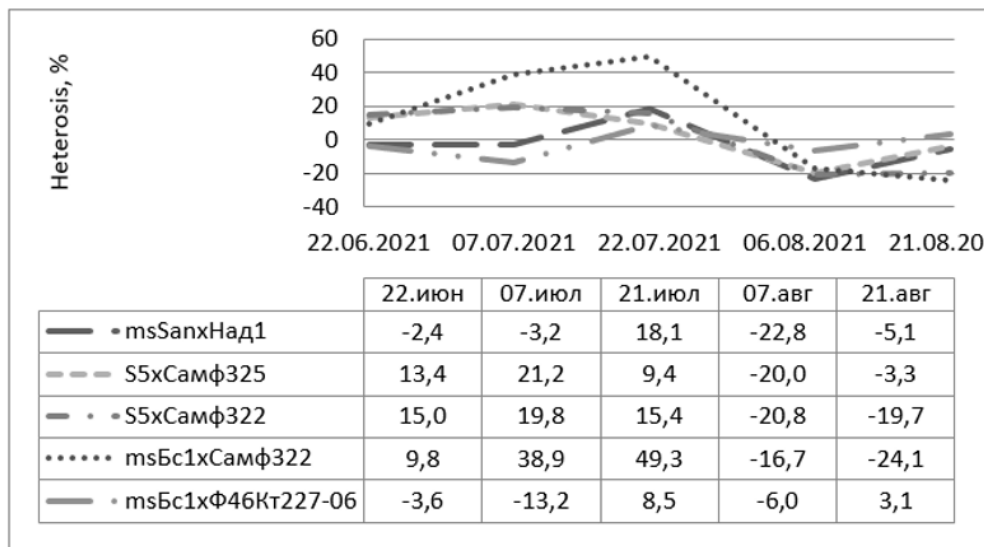
**Fig. 3.** Dynamics of the average fruit weight by harvest dates in maternal lines

The varying degree of reaction to the growing conditions, both of hybrids and parental lines, had an ambiguous effect on the manifestation of heterosis based on the fruit weight during the growing season. Figures 5 and 6 show that heterosis is a rather dynamic value and its value varied in medium-fruited hybrids in the range from -24.1% to 49.3%, in the large-fruited group from -24.0 to 41.4%. For each hybrid, the nature of the change in this value during the harvesting process has its own identity, but a general pattern was observed - for most hybrids on the date of July 21, the heterosis value was maximum, with the exception of 2 combinations (S5xSamph 325) and (San1xF46Kt2181). But this did not mean that during this harvesting, the fruits of the hybrids were the largest (Figures 1, 2), since the cause of the increased heterosis is associated with a sharper decrease in the weight of fruits in the parental lines at this date of harvesting.

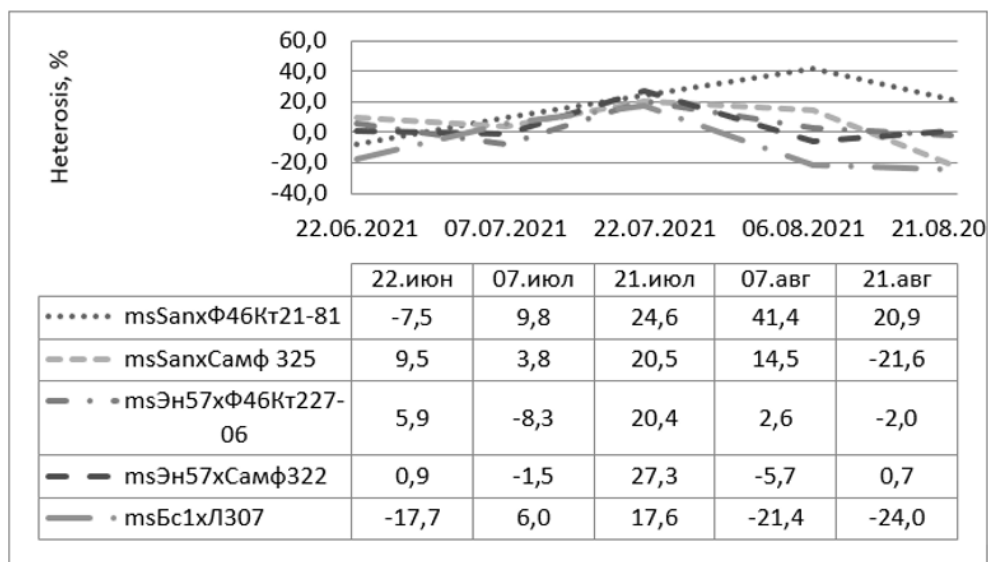
It is necessary to emphasize the following tendency: when harvesting a late yielded, hybrids with smaller fruits showed negative heterosis in fruit weight (Figure 5), while in large-fruited hybrids, the values of heterosis have both positive and negative values (Figure 6). Of all the hybrids, a higher stability in the manifestation of heterosis in the mass of the fruit was shown by (San1xF46Kt2181), which determined the overall positive heterosis during early and late harvest (Tables 1, 2).



**Fig. 4.** Dynamics of the average fruit weight by harvest dates in paternal lines



**Fig. 5.** Manifestation of heterosis on fruit weight by harvest dates in medium-fruited hybrid



**Fig. 6.** Manifestation of heterosis on fruit weight by harvest dates in large-fruited hybrids

## 4 Conclusions

In an early yield and a late yield in 50% of sweet pepper hybrids, the value of heterosis varied, but had the same character; in 50% of hybrids, a change in the sign of heterosis to the opposite was noted.

The average weight of fruits changed insignificantly and was maximum at the first 5 harvests; at the last harvest, a decrease by 1,3-2,5 times was noted.

Two hybrid combinations were identified with a more stable average fruit weight with multiple harvests: (Bs1xF46Kt22706) and (San1xF46Kt2181) with a variation of the trait within 77-99 g and 81-123 g.

The effect of heterosis by the trait of the fruit weight is manifested unevenly with multiple harvests of pepper - the maximum effect in 80% of large-fruited (17.6-27.3%) and medium-fruited hybrids (8.5-49.3%) was noted after the early harvest - July 21. The maximum effect of heterosis does not correspond to the maximum value of fruit weight in the experiment and is associated with a more pronounced reaction of the parental lines compared to hybrids to extreme temperatures during the period of fruit formation.

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