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Potential Adoption of the F_2 Generation of Some TYLCV-Resistant Tomato Hybrids for Commercial Production under Natural Field Infection

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THE ECONOMIC feasibility of using the tomato yellow leaf curl virus (TYLCV) resistant F_1 tomato hybrids (*Solanum lycopersicum* L.) may be improved by using their F_2 generation in commercial production. Hence, this study was performed to evaluate the F_1 and F_2 generations of 15 TYLCV-resistant/tolerant commercial tomato hybrids during the 2018 and 2019 fall seasons to identify the best hybrids and F_2 populations for commercial production. Both F_1 and F_2 populations were evaluated separately for TYLCV-resistance, yield, and fruit quality traits. Broad sense heritability (H^2_b) values of TYLCV-resistance were high, being > 60% in hybrids 186, Goldstone, Rabha, SV0922, and SV8320 in both seasons. F_1 and F_2 populations of '186', 'Dania', 'PS550', 'Rozalina', 'SV0922', 'SV8320', and 'Tyrmes' had the highest total yield (TY)/plant, low TYLCV disease (TYLCVD) mean scores, acceptable fruit quality traits, and average fruit weight > 80 g. Desirable inbreeding depression (ID) values were observed for TYLCVD-mean score in F_2 populations of most evaluated hybrids; for TY/plant in F_2 populations of 'SV3773' in both seasons, and in populations of '186', '448', 'Goldstone', 'Rabha', 'SV8320' and 'SV0922' in the second season. Most hybrids had desirable significant ID values for fruit quality traits. Accordingly, it is concluded that the F_2 populations of hybrids 186, SV0922, and SV8320 may be used in commercial tomato production under TYLCV-infection in the fall season.

Keywords: Fruit quality, Heritability, Inbreeding depression, *Solanum lycopersicum*, Yield.

Introduction

Tomato (*Solanum lycopersicum* L.) is an economically and nutritionally important solanaceous fruit vegetable grown worldwide under open fields and protected cultivation. Egypt ranks fifth in production globally, and in 2018 reached 6,624,733 tons from 385,004.8 feedens with an average of 17.21 tons/fed. (<http://faostat.fao.org>). Tomato is susceptible to more than 200 diseases, causing yield losses ranging from 71 to 95%. Tomato yellow leaf curl virus (TYLCV; genus: *Begomovirus*; family: *Geminiviridae*) is the most devastating virus, as it causes yield losses of up to 100%. The tomato yellow leaf curl disease (TYLCD) occurs worldwide and spreads in tomato cultivation in protected and open field cultures (Lapidot & Polston, 2006). The whitefly exclusively transmits TYLCV (*Bemisia tabaci* Genn. and *B. argentifollii*: *B. tabaci* biotype B; Homoptera: Aleyrodidae), widely distributed globally.

Various strategies have been pursued to control the disease and decrease losses, mostly emphasizing vector control. However, control efficiency is often insufficient, and economic losses are incurred (Polston & Anderson, 1997). Therefore, the best way to reduce yield losses inflicted by TYLCD and to reduce the spread of the virus is using virus-resistant tomato cvs, as their use is perhaps the

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easiest, safest, most practical, and best environment-friendly method for controlling this viral disease (Lapidot & Friedmann, 2002). Therefore, breeding for TYLCV-resistance has been one of the most important goals of tomato breeding.

Initially, no TYLCD-resistance was found in cultivated *S. lycopersicum* (Nariani & Vasudera, 1963; Pilowsky & Cohen, 1974; El-Hammady et al., 1976; Hassan et al., 1991), but resistance was found in several accessions of the wild relatives (Nariani & Vasudera, 1963; Pilowsky & Cohen, 1974; El-Hammady et al., 1976; Hassan et al., 1991; Laterrot, 1992; Laterrot & Moretti, 1996; Hassan & Abdel-Ati, 1999; Abdel-Ati, 2008). The urgency to solve the TYLCV problem led to satisfactory introgression of TYLCV-resistant genes from some wild relatives. Recently, several resistant/tolerant F_1 hybrids have been released for commercial production by international seed companies (Vidavski, 2007; Vidavski et al., 2008). In Egypt, commercial tomato production is based on high cost imported hybrid seeds. Therefore, using selected F_2 hybrids with consistent yield and quality has become imperative, but segregation in an F_2 generation could impose problems. However, many reports indicated no statistically significant differences between F_1 and F_2 populations for yield (Dagade et al., 2015) and fruit quality as average fruit weight (Stommel, 2001; Rodríguez et al., 2010) and TSS (Rodríguez et al., 2010). Also, Bhnan (2002) and Kumar & Singh (2016) reported that the inbreeding depression (ID) in some produced hybrids was not significant for yield and fruit quality. However, this approach has not been discussed in earlier studies. Hence, this study aimed to evaluate the F_1 and F_2 generations of some TYLCV- resistant/tolerant commercial tomato hybrids under fall season conditions to identify the best hybrids and F_2 populations for commercial production.

Materials and Methods

This study was conducted during the period from 2017 to 2020 at the Agricultural Experiment Station (AES) of the Faculty of Agriculture, Cairo University, Giza, Egypt (30°01′07″N; 31°12′28″E).

Tomato cultivars

Fifteen commercial TYLCD- resistant/tolerant tomato hybrids (Table 1) were selected to evaluate their F_1 and F_2 populations for TYLCV--resistance/tolerance and productivity under fall season conditions. The F_2 populations were produced by self-crossing eight hybrid plants under greenhouse conditions at AES during the 2017 winter planting.

TABLE 1. Characteristics of the F1 tomato commercial hybrids

Hybrid	Source	Phenotype[z]
186	Hazera	Determinate and TYLCV-resistant.
448	Syngenta	Determinate and highly tolerant to TMV, fusarium and verticillium wilts.
65010	Syngenta	Determinate and resistant to TYLCV, fusarium (F-1 and F-2) and verticillium wilt.
Brivio	Monsanto	Determinate and TYLCV-resistant.
Dania	Nikrson Zwan	Determinate, TYLCV-resistant, and sensitive to soil fungi.
Goldstone	Nenhumis	Determinate and TYLCV-resistant.
Nairouz (TH99806)	Syngenta	Determinate; highly tolerant to TMV, verticillium and fusarium wilts; and TYLCV-moderately tolerant.
Rabha	Syngenta	Determinate; tolerant to TYLCV and TOMV; and highly tolerant to fusarium.
Rozalina 903	Zerium	Indeterminate and resistant to TYLCV, fusarium (I-1 and I-2), verticillium (Ve), and TMV.
Tyrmes	Syngenta	Indeterminate; and highly tolerant to verticillium and fusarium wilts (*I-1* and *I-2*), and TMV (*Tm-2*); and TYLCV-moderately resistance/tolerance.
PS 550	Monsanto	Determinate and tolerant to TYLCV, TMV, and nematode.
SV0922	Seminis	Determinate and TYLCV-resistant.
SV3773	Seminis	Determinate and TYLCV-resistant.
SV 8320	Seminis	Indeterminate and tolerant to fusarium wilt, verticillium wilt, powdery mildew, and TYLCV.
V262	Vilmorin	Determinate; TYLCV-resistant; and moderately tolerant to nematodes.

[z]Phenotype are based on pamphlets of producing companies.

Planting and experimental design

Seeds of the thirty populations (15 F_1's and 15 F_2's) were sown on July 1, 2018, and June 1, 2019, in seedling trays (209 cells) filled with a mixture enriched with macro and microelements under seran-house conditions. With three replicates, five-week-old seedlings were field-transplanted in a randomized complete block design (RCBD - Singh and Choudhary, 1979). Each experimental unit (EU) consisted of two rows/F_1 population and five rows/ F_2 population. Each row was 1 m wide and 3 m long. Plants were set 50 cm apart and subjected to the common agricultural practices without applying insecticides.

TYLCV inoculation

TYLCV is transmitted to plants naturally by the whitefly (*Bemisia tabaci* Genn; Homoptera: *Aleyrodidae*), which flourishes widely from April through November, with a peak from August to October (Shaheen, 1983). Therefore, virus inoculation depended on natural infection with viruliferous whiteflies in both nursery and field (Fig. 1) without using insecticides.

Characters measured

Level of TYLCV resistance

Data on TYLCVD-resistance were recorded for individual plants three months after transplanting on a 1–5 scale as described by Chagué et al. (1997), depending on the severity of TYLCV symptoms. Individual plant ratings of each accession were added and divided by the number of evaluated plants to obtain the corresponding mean disease score.

Yield and fruit quality traits

Yield (early: the first two harvests; and total: all collected fruits) and fruit quality traits (average fruit weight: AFW; fruit firmness: FF; fruit shape index: FSI; and contents of TSS%, titratable acidity: TA; and ascorbic acid: AAC) were measured. At the peak harvesting period, samples of 20 fully red-ripe fruits from each EU were harvested, weighed to estimate AFW, and washed with distilled water to analyze fruit traits. FSI was calculated as the ratio between polar and equatorial diameters of fruit according to Yeager (1937), where FSI is >1.2 in oval fruits, 0.95–1.2 in round shape, and < 0.95 in oblate fruits. Fruit firmness was determined using a food pressure tester (Force Gage Model M4-200) Mark-10 (Series 4). Then, fruit extract was obtained by blending and filtering the flesh. Total Soluble Solides (TSS) was determined using a hand refractometer. TA was ascertained using 0.1 N NaOH solution and phenolphthalein as indicators. AA was determined using 2, 6 dichlorophenol indophenol dye (AOAC, 1990).

Statistical analysis

Data collected on evaluated traits in the F_1 and F_2 generations during the two fall seasons were statistically analyzed for each generation using MSTAT-C v.2.1 (Michigan State University, Michigan, USA), and mean comparisons were based on least significant differences (LSD) at a 5 % probability level (Steel & Torrie, 1984).

Estimation of genetic parameters

Broad sense heritability

Heritability is the ability to inherit a trait from a selected plant to its generation. In the populations of each hybrid, the F_1 variance is essentially environmental only as all individuals have identical genotypes (homogenous population), and the F_2 variance consists of a combination of environmental and genetic components due to segregations. Hence, F_1 variance was considered as environmental variance (V_e) and F_2 variance as phenotypic variance (V_p), and genotypic variance (V_g) as $V_p – V_e$ (Griffiths et al., 2000). Accordingly, the broad sense heritability (h^2_b) was estimated for the TYLCVD-mean score trait by the equation of Weber & Moorthy (1952) as h^2_b (%) = (V_g/ V_p) × 100. The h^2_b percentage was categorized as demonstrated by Lush (1949), Johnson (1955), and Hanson (1956): low (<30%), moderate (30%–60%), and high (>60%).

Inbreeding depression

The inbreeding depression (ID) in plants reduces the biological fitness and vigor due to the expression of recessive deleterious mutations in homozygotes resulting from selfing individuals (Liedl & Anderson, 1993). The ID of the F_2s populations was calculated according to Mather & Jinks (1971) by using the equation:

$$ID\ \% = \left((\overline{F_1} - \overline{F_2})/\overline{F_1}\right) \times 100;$$

Where, $\overline{F_1}$ and $\overline{F_2}$ are mean performance over replications for each trait of F_1 and F_2, respectively. Test of significance of inbreeding depression is performed by testing the difference $(\overline{F_1}-\overline{F_2})$ using the t test:

$$t = (\overline{F_1} - \overline{F_2})/\sqrt{(MS_e F_1/r) + (MS_e F_2/r)};$$

Where, $\overline{F_1}$ and $\overline{F_2}$: are the mean value of F_1 and F_2

generations, respectively; MS_eF_1: is the mean square of error F_1 analysis of variance; MS_eF_2: is the mean square of error F_2 analysis of variance; and r: is the number of replications. The calculated values of (t) are to be compared with a tabulated value of (t) at 5% level of probability.

Results and Discussion

Both F_1 and F_2 populations were evaluated separately for TYLCV-resistance, yield, and fruit quality traits along with ID values, and h^2_b for TYLCVD-mean scores to determine the possibility of using F_2 populations in commercial production.

TYLCV-resistance

The evaluated tomato germplasm showed a wide range of responses to TYLCV-infection, with significant differences among them (Table 2). TYLCVD-mean scores of the F_1 hybrids ranged from 1.99 to 3.66 and from 1.80 to 4.62 during the first and second seasons. The most promising F_1 hybrids for TYLCV-resistance in the two seasons were '186', '65010', 'Rabha', 'Rozalina', 'Tyrmes', 'SV0922' and 'SV8320'. Their TYLCVD-mean scores ranged from 1.99 to 2.55 and from 1.88 to 2.66 in the first and second seasons, respectively. The F_1 hybrids 448, Brivio, and Goldstone gave the highest TYLCVD-mean scores over the two seasons. Variation in the reaction to TYLCV among hybrids could be due to differences in their genetic backgrounds. Seasonal differences within individual hybrids may be due to seasonal differences in natural inoculum potential and prevailing temperature, as illustrated in Fig. 1. Higher temperatures during the second season contributed to increased viruliferous whitefly activity, and consequently, the TYLCV-mean scores increased.

TYLCVD-mean scores of the F_2 populations ranged from 1.66 to 3.29 and from 2.67 to 3.97 in the two seasons, respectively (Table 2). The Dania F2 population recorded the least TYLCVD-mean scores in both seasons, followed by F2 populations of hybrids 186, 65010, Rabha, Rozalina, SV0922 SV3773, and SV8320 without significant differences among them. F_2 populations of hybrids 448, Brivio, Nairouz, and Goldstone gave the highest TYLCVD-mean scores over the two seasons.

ID values in the first season ranged from −27.03 in the 'Nairouz' population to 37.6 in 'Dania' population. All hybrids recorded non-significant ID values (desirable), except those of hybrids 448 and Dania, which were significant and positive (desirable). In the second season, ID values ranged from −83.3 in the 'Tyrmes' population to 14.1 in '448' population, and all hybrids recorded non-significant values, except those of hybrid 448. In both seasons, significant positive ID values of F_2 populations of '448' were of no value due to their high TYLCVD-mean scores, whereas F_2 population of 'Dania' in the first season was promising, having 1.66 mean score. Based on these results, F_2 populations of '65010', 'Dania', 'Rabha' and 'SV8320' may be promising, according to their acceptable TYLCVD-mean scores (Table 2). Mazyed et al. (2007) found that ID of TYLCV-resistance in some tomato crosses between Favi-9 (TYLCD-resistant), and susceptible cvs Edkawy, Castlerock, Strain B, Peto86, and Marmande were −17.7, −4.82, −27.66, −18.7, and 9.98, respectively. The non-significant ID values of most evaluated hybrids could mean that both of their parents carry TYLCV-resistance genes.

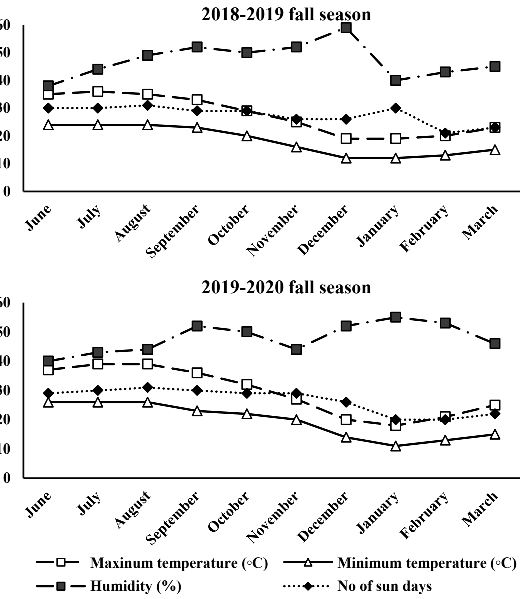

Fig. 1. Average monthly maximum and minimum temperatures, relative humidity, and No. of sunny days during the period from June to March in the 2018 and 2019 seasons [Source: The Egyptian Meteorological Authority (EMA)]

h^2_b of TYLCD-resistance trait ranged from 38.21 to 77.59% in the first season and from 49.12 to 92.58% in the second (Table 2). According to Lush (1949), Johnson et al. (1955), and Hanson et al. (1956), h^2_b values were high, being >60% with hybrids 186, Goldstone, SV0922, and SV8320 in two seasons. Also, h^2_b values were high with hybrids Tyrmes, PS 550, and V262 in the first season; and with hybrids 65010, Brivio, Dania, Nairouz, Rabha, and SV3773 in the second. The present results follow those obtained by Abdel-Ati et al. (2005), who found that h2b was high, being > 67.7% in four crosses between susceptible cv Castlerock and TYLCD-resistant lines being > 63.6% in three resistant × resistant crosses. Mazyed et al. (2007) estimated h^2_b as 55.76, 59.31, 75.64, 83.27, and 88.38% for crosses between the resistant tomato line Favi-9 and susceptible cvs Edkawy, Strain B, Marmmande, Castlerock, and Peto 86, respectively. Mahmoud (2010) found that h^2_b in the cross Castlerock × *S. lycopersicum* var. *flammatum* LYC 179.83 sel was 60.43%. Most of the evaluated genotypes exhibited high h^2_b estimates in two seasons or one season, indicating that the TYLCV-resistance trait is genetically controlled and less affected by the environment. It is worthy of mentioning that hybrids 448 and Rabha in the first season and PS 550 in the second showed nonexplainable negative h^2_b values.

TABLE 2. TYLCV-disease mean scoresz, inbreeding depression (ID[y]), and broad sense heritability (h^2b) values of the evaluated commercial tomato hybrids and their F_2 populations in the 2018 and 2019 fall seasons

Hybrid	F_1	F_2	ID	h^2_b
		2018 fall season		
186	2.49 c-e	2.38 b-e	4.42^{ns}	72.39
448	3.66 a	2.95 a-c	19.40*	-13.24
65010	2.55 b-e	2.15 c-e	15.69^{ns}	48.81
Brivio	3.11 ab	2.83 a-d	9.00^{ns}	44.78
Dania	2.66 b-d	1.66 e	37.59*	51.93
Goldstone	3.65 a	3.13 ab	14.25^{ns}	69.98
Nairouz	2.59 b-d	3.29 a	-27.03^{ns}	58.98
Rabha	2.50 c-e	2.49 a-e	0.40^{ns}	-70.52
Rozalina	1.99 e	1.97 de	1.01^{ns}	40.11
Tyrmes	2.41 c-e	2.43 a-e	-0.83^{ns}	76.51
PS 550	2.62 b-d	2.66 a-d	-1.53^{ns}	67.82
SV0922	2.25 de	2.50 a-e	-11.11^{ns}	77.59
SV3773	2.76b-d	2.53 a-e	8.33^{ns}	38.21
SV8320	2.33 c-e	2.18 c-e	6.44^{ns}	66.92
V262	2.87 bc	2.58 a-d	10.10^{ns}	71.51
$LSD_{5\%}$	**0.502**	**0.756**		
		2019 fall season		
186	2.52 e	3.00 b-e	-19.05^{ns}	60.56
448	4.62 a	3.97 a	14.07*	52.88
65010	1.92 g	2.82 de	-46.88^{ns}	69.08
Brivio	2.94 cd	3.58 ab	-21.77^{ns}	75.39
Dania	2.52 de	2.67 e	-5.95^{ns}	74.67
Goldstone	3.63 b	3.39 a-d	6.61^{ns}	69.98
Nairouz	3.07 c	3.43 a-c	-11.73^{ns}	92.58
Rabha	2.66 c-e	2.88 c-e	-8.27^{ns}	73.10
Rozalina	2.55 de	3.13 b-e	-22.75^{ns}	49.12
Tyrmes	1.80 g	3.30 b-d	-83.33^{ns}	55.45
PS 550	2.87 cd	3.33 b-d	-16.03^{ns}	-9.60
SV0922	2.42 ef	3.04 b-e	-25.62^{ns}	63.23
SV3773	2.84 cd	3.10 b-e	-9.15^{ns}	75.85
SV8320	2.02 fg	2.82 c-e	-39.60^{ns}	68.97
V262	2.67 c-e	3.49 ab	-30.71^{ns}	56.36
$LSD_{5\%}$	**0.351**	**0.503**		

[z]TYLCV disease-mean scores: 1, symptomless; 2, slight; 3, moderate; 4, severe; and 5, very severe symptoms.
[y]ID value: *significant ($P \leq 0.05$) and [ns]non-significant.

Early yield

Significant differences for EY/plant among the evaluated germplasm were detected (Table 3). EY/plant for the F_1 hybrids ranged from 71.7 to 743.7 g; and 10.3 to 934 g in the first and second seasons, respectively. Hybrids 186, Dania, PS550, and V262, had the highest significant EY in both seasons. In the first season, EY/plant of F_2 populations ranged from 53.3 g in F_2 of 'SV3773' to 566.3 g in F_2 of 'Dania'. The F_2 populations of 'Dania' and 'PS 550' recorded the highest significant EY/plant (566.3 and 403.7 g, respectively) without significant differences. The F_2 populations of '186', '448', 'Nairouz', 'Rozalina', 'Tyrmes', 'SV0922' and 'SV8320' ranked second. In the second season, the highest significant EY/plant was given by F_2 populations of hybrids 186 (354.3g), Dania (285.7g), Goldstone (237.3g), Rabha (234g), Nairouz (215.7g), PS 550 (196.3g), Tyrmes (186g) and Brivio (166g) without significant difference among them (Table 3).

Over the two seasons, ID values were positive for all F_2 populations, except populations of 'Rozalina', 'SV0922' and 'SV8320' in the first season, having negative values (Table 3). Over the two seasons, F_2 populations of 448, Rabha, Rozalina, SV0922, SV3773, and SV8320 recorded non-significant positive or negative ID values (desirable). Bhnan (2002) reported that F_2 populations of crosses Supermarmande × VF145-B-7879, Supermarmande × Tivoli, Tivoli × Castlerock, and Supermarmande × Castlerock showed significant positive ID values for EY. Also, Shalaby (2013) reported that ID of EY in tomato cross Castlerock × CLN2498E was 54.2%.

Total yield

Significant differences were found for TY/plant among the evaluated genotypes in both F_1 and F_2 populations (Table 3). TY/plant values of the F_1 hybrids ranged from 684.8 to 2021.5g and from 987.3 to 3154.3g during the first and second seasons, respectively. In the 2018 fall season, F_1 hybrids that produced the highest TY (g/plant) were '186' (2121.5), 'Tyrmes' (1976.8), 'SV8320' (1841.8), 'PS 550' (1757.5), 'Rozalina' (1743.5), 'Dania' (1703.5) and 'V262' (1622.2) without significant differences among them. In the second season, hybrids Dania and Rozalina recorded the highest significant TY/plant values (3154 and 2689 g), followed by hybrids 186, 65010, PS 550 SV0922, SV8320, and V262. TY/plant values for F_2 populations ranged from 355.4 to 1326.9 g and 821.3 to 2652.3 g in the first and second seasons, respectively (Table 3). F_2 populations that produced the highest TY/plant were hybrids 186, Dania, Rozalina, and SV0922 in both seasons; Tyrmes and PS 550 in the first season; and 65010, Goldstone, Rabha, and SV8320 in the second season.

The estimated ID values in the first season ranged from 26.02% in 'SV3773' F_2 population to 59.16% in 'Goldstone' F_2 population. All values were significantly positive, except that of 'SV3773' population, which showed a non-significant positive value, but was of no value due to it is poor TY (506.6 g/plant). In the second season, ID values ranged from −47.1 in 'Goldstone' F_2 population to 67.1% in 'V262' F_2 population. Eight F_2 populations exhibited significant positive ID values, 3 exhibited non-significant negative values (desirable), and 4 exhibited non-significant positive values (desirable) (Table 3). In previous reports, Bhnan (2002) found that F_2 populations of all evaluated tomato crosses showed non-significant ID for TY except in the F_2 of the cross Tivoli × Castlerock, in which significant positive ID was found. Also, Shalaby (2013) reported that ID for TY for tomato cross Castlerock × CLN2498E was 23.0%; and Kumar & Singh (2016) found that ID for yield/plant ranged from −5.94 to 12.50%, and 4 F_2 populations exhibited a desirable negative ID. The ID significance of most evaluated hybrids indicates their parents could have fewer dominant genes that control TY, and thus F_2 segregated a greater number of poor-yielding plants. In contrast, F_2 of some hybrids, *viz.* 186, SV0922, and SV8320, which recorded non-significant ID, contained several high-yielding segregates and possibly resulted from the parents having numerous partially or completely dominant genes for yield.

Fruit quality

Average fruit weight

Significant differences were found for AFW among the evaluated genotypes in both F_1 and F_2 populations, as illustrated in Table 4. AFW of the F_1 hybrids ranged from 71g in 'V262' to 129g in 'SV3773' in the first season and from 76 g in 'V262' to 129g in 'SV3773' in the second. In the first season, the heaviest AFW (g) was produced by F_1 hybrids SV3773 (129.1), 65010 (128.3), Goldstone (128.2), SV8320 (126.9), PS 550 (126.4) and SV0922 (125.4). In the second season, the greatest significant AFW (g) was produced by

'SV3773' (129.0), 'SV0922' (124.0), 'Rabha' (123.5) and 'Rozalina' (118.8). F_2 generations that produced the greatest significant AFW were of hybrids SV3773, SV8320, Goldstone, Rabha, Rozalina, PS 550, and SV0922 in both seasons; Tyrmes in the first season; and 65010 in the second season (Table 4).

Concerning ID values of the evaluated F_2 populations, six populations showed significant positive values, two showed non-significant negative values (desirable), and seven exhibited non-significant positive values (desirable) in the first season. In the second season, two populations showed significant positive values, two showed non-significant negative values (desirable) and 11 showed non-significant positive values (desirable). Most of the evaluated populations showed desirable ID values in both seasons (Table 4). Chauhan et al. (2019) reported that AFW of F_2 population for tomato cross Roma × Cherry was higher than its respective F_1. Kumar & Singh (2016) found that six from 28 F_2 populations showed negative ID for AFW. Also, Shalaby (2013) found a non-significant negative ID value for AFW for tomato cross Castlerock × CLN 2498E; and Bhnan (2002) reported a non-significant positive ID value for AFW in the F_2 of the cross VF145-B-B7879 × Castlerock.

Firmness

Significant differences for FF among the evaluated hybrids were detected in both seasons as illustrated in Table 4. FF of F_1 hybrids ranged from 2.23 to 3.63 kg/cm^2 and from 2.40 to 3.63kg/cm^2 in the first and second seasons. F_1 hybrids which produced the highest FF were 65010, Rabha, Rozalina, Tyrmes, SV8320, and V262 in both seasons; 186, Brivio, Dania, and PS 550 in the first season; and SV0992 in the second season. FF of the F_2 populations ranged from 2.11 to 2.89 kg/cm^2 in the first season and 2.4 to 3.4 kg/cm^2 in the second (Table 4). 13 out of the 15 evaluated F2 populations had the highest FF values in the first season and were not significantly different. In the second season, F_2 populations of hybrids 186, 65010, Brivio, Nairouz, Rozalina, Tyrmes, SV0922, and SV8320 had the highest significant FF values.

In both seasons, 10 out of the 15 evaluated F_2 populations exhibited non-significant positive or negative ID values (desirable) for FF trait, i.e., F_1 and F_2 of a given hybrid were not significantly different in FF. These results partly agree with those of Bhnan (2002) who found that all F_2 populations showed non-significant ID for fruit firmness except the F_2 of the cross Tivoli × Castlerock which was significantly positive; while Shalaby (2013) reported that ID for tomato cross Castlerock × CLN 2498E was non-significantly negative in FF.

Shape index

Significant differences for FSI among the evaluated germplasm were detected (Table 4). According to FSI values, hybrids 186, Dania and V262 produced oval fruits; hybrids Brivio and Nairouz produced round fruits, and the remaining hybrids had oblate fruits. However, in every hybrid, FSI was similar in both seasons. In addition, fruits of every F_1 hybrid were similar in FSI to those of their F_2s. These results were confirmed with non-significant ID values in the two seasons (Table 4).

Total soluble solids

Table 5 showed significant differences among the evaluated germplasm in fruit TSS content during the evaluation seasons. Fruit TSS content of the F_1s ranged from 4.07 to 5.57 ◦Brix in the first season and 5.73 to 7.27 ◦Brix in the second. F_1 hybrids that produced fruits with the highest significant TSS without significant differences were hybrids 186, Brivio, PS 550 and SV8320; 448, SV0922 and Tyrmes in the first; and 65010, Dania, Goldstone, and Nairouz in the second season. Fruit TSS content in the F_2 populations ranged from 4.2 to 5.8 ◦Brix in the first season and 6.0 to 7.2 ◦Brix in the second. In the first season, all populations had high fruit TSS and were not significantly different in their TSS content, except for F_2 of hybrids Brivio and SV8320, which were significantly inferior in their fruits TSS content (Table 5).

ID values of the evaluated F_2 populations ranged from −48.7 to 21.2%; and −5.6 to 7.95% in the first and second seasons, respectively (Table 5). In both seasons, F_1 and F_2 of all hybrids were not significantly different in fruit TSS content, except for hybrid Brivio in the first season and hybrid SV8320 in both seasons, which showed significant positive ID values. This means that F_2 populations of most of the evaluated hybrids are promising regarding fruit TSS content. Shalaby (2013) found that ID for TSS for tomato cross Castlerock × CLN2498E was 8.51%.

TABLE 3. Early and total yield (g/plant) and inbreeding depression (ID[z]) values of the evaluated commercial tomato hybrids and their F_2 populations in the 2018 and 2019 fall seasons

Hybrid	Early yield (g/plant)			Total yield (g/plant)		
	F_1	F_2	ID	F_1	F_2	ID
			2018 fall season			
186	732.7 a	345.3 bc	52.87*	2021.5 a	1326.9 a	34.36*
448	486.3 b-d	343.0 bc	29.47ns	1354.1 cd	897.3 b-e	33.73*
65010	383.3 de	166.0 d-g	56.69*	1406.1 b-d	717.2 d-g	48.99*
Brivio	470.3 b-d	150.3 e-g	68.04*	1224.9 de	580.5 e-g	52.61*
Dania	648.3 a-c	566.3 a	12.65ns	1703.5 a-c	1214.0 ab	28.73*
Goldstone	464.3 b-d	28.7 g	93.82*	870.2 ef	355.4 g	59.16*
Nairouz	388.7 de	287.3 b-e	26.09ns	1253.3 de	732.4 d-f	41.56*
Rabha	304.7 d-f	185.0 c-g	39.28ns	1311.6 c-e	860.2 b-f	34.42*
Rozalina	236.7 e-g	331.3 b-d	-39.97ns	1743.5 a-c	1115.6 a-c	36.01*
Tyrmes	447.7 cd	274.0 b-e	38.80*	1976.8 a	1008.9 a-d	48.96*
PS 550	743.7 a	403.7 ab	45.72*	1757.5 a-c	1110.3 a-c	36.83*
SV0922	144.7 fg	293.0 b-e	-102.49ns	1469.7 b-d	1047.1 a-d	28.75*
SV3773	71.7 g	53.3 fg	25.66ns	684.8 f	506.6 fg	26.02ns
SV8320	172.3 fg	272.0 b-e	-57.86ns	1841.8 ab	947.6 b-e	48.55*
V262	673.3 ab	220.7 c-f	67.22*	1622.2 a-d	767.1 c-f	53.85*
$LSD_{5\%}$	**209.6**	**175**		**372.35**	**310.52**	
			2019 fall season			
186	847.7 a	354.3 a	58.20*	2519.0 bc	2501.0 a	0.71ns
448	351.0 b-d	106.7 bc	69.60ns	987.3 d	1085.0 b-d	-9.90ns
65010	217.0 cd	16.0 c	92.63ns	2552.7 bc	1832.7 a-c	28.21*
Brivio	523.7 a-c	166.0 a-c	68.30*	2284.3 bc	1047.7 b-d	54.13*
Dania	938.0 a	285.7 ab	69.54*	3154.3 a	1700.7 a-d	46.08*
Goldstone	321.0 cd	237.3 ab	26.07ns	1244.7 d	1831.0 a-c	-47.10ns
Nairouz	574.0 a-c	215.7 ab	62.42*	2203.7 bc	1350.3 b-d	38.73*
Rabha	309.7 cd	234.0 ab	24.44ns	2119.0 c	1948.3 ab	8.06ns
Rozalina	210.7 cd	121.3 bc	42.43ns	2689.0 ab	1878.7 ab	30.13*
Tyrmes	232.7 cd	186.0 a-c	20.07ns	2073.0 c	1316.3 b-d	36.50*
PS 550	782.0 ab	196.3 a-c	74.90*	2478.7 bc	1479.7 b-d	40.30*
SV0922	42.0 d	9.7 c	76.90ns	2355.7 bc	1943.3 ab	17.51ns
SV3773	10.3 d	7.7 c	25.24ns	995.7 d	821.3 d	17.52ns
SV8320	207.7 cd	118.0 bc	43.19ns	2203.0 bc	2652.3 a	-20.39ns
V262	769.3 ab	146.0 bc	81.02*	2550.3 bc	840.3 cd	67.05*
$LSD_{5\%}$	**447**	**195.9**		**471.03**	**835.24**	

[z]ID value: *significant (P≤0.05) and [ns]non-significant.

TABLE 4. Average fruit weight (AFW), fruit shape index (FSI), fruit firmness (FF), and inbreeding depression (ID[z]) values of the evaluated commercial tomato hybrids and their F_2 populations in the 2018 and 2019 fall seasons

Hybrid	AFW (g)			FSI			FF (kg/cm²)		
	F_1	F_2	ID	F_1	F_2	ID	F_1	F_2	ID
					2018 fall season				
186	97.7 f	89.6 de	8.29^{ns}	1.17 b	1.20 a	-2.56^{ns}	3.21 a-c	2.13 b	33.64*
448	122.9 c-e	111.9 bc	8.95*	0.88 e	0.87 d	1.14^{ns}	2.65 b-d	2.58 ab	2.64^{ns}
65010	128.3 ab	105.4 cd	17.85*	0.82 e	0.86 d	-4.88^{ns}	3.12 a-d	2.11 b	32.37*
Brivio	96.4 f	79.4 e	17.63*	1.00 cd	1.0 bc	0.00^{ns}	2.87 a-d	2.55 ab	11.15^{ns}
Dania	96.3 f	90.1 de	6.44^{ns}	1.22 ab	1.21 a	0.82^{ns}	3.57 ab	2.68 ab	24.65*
Goldstone	128.2 ab	121.7 ab	5.07^{ns}	0.84 e	0.88 cd	-4.76^{ns}	2.57 cd	2.67 ab	-4.28^{ns}
Nairouz	89.7 g	78.5 e	12.49*	1.03 c	1.05 b	-1.94^{ns}	2.52 cd	2.43 ab	3.57^{ns}
Rabha	121.7 de	114.5 a-c	5.92^{ns}	0.87 e	0.86 d	1.15^{ns}	2.82 a-d	2.34 ab	17.02^{ns}
Rozalina	123.8 b-d	124.3 ab	-0.40^{ns}	0.84 e	0.82 d	2.38^{ns}	2.88 a-d	2.49 ab	13.54^{ns}
Tyrmes	118.6 e	116.0 a-c	2.36^{ns}	0.84 e	0.83 d	1.19^{ns}	2.86 a-d	2.70 ab	5.59^{ns}
PS 550	126.4 a-d	115.6 a-c	8.54*	0.78 e	0.80 d	-2.56^{ns}	2.75 a-d	2.42 ab	12.00^{ns}
SV0922	125.4 a-d	118.2 a-c	5.74^{ns}	0.89 de	0.82 d	7.87^{ns}	2.41 cd	2.88 a	-19.50^{ns}
SV3773	129.1 a	128.9 a	0.15^{ns}	0.87 e	0.85 d	2.30^{ns}	2.23 d	2.69 ab	-20.63^{ns}
SV8320	126.9 a-c	117.4 a-c	7.49*	0.82 e	0.86 d	-4.88^{ns}	3.57 ab	2.57 ab	28.01*
V262	71.4 h	82.2 e	-15.13^{ns}	1.31 a	1.30 a	0.76^{ns}	3.63 a	2.89 a	20.39*
$LSD_{5\%}$	**4.22**	**13.23**		**0.05**	**0.1**		**0.77**	**0.49**	
					2019 fall season				
186	98.3 de	87.6 cd	10.89^{ns}	1.20 b	1.27 b	-5.83^{ns}	3.13 b-f	3.30 ab	-5.33^{ns}
448	99.2 de	92.3 bc	7.03^{ns}	0.92 d	0.96 de	-4.35^{ns}	2.87 e-h	2.57 de	10.46^{ns}
65010	110.4 cd	121.4 a	-9.92^{ns}	0.85 d-f	0.83 f	2.35^{ns}	3.43 a-d	3.10 a-c	9.70^{ns}
Brivio	87.3 ef	83.6 cd	4.34^{ns}	1.04 c	1.06 c	-1.92^{ns}	2.60 gh	2.93 a-d	-12.81^{ns}
Dania	86.1f	80.9 cd	5.95^{ns}	1.25 b	1.28 b	-2.40^{ns}	2.97 d-g	2.70 c-e	9.00^{ns}
Goldstone	114.7 bc	112.7 a	1.77^{ns}	0.89 de	0.90 ef	-1.12^{ns}	3.03 c-g	2.40 e	20.87^{ns}
Nairouz	79.4 f	75.2 d	5.25^{ns}	1.05 c	1.00 cd	4.76^{ns}	2.67 f-h	3.03 a-d	-13.72^{ns}
Rabha	123.5 ab	117.3 a	4.97^{ns}	0.86 d-f	0.90 ef	-4.65^{ns}	3.63 a	2.83 b-e	22.02^{ns}
Rozalina	118.8 a-c	117.1 a	1.49^{ns}	0.80 f	0.85 f	-6.25^{ns}	3.43 a-d	3.27 ab	4.84^{ns}
Tyrmes	115.4 bc	94.2 bc	18.37*	0.83 ef	0.86 f	-3.61^{ns}	3.47 a-c	3.40 a	1.93^{ns}
PS 550	113.7 bc	107.8 ab	5.26^{ns}	0.83 ef	0.83 f	0.00^{ns}	2.87 e-h	2.63 c-e	8.16^{ns}
SV0922	124.0 ab	110.6 a	10.74*	0.86 d-f	0.87 ef	-1.16^{ns}	3.57 ab	3.00 a-d	15.90^{ns}
SV3773	129.0 a	123.3 a	4.45^{ns}	0.86 d-f	0.84 f	2.33^{ns}	2.40 h	2.70 c-e	-12.50^{ns}
SV8320	116.8 bc	119.8 a	-2.60^{ns}	0.83 ef	0.85 f	-2.41^{ns}	3.40 a-d	3.07 a-c	9.79^{ns}
V262	75.7 f	73.4 d	3.22^{ns}	1.40 a	1.39 a	0.71^{ns}	3.20 a-e	2.90 b-d	9.38^{ns}
$LSD_{5\%}$	**10.1**	**13.14**		**0.062**	**0.076**		**0.39**	**0.39**	

[z]ID value: [*]significant (P≤0.05) and [ns]non-significant.

TABLE 5. Fruit total soluble solids (TSS) content, ascorbic acid (AC), titratable acidity (TA), and inbreeding depression (ID[z]) values of the evaluated commercial tomato hybrids and their F_2 populations in the 2018 and 2019 fall seasons

Hybrids	TSS (◦Brix)			ACC (mg/100g fresh fruit)			TAC (mg citric acid/100g fresh fruit)		
	F_1	F_2	ID	F_1	F_2	ID	F_1	F_2	ID
2018 fall season									
186	5.00 a-c	4.98 a-c	0.60ns	8.89 b-e	9.313 b-d	-4.72ns	0.42 d	0.54 bc	-28.57ns
448	5.00 a-c	5.17 a-c	-3.40ns	13.44 a	13.23 a	1.56ns	0.62 ab	0.64 a-c	-3.23ns
65010	4.83 bc	5.73 a	-18.63ns	10.37 bc	8.99 b-d	13.31ns	0.44 cd	0.52 bc	-18.18ns
Brivio	5.33 a-c	4.20 c	21.20*	9.21 b-e	7.51 c-e	18.46ns	0.64 a	0.54 bc	15.63ns
Dania	4.10 de	5.30 ab	-29.27ns	8.04 d-f	10.58 ab	-31.59ns	0.59 a-c	0.49 c	16.95ns
Goldstone	4.67 cd	4.83 a-c	-3.43ns	7.41 ef	8.78 b-d	-18.49ns	0.47 b-d	0.67 bc	-31.91ns
Nairouz	3.90 e	5.80 a	-48.72ns	6.56 f	7.46 de	-13.72ns	0.52 a-d	0.64 ac	-23.08ns
Rabha	4.67 cd	5.33 ab	-14.13ns	10.27 b-d	9.10 b-d	11.39ns	0.57 a-d	0.67 ab	-17.54ns
Rozalina	4.07 de	5.77 a	-41.77ns	9.52 b-e	5.39 e	43.38*	0.57 a-d	0.79 a	-38.60ns
Tyrmes	5.57 a	5.23 a-c	6.10ns	9.10 b-e	9.42 b-d	-3.52ns	0.52 a-d	0.49 c	5.77ns
PS 550	5.17 a-c	5.00 a-c	3.29ns	9.74 b-d	8.04 b-e	17.45ns	0.57 a-d	0.64 a-c	-12.28ns
SV0922	5.27 a-c	5.10 a-c	3.23ns	8.36 c-f	10.48 a-c	-25.36ns	0.49 a-c	0.49 c	0.00ns
SV3773	4.83 bc	5.20 a-c	-7.66ns	9.95 b-d	8.87 b-d	10.65ns	0.54 a-d	0.63 bc	-16.67ns
SV8320	5.50 ab	4.52 bc	17.82*	8.78 b-f	9.10 b-d	-3.64ns	0.62 ab	0.49 c	20.97ns
V262	4.70 cd	5.23 a-c	-11.28ns	10.79 b	9.52 b-d	11.77ns	0.42 d	0.64 a-c	-52.38ns
$LSD_{5\%}$	**0.561**	**0.761**		**1.92**	**2.47**		**0.129**	**0.132**	
2019 fall season									
186	6.93 ab	6.97 a-c	-0.58ns	20.50 a-c	13.70 b	33.17*	0.27 fg	0.30 de	-11.11ns
448	6.03 de	6.37 c-f	-5.64ns	17.40 c-f	16.00 ab	8.05ns	0.39 d-f	0.52 a-c	-33.33ns
65010	7.27 a	6.80 a-e	6.46ns	15.67 d-f	16.73 ab	-6.76ns	0.54 a-c	0.49 a-d	9.26ns
Brivio	6.93 ab	6.90 a-d	0.43ns	16.20 c-f	17.30 ab	-6.79ns	0.42 c-e	0.34 c-e	19.05ns
Dania	6.77 a-c	6.40 b-f	5.47ns	23.83 ab	14.57 b	38.86*	0.52 a-d	0.25 e	51.92*
Goldstone	6.70 a-c	6.23 ef	7.01ns	17.83 c-e	12.83 b	28.04*	0.32 e-g	0.42 a-e	-31.25ns
Nairouz	7.03 ab	7.20 a	-2.42ns	16.00 c-f	13.43 b	16.06ns	0.44 b-e	0.59 ab	-34.09ns
Rabha	5.97 de	6.17 ef	-3.35ns	15.47 d-f	14.67 b	5.17ns	0.25 g	0.39 b-e	-56.00ns
Rozalina	6.27 c-e	6.07 f	3.19ns	16.27 c-f	16.00 ab	1.66ns	0.47 a-d	0.42 a-e	10.64ns
Tyrmes	6.30 c-e	6.53 b-f	-3.65ns	18.73 c-e	14.77 b	21.14*	0.32 e-g	0.30 de	6.25ns
PS 550	6.80 a-c	7.03 ab	-3.38ns	19.27 b-d	19.80 a	-2.75ns	0.42 c-e	0.62 a	-47.62ns
SV0922	6.53 b-d	6.27 d-f	3.98ns	12.90 f	12.97 b	-0.54ns	0.57 ab	0.35 c-e	38.60*
SV3773	5.73 e	6.00 f	-4.71ns	14.50 ef	13.47 b	7.10ns	0.59 a	0.57 ab	3.39ns
SV8320	7.17 a	6.60 a-f	7.95*	17.77 c-e	12.93 b	27.24*	0.40 d-f	0.40 b-e	0.00ns
V262	5.93 e	6.13 f	-3.37ns	23.97 a	16.57 ab	30.87*	0.32 e-f	0.25 e	21.88ns
$LSD_{5\%}$	**0.479**	**0.541**		**3.83**	**4.02**		**0.108**	**0.176**	

[z]ID value: *significant ($P \leq 0.05$) and [ns]non-significant.

Ascorbic acid content

Significant differences for AAC among the evaluated hybrids were detected (Table 5). Fruit AAC of the evaluated F_1 hybrids ranged from 6.56 to 13.44mg /100g fresh weight in the first season and from 12.90 to 23.97 in the second, as shown in Table 9. The highest significant AA content value was recorded in fruits of '448' (13.44mg/100g fresh fruit), followed in a descending order by 'V262' (10.79), '65010' (10.37), 'Rabha' (10.27), 'SV3773' (9.95), 'PS 550' (9.74) and 'Rozalina' (9.52mg/100g fresh fruit). In the second season, the highest significant AA content values were recorded in fruits of 'V262', 'Dania' and '186' (23.97, 23.83 and 20.50mg/100g, respectively), followed significantly by 'PS 550', 'Tyrmes', 'Goldstone' and 'SV8320'. The highest significant AAC values in F_2 populations were recorded in fruits of F_2 populations of hybrids 448, Dania, and SV0922 (respectively, 13.23, 10.58, and 10.48mg/100g fresh fruit). In the second season, fruits of the F_2 population of "PS 550" had the highest AAC without significant difference from F_2 populations of ‘V262’, ‘Rozalina’, ‘448’, ‘65010’ and ‘Brivio’ (Table 5).

According to ID values for AAC, no significant differences between F_1 and F_2 of each hybrid were estimated for all populations in both seasons, except ‘Rozalina’ populations in the first season and populations of ‘186’, ‘Dania’, ‘Goldstone’, ‘Tyrmes’, ‘SV8320’, and ‘V262’ in the second (Table 5).

Titratable acidity

Significant differences for TA among the evaluated hybrids were detected (Table 5). Values of TA ranged from 0.42 to 0.64mg citric acid/100g fresh weight; and from 0.25 to 0.59mg citric acid/100g, in the first and second seasons, respectively. Eleven out of the 15 F_1 hybrids evaluated in the first season had high TA values without significant differences. In the second season, the highest significant TA (mg citric acid/100g) fresh fruit values were found in hybrids 65010 (0.54), Dania (0.52), Rozalina (0.47), SV0922 (0.57) and SV3773 (0.59). TA values of F_2 populations ranged from 0.44 to 0.79; and from 0.25 to 0.62 mg citric acid/100 g fresh fruit in the first and second seasons, respectively. F_2 populations that produced the highest significant TA values were hybrids Rozalina, PS 550, 448, and Nairouz in both seasons; Rabha and V262 in the first season; and 65010, Goldstone, and SV3773 in the second season (Table 5).

In both seasons, ID values for TA were non-significant (desirable) for all evaluated F_2 populations, except F_2 of hybrids Dania and SV0922 in the second season, which gave significant, positive ID.

Tomato breeding programs for TYLCV-resistance were directed toward developing superior F_1 hybrids for their hybrid vigor. Growers prefer hybrids over pure line varieties because of their maturity, earliness, uniformity, disease resistance, and superiority of marketable fruit yield and fruit quality (Vidavski, 2007). Commercial tomato production in Egypt, especially in the summer and fall seasons which suffer from heavy TYLCV-infection, depends on the imported F_1 hybrids at a high cost. However, the high price of seeds of F_1 hybrid cultivars limits their use. The economic feasibility of using the imported hybrids would be improved by using their F_2 generation in commercial production. However, segregation that occurs in an F_2 generation could impose problems. Therefore, using selected F_2 hybrids with consistent yield and quality has become imperative. The F_2s of hybrid cultivars have not received much attention to providing cost effective hybrid vegetable cultivars. This may be attributed to the fact that F_2 populations have a reputation for low yield and unacceptable uniformity of fruit quality. Nevertheless, the cost of F_2 seeds should be considerably less than that of F_1 hybrid cultivars because it can be produced by open-pollination without the precaution against selfing or sibbing required for producing F_1 hybrid cultivar seeds. The retail seed cost of these F_2 populations is less than one-half the price of a comparative F_1 hybrid cultivar. In vegetable crops, few F_2 cultivars are merchandized.

In the present study, F_1 hybrids Dania, Rozalina, 186, 65010, Tyrmes, SV0922, PS550, SV8320, and V262 had the highest TY/plant, low TYLCVD-mean scores, acceptable fruit quality, and AFW > 80 g, except ‘V262’ which had AFW about 70 g in both seasons. Therefore, these F_1 hybrids may be suitable for tomato production during the fall seasons when severe TYLCV-infection occurs. F_2 populations of ‘186’, ‘Dania’, ‘Rozalina’, ‘SV0922’, ‘Rabha’, ‘Tyrmes’, ‘PS 550’, and ‘SV8320’ had high TY/plant; low TYLCVD-mean scores; AFW > 80g; and acceptable fruit quality.

Inbreeding depression is a key criterion in the crop breeding program. Due to minimal genetic load in self-pollinated species like tomatoes, low inbreeding depression is observed (Voillemot & Pannell, 2017). Therefore, the ID observed in this study is assumed not to be due to the expression of deleterious homozygous alleles as a case in cross-pollinated crops (Burton & Brownie, 2006). Desirable ID values were observed for TYLCVD-mean scores in F_2 populations of most evaluated hybrids; for TY/plant in F_2 populations of ‘SV3773’ in both seasons, and in populations of ‘186’, ‘448’, ‘Goldstone’, ‘Rabha’, ‘SV8320’ and ‘SV0922’ in the second season; for EY/plant in F_2 populations of ‘448’, ‘Rabha’, ‘Rozalina’, ‘SV0922’, ‘SV3773’, and ‘SV8320’; for AFW in F_2 populations of ‘186’, ‘Dania’, ‘Goldstone’, ‘Rabha’, ‘Rozalin’, ‘SV3773’, and ‘V262’; for FF in all evaluated hybrids, except those of ‘186’, ‘Dania’, ‘SV8320’, and ‘V262’; for fruit TSS in all evaluated hybrids, except those of ‘SV8320’ and ‘Brivio’; for fruit AA content in F_2 of ‘448’, ‘65010’, ‘Brivio’, ‘Nairouz’, ‘Rabha’, ‘PS550’, 'SV0922', and 'SV3773'; and for fruit TA content in F_2 populations of all evaluated hybrids except those of 'Dania' and 'SV0922'. The F_1 and F_2 populations of hybrids 186, SV0922, and SV8320 recorded high heritability value (h^2_b) of TYLCV-resistance trait; significant values of TYLCVD-mean scores, yield, and fruit quality traits; and desirable significant ID for these traits. Therefore, they may be used in commercial tomato production in the fall season under severe TYLCV-infection. These results are consistent with those of Bhnan (2002), who recommended F_2 generation for some evaluated tomato hybrids in commercial production when they record desirable ID values for yield and some fruit quality traits.

Conclusion

This approach is new and benefits from the available commercial F_1 hybrids. The economic feasibility of some tomato TYLCV-resistant hybrids could be increased by using their F_2 populations in commercial production. Continuous efforts are needed to evaluate F_2 populations of different tomato hybrids in several locations and seasonal conditions to select highly suitable hybrids for each location and season.

Conflicts of interest: No conflicts of interest have been declared.

Author contribution: Hassan and Abdel-Ati contributed to define the study idea and objectives; plan the practical experiment; and write the manuscript. Mahmoud and Mohamed contributed to plant the practical experiment, data collection, statistical analysis for data, and write the manuscript.

Ethical approval: Not applicable

List of abbreviations

AAC	:	Ascorbic acid content.
AES	:	Agricultural experiment station.
AFW	:	Average fruit weight.
BSH (h^2_b)	:	Broad sense heritability.
cvs	:	Cultivars
EU	:	Experimental unit.
EY	:	Early yield.
F_1, F_2	:	First and second Filial generations
FSI	:	Fruit shape index.
FF	:	Fruit firmness
ID	:	Inbreeding depression
RCBD	:	Randomized complete block design.
TA	:	Titratable acidity.
TLCV	:	Tomato leaf curl virus.
TSS	:	Total soluble solids.
TY	:	Total yield.
TYLCD	:	Tomato yellow leaf curl disease.
TYLCV	:	Tomato yellow leaf curl virus.

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تبى قدرة الجيل الهجينى الثانى (F_2) لبعض هجن الطماطم المقاومة لفيروس TYLCV فى الإنتاج التجارى تحت ظروف العدوى الطبيعية بالحقل

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يمكن تحسين الجدوى الإقتصادية لهجن الطماطم التجارية المقاومة لفيروس إصفرار وتجعد أوراق الطماطم (TYLCV) بإستخدام الجيل الثانى (F_2) لها فى الإنتاج التجارى. ولذلك أجريت هذه الدراسة لتقييم الجيلين الأول (F_1) والثانى (F_2) لخمسة عشر هجين تجارى من الطماطم مقاومة/متحملة لفيروس TYLCV خلال العروة الخريفية لعامى 2018 و 2019 لتحديد أفضل الهجن وعشائر الـ F_2 لها للإنتاج التجارى. قيمت كلا من عشائر الـ F_1، و F_2 منفصله لصفات المقاومة لفيروس TYLCV، والمحصول، وجودة الثمار. كانت قيم المكافئ الوراثى العام (H^2_b) لصفة المقاومة للفيروس عالية (<60%) فى الهجن ‘186’، و ‘Goldstone’، و ‘Rabha’، و ‘SV0922’، و ‘SV8320’ فى الموسمين. أعطت عشائر الـ F_1، و F_2 للهجن ‘186’، و‘Dania’، و ‘PS 550’، و ‘Rozalina’، و ‘SV0922’، و ‘SV8320’ أعلى محصول كلى/النبات، ومتوسط شدة إصابة بالفيروس منخفضة، وصفات جودة مقبولة، ومتوسط وزن ثمرة > 80جم. كانت قيم معامل التدهور الناتج عن التربية الداخلية مرغوبة لصفة متوسط شدة الإصابة بالفيروس فى عشائر الـ F_2 لغالبية الهجن المقيمة؛ ولصفة المحصول الكلى/النبات فى عشائر الـ F_2 للهجين ‘SV3773’ فى كلا الموسمين، وفى عشائر الـ F_2 للهجن ‘186’، و ‘448’، و ‘Goldstone’، و ‘Rabha’، و ‘SV8320’، و ‘SV0922’ فى الموسم الثانى. أظهرت غالبية الهجن قيم مرغوبة لمعامل التدهور لصفات الجودة. وفقاً لذلك، يمكن إستنتاج أن عشائر الـ F_2 للهجن ‘186’، و ‘SV0922’، و ‘SV8320’ يمكن استخدامها فى الإنتاج التجارى تحت ظروف العدوى الطبيعية بفيروس TYLCV فى الموسم الخريفى، حيث سجلت تلك العشائر مكافئ وراثى عالى لصفة المقاومة للفيروس وقيم مرغوبة لمعامل التدهور لصفات المقاومة للفيروس، والمحصول، وجودة الثمار.