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Production and Evaluation of High Yielding Sweet Pepper Hybrids under Greenhouse Conditions

[1]Ahmed M.A. Mahmoud and [2]Ahmed A.S.A. El-Eslamboly

[1]Department of Vegetable Crops, Faculty of Agriculture, Cairo University, Giza, Egypt
[2]Horticulture Research Institute, Agriculture Research Center, Giza, Egypt

Abstract: Seven sweet pepper accessions were used to study the heterotic response of economic traits. Out of 7 accessions, 2 high yielding accessions with large elongated fruits, *viz*. PI 378647 (P_1) and PI 592833 cv. Royal King (P_2), were used as lines and 5 blocky large fruited accessions, *viz*. PI 592804 cv. Burrells Rocky Ford (P_3), PI 592809 cv. Wondergreen (P_4), PI 592834 cv. Titan (P_5), PI 592838 cv. Yellow Belle (P_6) and PI 659103 cv. Chocolate Bell (P_7), were used as testers. Ten F_1 hybrids produced by a line × tester mating system, their parents and the commercial hybrid cv. Gedion were evaluated based on their fruit yield and quality traits under greenhouse conditions during 2012 and 2013 autumn plantings. Significant variations of fruit yield and quality traits were observed among the F_1 hybrids, their parents and the commercial hybrid cv. The maximum extent of significant positive heterobeltiosis was recorded for early yield per plant (EY - 62.9%), total yield per plant (TY - 50.5%), average fruit weight (AFW - 96.7%), pericarp thickness (PT - 41.07%), fruit diameter (FD - 23.55%), mature fruit TSS (MTSS - 13.18%), mature fruit ascorbic acid content (MAAC - 14.06%) and ripe fruit ascorbic acid content (RAAC -17.56%). As compared to commercial hybrid cv. Gedion, nine hybrids exhibited significant positive commercial heterosis for PT; seven hybrids for mature fruit TSS (MTSS) and RTSS; six hybrids for fruit length; five hybrids for TY, AFW and FD; four hybrids for RAAC; and two hybrids for EY.Hybrids $P_2 \times P_3$ and $P_2 \times P_4$ had highest positive commercial heterosis on TY, AFW, FD, PT, MTSS and RTSS. Therefore, these hybrids may use commercially after their evaluation on large scale.

Key words: Sweet pepper · *Capsicum annuum* · Heterobeltiosis · Economic heterosis · Yield · Fruit quality

INTRODUCTION

Sweet Pepper (*Capsicum annuum* L.) is among the most important vegetable crops in the Solanaceae family grown worldwide for its delicate taste, pleasant flavor and color. Also, it is the most leading crop in protected cultivation. Sweet pepper fruits are generally blocky, thick fleshed, three to four lobed, large and non-pungent. Also, sweet pepper fruits are known to have high nutritional values; they contain various vitamins, biological pigments (lycopene, carotenoids and xanthophyll), dietary fiber and several essential minerals. Therefore, pepper consumption is increasing and may represent an important source of vitamins for world populations [1]. The antioxidant vitamins C (ascorbic acid) and E (alpha-tocopherol) and pro-vitamin A (â-carotene), which are preventive of cancer and cardiovascular human diseases, are present in high concentrations in various pepper types [2].

Peppers are grown in most countries of the world and their annual production has increased substantially over the years. Egypt ranked seventh global among the pepper-producing countries with about 650554 tons with an average of 6.86 tons/fed grown on 94807 feddens in 2012 (Department of Agricultural Statistics, Ministry of Agriculture and Land Reclamation, Egypt).

Commercial hybrids show superiority of marketable fruit yield and fruit quality over the open pollinated cvs through heterosis. Heterosis or hybrid vigor is defined as the superiority of the F_1 hybrid over its parents in terms of yield and other traits [3]. It has been widely used in agriculture to increase yield and to broaden adaptability of hybrid varieties and applied to increasing number of crop species [4]. If the hybrid is superior to the mid-parent value (average of the two parents), it is called as heterosis (H). It is called heterobeltiosis (BPH) when the performance of the F_1 exceeds this of the better parent.

Corresponding Author: Ahmed M.A. Mahmoud, Vegetable Crops Department, Faculty of Agriculture, Cairo University, Giza, Egypt. E-mail: ahmed.ali@agr.cu.edu.eg.

The economic heterosis (EH) is the difference between the values of the F_1 and the best commercial cv. Commercial exploitation of heterosis is feasible only if the vigor is in excess of prevailing commercial hybrid and the better parent. In practical plant breeding, superiority of F_1 over mid parent is of no consequence as it does not prove any advantage over the better parent. In most cases, mid parent values may be inferior to commercial hybrids [5].

The main breeding objectives in sweet pepper are to increase yield by heterosis breeding. Heterosis in yield is the result of the interplay of several components: plant size, earliness of bloom, average fruit weight and number of fruits produced on a plant vigorous enough to support the crop. Heterosis in sweet peppers has been reported for plant height, fruit weight, number of fruits per plant, early yield and total yield [6-19].

In sweet pepper, mere breeding for enhanced yield is not important unless it is qualified by the quality requirements desired by the consumers. Significant heterotic effects were shown by some crosses for fruit quality, such as pericarp thickness and fruit contents of TSS and ascorbic acid [11-13, 20, 21].

In Egypt, imported F1 hybrid pepper cvs are popular in the commercial market, although open-pollinated cvs are still commonly available. Hybrids preferred by both growers and consumers because of their superiority in yield, disease resistance and quality traits. Therefore, there is a growing demand in Egypt for developing and producing local hybrid cvs adapted to local conditions with high yield, good quality and resistance to prevalent local races of pathogens. These objectives can be achieved through breeding programs. Therefore, as an attempt to produce local high yielding and good quality sweet pepper hybrids, this study was conducted to estimate the heterotic effects for fruit yield and quality traits over both the better parent and a commercial hybrid cv.

MATERIALS AND METHODS

This study was carried out under greenhouse conditions in Kaha Vegetable Research Farm, Horticulture Research Institute, Agriculture Research Center (ARC), Kalubia Governorate, Egypt, to produce and evaluate some F_1 sweet pepper hybrids. The basic material comprised of two high yielding accessions with large elongated fruits, *viz.* PI 378647 (P_1) and PI 592833 cv. Royal King (P_2), used as lines and5 blocky large fruited accessions, *viz*. PI 592804 cv. Burrells Rocky Ford (P_3), PI 592809 cv. Wondergreen (P_4), PI 592834 cv. Titan (P_5), PI 592838 cv. Yellow Belle (P_6) and PI 659103 cv. Chocolate Bell (P_7), used as testers. Theses accessions of sweet pepper were kindly provided by the USDA, Plant Introduction Station, Ames, Iowa, USA. Ten crosses were produced by a line × tester mating system during the 2011 winter planting under greenhouse conditions.

Seeds of the 17 genotypes (7 parents + 10 F_1's) in addition to the commercial hybrid cv. Gedion were grown in a randomized complete block design, replicated thrice in 2012 and 2013 autumns under greenhouse conditions. The area of the greenhouse was divided into 5 rows. Each row was 1.2 m wide and 5 weeks old healthy seedlings were transplanted on both sides of the row. The distance between plants, on each side of the row, was 30 cm and each experimental unit (EU) consisted of ten plants. All recommended cultural practices for sweet pepper production under greenhouse conditions including plant pruning, fertilization, irrigation and controlling the weeds, diseases and insects to raise good crop were performed in both nursery and field.

Data were recorded on evaluated genotypes on early (EY - the first three harvests) and total yield (TY - all fruits) per plant and fruit quality traits, i.e. average fruit weight (AFW - average weight of 30 fruits/EU), pericarp thickness (PT - means of 10 fruits/EU), fruit diameter (FD - means of 10 fruits/EU), fruit length (FL - means of 10 fruits/EU) and mature and ripe fruit contents of total soluble solids (TSS) and ascorbic acid (AAC) contents. TSS was determined using a hand refractometer, while AAC (vit. C) was measured using 2, 6 dichlorophenol indophenol dye [22].

Statistical Analysis: Data obtained were statistically analyzed using combined analysis by MSTAT-C v. 2.1 (Michigan State University, Michigan, USA) and mean comparisons were based on the Duncan's multiple range test [23].

Estimation of Heterosis: The magnitude of heterosis was estimated in relation to the better-parent (BPH) and a commercial hybrid cv. (EH). Both values were calculated as percentage increase or decrease of F_1s over values of better-parent and commercial hybrid cv. Gedion, respectively, using the following equations:

$$BPH = \frac{F_1\text{-}BP}{BP} \times 100 \text{ [24]}$$

$$EH = \frac{F_1\text{-}SV}{SV} \times 100 \text{ [5]}$$

Where, F_1, mean value of hybrid; BP, mean value of better parent and SV, mean value of the commercial hybrid cv.Gedion.

RESULTS AND DISCUSSION

Yield and its Components: Data obtained on performance of EY, TY and AFW and the estimates of BPH and EH of the evaluated genotypes are presented in Table 1. Significant differences were found among the evaluated genotypes (parents and their hybrids) and also between genotypes and the commercial hybrid cv. Gedion under greenhouse conditions for these traits.

Early yield per plant in the parental accessions ranged from 0.48 (P_7) to 0.86 kg (P_2) and was significantly lower than EY/plant of the commercial hybrid cv. Gedion, except P_2, which was significantly similar to "Gedion" (Table 1). With regard to the evaluated hybrids, EY/plant ranged from 0.46 ($P_2 \times P_3$ and $P_2 \times P_5$) to 1.07 ($P_1 \times P_6$ and $P_2 \times P_7$). Hybrids $P_1 \times P_6$ and $P_2 \times P_7$ were produced the highest significant EY/plant than commercial hybrid cv. Gedion, followed by $P_1 \times P_3$ and $P_2 \times P_4$ (1.01 and 0.99 kg, respectively) without significant differences between them. The commercial hybrid cv. Gedion (0.93 kg/plant) was ranked third in this respect without significant differences from the hybrids $P_1 \times P_3$ and $P_2 \times P_4$ (Table 1).

Regarding TY/plant, all evaluated parents, except P_6, were superior for TY/plant and were not significantly different from the commercial hybrid cv. Gedion. The highest TY/plant was produced by P_1, P_2 and P_3 (3.37, 3.07 and 3.03 kg, respectively) without significant differences between them (Table 1). The TY/plant for the evaluated hybrids was ranged from 3.06 ($P_1 \times P_7$) to 4.62 kg ($P_2 \times P_3$). The hybrid $P_2 \times P_3$ produced the highest significant TY/plant over all evaluated genotypes followed by $P_1 \times P_6$, $P_2 \times P_4$ and $P_2 \times P_7$ (4.23, 4.20 and 4.15 kg, respectively) without significant differences among them. The hybrid $P_2 \times P_5$ was the second in this respect, being 3.96 kg, without significant differences from the last three hybrids. TY/plant of the remaining evaluated hybrids was not significantly different from the commercial hybrid cv. Gedion (Table 1).

Generally, sweet pepper accessions used as lines (P_1 and P_2) produced medium-size fruits (71.4 and 86.96 g, respectively), while sweet pepper accessions used as testers produced larger fruits, where their AFW ranged from 95.33 to 130.20 g. Parents P_4 and P_5 showed large AFW than that of cv. Gedion. Regarding to hybrids, hybrid $P_2 \times P_3$ had the highest significant AFW (198.7 g) among all evaluated germplasm followed by hybrids $P_2 \times P_5$, $P_2 \times P_4$ and $P_1 \times P_3$, being 154.3, 153.7 and 152.7 g (Table 1).

For EY/plant, 7 hybrids gave desired positive BPH, *viz*. $P_1 \times P_6$, $P_1 \times P_3$, $P_1 \times P_5$, $P_2 \times P_7$ (highly significant BPH) $P_1 \times P_7$, $P_1 \times P_4$ and $P_2 \times P_4$ (significant BPH). Meanwhile, only two hybrids, *viz*. $P_1 \times P_6$ and $P_2 \times P_7$ exhibited the highest positive EH for EY/plant over hybrid cv. Gedion (15.05%). Regarding to TY/plant, 5 out of the 10 evaluated hybrids, *viz*. $P_1 \times P_6$, $P_2 \times P_3$, $P_2 \times P_4$, $P_2 \times P_5$ and $P_2 \times P_7$, showed superiority to their parents (Table 1), where these hybrids exhibited high significant positive BPH and EH for TY/plant over commercial hybrid cv. Gedion. Also, 5 F_1 hybrids exhibited positive highly significant BPH and EH for AFW, *viz*. $P_1 \times P_3$, $P_1 \times P_4$, $P_2 \times P_3$, $P_2 \times P_4$ and $P_2 \times P_5$. Hybrid $P_2 \times P_3$ showed the highest positive BPH and EH for TY/plant (50.49% and 96.7%, respectively) and AFW (38.47% and 71.46%, respectively). Also, hybrids $P_2 \times P_4$ and $P_2 \times P_5$ exhibited large positive BPH and EH for TY/plant and AFW (Table 1).

Fruit yield is the most important economic trait of sweet pepper. The hybrid vigor for fruit yield in sweet pepper has been reported earlier by Betlach[6], Gill *et al*. [8], Thakur *et al.*[19] and Konsuwa [12] who reported an increased yield in F_1 hybrids due to over-dominance coupled with non-additive gene action. Several investigations demonstrated a role of heterosis in fruit yield improvement of sweet pepper and observed that crosses between two poor yielding parents usually showed the highest heterosis over the better-parent for fruit yield per plant [9, 13-15, 17,18, 25-27]. Similar findings were observed in this study.

Ahmed and Muzafar [28] reported the highest heterosis of 174.52% over better parent on fruit yield per plant in sweet pepper. Also, Shrestha *et al*. [16] obtained up to 141.2% heterosis, 119.3% better parent heterosis and 29.1% economic heterosis for fruit yield per plant. Khalil and Hatem [11] estimated the increase in fruit yield over better-parent up to 74.6%.

Average fruit weight is one of the most important component traits which contribute for yield. Consumers prefer long sized fruits weighing more than 150 g. Most investigations of inheritance of AFW in sweet pepper showed that the small fruit was partially or completely dominant over the large one and estimation of heterosis values were insignificant [11,17, 18, 29]. On the other hand, positive heterotic effects were observed in some crosses of AFW [11, 26, 30 -34]. Similar findings were observed in this study.

Table 1: Mean performance and estimates of heterobeltiosis (BPH) and economic heterosis (EH) for yield and its components for 7 sweet pepper accessions and their F_1's.

	Early yield			Total Yield			AFW		
Genotype	Mean^z (kg/plant)	BPH (%)	EH (%)	Mean^z (kg/plant)	BPH (%)	EH (%)	Mean^z (g)	BPH (%)	EH (%)
PI 378647 (P_1)	0.62 gh			3.37 d-f			71.37 j		
PI 592833 (P_2)	0.86 cd			3.07 d-f			86.96 hi		
PI 592804 (P_3)	0.54 hi			3.03 d-f			101.00 f		
PI 592809 (P_4)	0.63 f-h			2.89 f			125.80 d		
PI 592834 (P_5)	0.65 fg			2.91 f			130.20 d		
PI 592838 (P_6)	0.49 i			2.09 g			96.98 g		
PI 659103 (P_7)	0.48 i			2.96 ef			95.33 g		
$P_1 \times P_3$	1.01 ab	62.90**	8.60	3.30 e-f	-2.08	-0.90	152.70 b	51.19**	
$P_1 \times P_4$	0.73 ef	15.87*	-21.51**	3.50 c-e	3.86	5.11	142.00 c	12.88**	
$P_1 \times P_5$	0.88 cd	35.38**	-5.38	3.57 cd	5.93	7.21	112.20 e	-13.82**	2.47
$P_1 \times P_6$	1.07 a	72.58**	15.05**	4.23 ab	25.52**	27.03**	92.71 g	-4.40	-15.33**
$P_1 \times P_7$	0.78 de	25.81*	-16.13	3.06 d-f	-9.20	-8.11	82.44 i	-13.52**	-24.71**
$P_2 \times P_3$	0.46 i	-46.51**	-50.54**	4.62 a	50.49**	38.74**	198.70 a	96.73**	
$P_2 \times P_4$	0.99 ab	15.12*	6.45	4.20 ab	36.81**	26.13**	153.70 b	22.18**	
$P_2 \times P_5$	0.46 i	-46.51**	-50.54**	3.96 bc	28.99**	18.92**	154.30 b	18.82**	
$P_2 \times P_6$	0.86 cd	0	-7.53	3.31 d-f	7.82	-0.60	91.51 gh	-5.64*	-16.43**
$P_2 \times P_7$	1.07 a	24.42**	15.05**	4.15 ab	35.18**	24.62**	88.70 hi	-6.95*	-19.00**
Gedion	0.93 bc			3.33 d-f			109.50 e		

^{z}Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

**Highly significant ($P \geq 0.01$) and *significant ($P \geq 0.05$).

Table 2: Mean performance and estimates of heterobeltiosis (BPH) and economic heterosis (EH) for fruit physical traits of 7 sweet pepper accessions and their F1's.

	Fruit diameter			Fruit length			Pericarp thickness		
Genotype	Mean^z (mm)	BPH (%)	EH (%)	Mean^z (mm)	BPH (%)	EH (%)	Mean^z (mm)	BPH (%)	EH (%)
PI 378647 (P_1)	56.25 h			209.10 a			5.00 gh		
PI 592833 (P_2)	65.00 g			147.00 b			6.00 fg		
PI 592804 (P_3)	77.50 c-e			116.50 cd			6.33 ef		
PI 592809 (P_4)	86.25 ab			101.80 de			7.83 a-d		
PI 592834 (P_5)	75.75 d-f			146.50 b			8.17 a-c		
PI 592838 (P_6)	87.00 ab			104.40 de			7.50 b-e		
PI 659103 (P_7)	69.00 e-g			107.00 de			6.20 f		
$P_1 \times P_3$	73.75 d-f	-4.84	9.75	120.30 cd	-42.47**	19.70*	7.17 c-f	13.27	69.50**
$P_1 \times P_4$	71.75 e-g	-16.81**	6.77	118.50 cd	-43.33**	17.91*	7.75 a-d	-1.02	83.22**
$P_1 \times P_5$	85.25 a-c	23.55**	26.86**	103.50 e	-50.50**	2.99	7.50 b-e	-8.20	77.30**
$P_1 \times P_6$	82.00 a-d	-5.75	22.02**	99.25 f	-52.53**	-1.24	6.17 f	-17.73*	45.86**
$P_1 \times P_7$	70.50 e-g	-6.93	4.91	129.70 bc	-37.97**	29.05**	4.87 gh	-21.45*	15.13
$P_2 \times P_3$	90.25 a	16.45**	34.30**	106.00 de	-27.89**	5.47	8.93 a	41.07**	111.11**
$P_2 \times P_4$	85.67 a-c	-0.67	27.49**	104.83 e	-28.69**	4.31	7.17 c-f	-8.43	69.50**
$P_2 \times P_5$	75.88 d-f	9.97	12.92	117.90 cd	-19.80*	17.31*	6.73 d-f	-17.63*	59.10**
$P_2 \times P_6$	80.50 b-d	-7.47	19.79**	145.50 b	-1.02	44.78**	8.67 ab	15.60*	104.96**
$P_2 \times P_7$	68.50 fg	-9.57	1.93	133.00 bc	-9.52	32.34**	7.73 a-d	24.68**	82.74**
Gedion F_1	67.20 g			98.77 f			4.23 h		

^{z}Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

**highly significant ($P \geq 0.01$) and *significant ($P \geq 0.05$).

Fruit Physical Traits: Currently, the global trend has shifted to production of cultivars with larger fruits, especially for the fresh market industry [35]. Also larger and wider fruit of sweet pepper are considered the best in quality and have better demand in Egyptian market. Therefore fruit length and diameter traits, in addition to pericarp thickness trait have become more important to pepper breeders. Data obtained on fruit physical traits (fruit diameter and length and pericarp thickness) and the estimates of BPH and EH of the evaluated genotypes are presented in Table 2. Significant differences were found among the evaluated genotypes (parents and their hybrids) and also between genotypes and the commercial cv. Gedion under greenhouse conditions for fruit physical traits.

Generally, parents used as lines were characterized by large elongated fruits and produced the highest fruit length but the lowest in fruit diameter among evaluated parents (Table 2). Fruits of P_4 and P_6 were the largest in diameter among evaluated parents. Fruits of P_1were the largest in length among evaluated genotypes followed by P_2 and P_5fruits with significant differences among them.

Regarding the produced hybrids, fruits of $P_2 \times P_3$ were the largest in diameter, followed by hybrids $P_2 \times P_4$, $P_1 \times P_5$ and $P_1 \times P_6$ without significant differences among them and both parents P_4 and P_5. Fruits of $P_2 \times P_6$, $P_2 \times P_7$ and $P_1 \times P_7$ were the largest in length without significant differences among them. Fruits of commercial hybrid cv. Gedion had lower fruits, where FD was 67.2 mm and FL was 98.8 mm (Table 2).

The highest values of PT among the evaluated genotypes were those of P_5 and P_4 (8.17 and 7.83 mm, respectively) and hybrids $P_2 \times P_3$, $P_2 \times P_6$, $P_1 \times P_4$ and $P_2 \times P_7$ (8.93, 8.67, 7.75 and 7.73 mm, respectively) without significant differences among them. On the contrary, the thinnest pericarp among evaluated genotypes was observed with commercial hybrid cv. Gedion (4.23 mm) and $P_1 \times P_7$ (4.87 mm - Table 2).

The estimates of BPH values expressed desired significant effects in two hybrids for FD and three hybrids for fruit PT. None of the hybrids expressed significant BPH in the desired direction for FL (Table 2). The extent of BPH varied from -16.81% ($P_1 \times P_4$) to 23.55% ($P_1 \times P_5$) for FD, -50.5% ($P_1 \times P_5$) to -1.02% ($P_2 \times P_6$) for FL and -21.45 ($P_1 \times P_7$) to 41.07 ($P_2 \times P_5$) for PT.

As compared to commercial cv. 5hybrids exhibited positive significant EH for FD, 6 hybrids for FL and 9 hybrids for PT. The extent of EH ranged from 1.93% ($P_1 \times P_7$) to 34.3% ($P_2 \times P_5$) for FD, -1.24 ($P_1 \times P_6$) to 44.78 ($P_2 \times P_6$) for FL and 15.13 ($P_1 \times P_7$) to 111.11 ($P_2 \times P_3$) for PT (Table 2).

Several examples are available verifying that a significant amount of positive heterosis can be exploited for fruit width, length and pericarp thickness after various pepper crosses were made [11, 18, 33]. Dominance for fruit length and diameter and pericarp thickness was observed by Hatem and Salem [36], Sood and Kumar [18] and Khalil and Hatem [11].

Fruit Chemical Traits: There is worldwide interest to identify genotypes with enhanced levels of antioxidants, such as ascorbic acid, for targeting increased functional properties in foods. Pepper is one of the richest vegetables in ascorbic acid (vit. C), providing more than 100% of the recommended dietary allowance for this vitamin. Sweet pepper fruits had a lower TSS during the early stage of growth and this increased with maturity [37]. Sugars are the major components of TSS. Nielsen *et al* [37] found that the increase in TSS of sweet pepper fruit is due to the increase in hexose sugars which accumulate during fruit ripening and so the sweetness taste increases.

Ascorbic acid and TSS contents in sweet pepper fruit are affected by genotypes and maturity stage [21, 25, 38 -39]. These effects were observed in this study, where, the levels of TSS and ascorbic acid were increased as the fruit ripened for all evaluated genotypes (Table 3 and 4). Also, there were significant differences among the evaluated genotypes under greenhouse conditions in AAC and TSS. The great variation in sugar and acid contents in pepper implies that genetic dissection of the contents of these compounds can be used to enable more precise and efficient breeding toward the development of sweet peppers with improved flavor, allowing their use by consumers as snacks because of their improved taste.

The highest significant TSS content (9.13 and 11%, respectively) was observed in P_1fruits at mature and ripe stages among the evaluated parents, followed by P_7 (8.57 and 9.67%, respectively) without significant difference between them at mature stage only. Other evaluated parents produced fruits having higher TSS content significantly differed from the commercial hybrid cv. Gedion, except parent P_4 and P_6 at fruit mature stage and these parents in addition to P_5 at fruit ripe stage. The highest significant TSS content among hybrids was produced by $P_2 \times P_5$ (6.9 and 8.73%, respectively) at mature and ripe stages, followed by $P_2 \times P_5$ (6.87%) at mature stage and by $P_1 \times P_7$ (8.53%) at ripe stage without significant differences among them (Table 3).

Only single F_1 hybrid $P_2 \times P_5$ expressed positive significant BPH for mature fruit TSS (13.18%), while none of the hybrids expressed significant BPH in the desired direction in ripe fruit TSS content (Table 3). As compared to commercial hybrid cv. Gedion, 7 hybrids exhibited positive significant EH for mature and ripe fruit TSS traits. The extent of EH ranged from -2.75% ($P_1 \times P_3$ and $P_2 \times P_7$) to 56.45% ($P_1 \times P_7$) for mature fruit TSS and from 12.57% ($P_2 \times P_7$) to 63.79% ($P_1 \times P_5$) for ripe fruit TSS.

The low TSS content in sweet pepper fruit was partially or completely dominant over the high content, therefore estimation of heterosis values were insignificant [25, 40].On the contrary, Geleta and Labuschagne [21] suggested the presence of over-dominance for TSS content trait. Moreover, positive heterotic effects were observed in some crosses of TSS content [31, 40].

The highest significant AAC among parents (101.9 and 120.7 mg/100g FW, respectively) was found in P_1 fruits at mature and ripe stages, followed by P_7 fruits

Table 3: Mean performance and estimates of heterobeltiosis (BPH) and economic heterosis (EH) for mature and ripe fruit TSS percentages traits of 7 sweet pepper accessions and their F_1's.

	TSS %					
	Mature			Ripe		
Genotype	Mean^z (%)	BPH (%)	EH (%)	Mean^z (%)	BPH (%)	EH (%)
PI 378647 (P_1)	9.13 a			11.00 a		
PI 592833 (P_2)	6.07 de			8.00 c-e		
PI 592804 (P_3)	5.87 ed			7.07 ef		
PI 592809 (P_4)	5.20 f-h			6.50 fg		
PI 592834 (P_5)	5.93 de			6.03 fg		
PI 592838 (P_6)	4.67 h			5.33 g		
PI 659103 (P_7)	8.57 a			9.67 b		
$P_1 \times P_3$	4.60 h	-49.62**	-2.75	6.33 fg	-42.45**	18.76
$P_1 \times P_4$	5.50 e-g	-39.76**	16.28*	6.53 fg	-40.64**	22.51*
$P_1 \times P_5$	6.90 bc	-24.42**	45.88**	8.73 bc	-20.64**	63.79**
$P_1 \times P_6$	5.47 e-g	-40.09**	15.64*	6.13 fg	-44.27**	15.01
$P_1 \times P_7$	7.4 b	-18.95**	56.45**	8.53 b-d	-22.45**	60.04**
$P_2 \times P_3$	6.60 cd	8.73	39.53**	8.40 cd	5	57.60**
$P_2 \times P_4$	6.07 de	0	28.33**	8.07 c-e	0.88	51.41**
$P_2 \times P_5$	6.87 bc	13.18*	45.24**	7.30 d-f	-8.75	36.96**
$P_2 \times P_6$	5.13 gh	-15.49**	8.46	7.13 ef	-10.88	33.77**
$P_2 \times P_7$	4.6 h	-22.43**	-2.75	6.00 fg	-0.5	12.57
Gedion F_1	4.73 h			5.33 g		

^{Z}Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.
**highly significant ($P \geq 0.01$) and *significant ($P \geq 0.05$).

Table 4: Mean performance and estimates of heterobeltiosis (BPH) and economic heterosis (EH) for mature and ripe fruit ascorbic acid contents traits of 7 sweet pepper accessions and their F_1's

	Ascorbic acid content					
	Mature			Ripe		
	Mean^z (mg/100 g FW)	BPH (%)	EH (%)	Mean^z (mg/100 g FW)	BPH (%)	EH (%)
PI 378647 (P_1)	101.90 a			120.70 c		
PI 592833 (P_2)	80.65 f-h			108.30 d-f		
PI 592804 (P_3)	76.19 h			95.25 ij		
PI 592809 (P_4)	77.77 h			92.76 jk		
PI 592834 (P_5)	80.00 gh			90.41 kl		
PI 592838 (P_6)	69.63 I			86.07 l		
PI 659103 (P_7)	92.10 b-d			105.30 ef		
$P_1 \times P_3$	86.69 d-f	-14.93**	-8.16**	100.30 gh	-16.90**	-3.84
$P_1 \times P_4$	96.48 ab	-5.32	2.21	112.80 d	-6.55**	8.15**
$P_1 \times P_5$	97.29 ab	-4.52	3.07	141.90 a	17.56**	36.05**
$P_1 \times P_6$	76.03 h	-25.39**	-19.45**	88.04 l	-27.06**	-15.59**
$P_1 \times P_7$	93.74 bc	-8.01**	-0.69	127.90 b	5.97**	22.63**
$P_2 \times P_3$	79.29 h	-1.69	-16.00**	99.01 hi	-8.58**	-5.07*
$P_2 \times P_4$	91.99 b-d	14.06**	-2.54	109.60 de	1.2	5.08*
$P_2 \times P_5$	88.98 c-e	10.33**	-5.73	108.40 d-f	0.09	3.93
$P_2 \times P_6$	85.63 e-g	6.17	-9.28	99.33 hi	-8.28**	-4.77*
$P_2 \times P_7$	52.67 j	-34.16**	-44.20**	80.00 m	-26.13**	-23.30**
Gedion F_1	94.39 bc			104.30 fg		

^{z}Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.
**highly significant ($P \geq 0.01$) and *significant ($P \geq 0.05$).

(92.1 mg/100g FW) at mature stage and by P_2 fruits (108.3 mg/100 g FW) at ripe stage with significant difference among them. The highest significant AAC among hybrids was produced by $P_1 \times P_5$ (97.29 and 141.9 mg/100g FW, respectively) at mature and ripe stages, followed by $P_1 \times P_4$ (96.48 mg/100g FW) at mature stage only without significant differences among them (Table 4). Also, hybrid $P_1 \times P_7$ ranked second in this respect at mature and ripe stages, being, 93.7 and 127.9 mg/100 g FW, respectively.

Two F_1 hybrids expressed positive significant BPH for mature ($P_2 \times P_4$ and $P_2 \times P_5$) and ripe ($P_1 \times P_5$ and $P_1 \times P_7$) fruit AAC (Table 3). As compared to commercial hybrid cv. Gedion, none of the hybrids exhibited positive significant EH for mature fruit AAC, but there were 2 hybrids ($P_1 \times P_5$ and $P_1 \times P_5$) exhibited insignificant positive EH for mature AAC. For ripe fruit AAC trait, 4 hybrids exhibited positive significant EH. The extent of EH for AAC ranged from -44.2% ($P_1 \times P_7$) to 3.07% ($P_1 \times P_5$) for mature fruit and from -23.3% ($P_2 \times P_7$) to 36.05% ($P_1 \times P_5$) for ripe fruit (Table 4). Gelete and Labuschagne [21] reported that high levels of AAC are over-dominance, therefore, significant positive heterotic effects were observed in some crosses for AAC trait in previous studies [11-13, 25].

The differences in values of BPH and EH for fruit yield and quality traits of the evaluated hybrids are mainly due to the varying extent of genetic diversity between the parents of different crosses. Genetic divergence existing in the population helps in the selection of suitable parents for utilization in breeding programs and is necessary to observe heterosis in F_1 hybrids [16, 41]. The positive BPH in some F_1 hybrids for the fruit yield and quality traits suggest an involvement of dominance (non-additive) genes in controlling these traits and the possibility of improving them by using an effecting crossing program. On the contrary, negative BPH might be due to the recessive alleles [9].

Development of improved pepper germplasm by way of cross-breeding two superior individuals can often produce high yielding and better quality hybrid. In most cases, reports indicate a successful achievement is due to an advertent scheme by breeders exploiting a worthwhile amount of heterosis present when two pepper individuals are brought together [42]. The estimated positive heterosis for fruit yield and quality traits in this study may be a breeding advantage to get higher yield and quality. No particular evaluated hybrid could be used to estimate BPH and EH for the studied traits with equal efficiencies. However, hybrids of $P_2 \times P_3$ and $P_2 \times P_4$ had the highest positive EH of TY, AFW and FD and good positive EH of FD, PT and TSS, therefore, can be used as commercial hybrids after their evaluation on large scale.

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