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A Study of Triploid Tomato Fruit Attributes

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Abstract. **A spontaneous tomato *(Lycopersicon esculentum* Mill.) triploid was studied with a view to its commercialization. Fruits induced by auxin contained 50% more DNA and 30% more protein than their diploid counterpart. The fruits were 50% larger than those of the diploid counterpart and were juicy but seedless. All fruit quality characteristics checked (polygalacturonase activity, reducing sugars content, electrical conductivity, pH, titratable acidity, pigment content, and shelf life) were comparable to the diploid except for ethylene evolution rate, which was lower than that of the diploid counterpart, and flavor, which was superior. The line seems suitable for agricultural cultivation.**

Triploid tomato plants are not readily obtainable through crosses between tetraploid and diploid tomato cultivars (Cooper and Brink, 1945; Jorgensen, 1928; Nilsson, 1950). However, they do arise occasionally in tomato plots and are readily identified by their vigor and fruitlessness (Rick, 1945).

In a study aimed at estimating the commercial potential of fruits from triploid tomatoes, we searched for triploids among the commercial greenhouses of the Negev (southern area of Israel). A triploid plant discovered in a greenhouse of the tomato hybrid cultivar FC121 was verified by chromosome count, and was found to descend from a haploid female and a diploid male parent (Kagan-Zur et al., 1991).

Triploid tomato plants often do not bear fruits in nature (Jorgensen, 1928; Nilsson, 1950; Rick, 1945). If induced by artificial means, fruits have virtually no seeds due to chromosomal imbalance of the gametes (Strickberger, 1976). Tetraploid tomato plants bear smaller fruits that contain about one-tenth as many seeds as isogenic diploid lines (Kagan-Zur and Mizrahi, 1987; Nilsson, 1950). Fruit size has been correlated with the number of seeds developing in the fruit (Varga and Bruinsma, 1976) and seed number correlated with auxin level (Mapelli et al., 1978).

In diploid plants, it is possible to meet the auxin demands of the ovary and produce seedless parthenocarpic fruit by exogenous application of an auxin to emasculated flowers (Bunger-Kibler and Bangerth, 1982/3; Mapelli et al., 1978). We assumed that the same treatment would induce fruit set and development on triploid plants.

As polyploidy usually causes gigas appearance of plant organs (Jorgensen, 1928; Rick and Butler, 1956; Saimbhi and Brar, 1978; Tarn and Hawkes, 1986), and the smaller fruit size of tetraploids is correlated with lack of auxin, we surmised that auxin treatment would cause triploid fruits to surpass normal diploid fruits in size.

We undertook this study to assess the possibility of obtaining triploid fruits, and to study their physiology and potential as a crop.

Materials and Methods

Plant material. A triploid of the tomato hybrid cultivar FC121 was identified in a commercial greenhouse in the Negev area and propagated through cuttings together with the diploid hybrid obtained from the same source. Parent lines-of 'FC121' were grown from seeds (kindly provided by its breeder, N. Kedar). The parent plants were initially grown from germinated seeds, then propagated from cuttings as needed.

Culture. Seeds were sown in vermiculite in a greenhouse, maintained under natural light conditions, and irrigated with Hoagland's solution (Hoagland and Arnon, 1950). Triploids as well as 'FC121' diploids were propagated through cuttings, which were allowed to root in half-strength Hoagland's solution. Three-week-old seedlings and rooted cuttings were transferred to dark, opaque 10-liter buckets containing 1 vermiculite : 1 perlite : 1 C1 Finnish peat (by volume). Plants were irrigated with half-strength Hoagland's solution every other day. Ten plants of each cultivar were cultivated and trained to a single stem. Only the first four fruits on each inflorescence were allowed to develop. Flowers were either manually pollinated, tagged, and allowed to develop, or emasculated and treated with auxin. A commercial diluted solution of auxin ["NO Seed", Bruinsma Ltd. Holland, consisting of 0.1 g of b -naphthoxy-acetic acid/liter in water and a drop of the surfactant Tween 20] was applied manually to emasculated diploid flowers and to nonemasculated triploid flowers at full anthesis. Plants were grown in four consecutive seasons—winter, spring, summer, and fall.

Cell size. Thin slices of fresh pericarp sectioned with a razor blade were observed under a microscope with a calibrated ocular at 400 × magnification. The same cell layer was measured in each sample. The length and width were taken to the largest and smallest diameter of a cell, respectively. Cell volume was approximated as: $(\text{width})^2 \times (\text{length}) = \text{volume}$.

DNA content. Pericarp tissue (0.1 g) was frozen in liquid N and ground with methanol. After centrifugation for 10 min at 1350 × g in a bench centrifuge (Runne Heidelberg Mod 100-2; Heidelberg, Germany) the supernatant was discarded; this was repeated until a white pellet was obtained. The pellet was resuspended in 2.0 ml of 0.5 N perchloric acid and heated to 70C for 45 min. Following centrifugation as above, the supematant served for the DNA assay. DNA was assayed according to Richards (1974) using diphenylamine in glacial acetic acid and acetaldehyde.

Protein content. For protein extraction, 2.0 ml of 1 M NaOH was added to ground pericarp after extraction of pigments (see below). The samples were then boiled for 20 rein, centrifuged at 1350 × g, and the supernatant set aside. This procedure was repeated twice at room temperature. All supernatants of a sample were combined and 0.4 ml was taken for protein determination. Protein content was determined using the method of Lowry et al. (1951), Na_2CO_3 and $CuSO_4$ being added to the samples followed by Folin–Ciocalteus reagent.

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Ethylene evolution. Ten fruits of each line were picked at 80% development (100% development being the time from anthesis to first red color in fruits) (Lyons and Pratt, 1964) and individually placed in the flowing air system described by Kopeliovitch et al. (1980). Ethylene evolution rate was measured daily by withdrawing a gas sample with a syringe and analyzing its contents by gas chromatography (Kopeliovitch et al., 1980). Each fruit was frozen 10 days after the onset of ethylene evolution, so that fruits all were at a comparable physiological stage when thawed for chemical analysis.

Polygalacturonase activity. Polygalacturonase (PG) (EC 3.2. 1.15.) activity was measured as described by Mizrahi et al. (1976). Frozen tissue (40 g) was diced and homogenized in 1.0 M NaCl, then filtered and centrifuged (600 × g). The supernatant was, dialyzed against cold water. This served as a crude extract of the pectolytic enzyme. Ten milliliters of 4% sodium polypectate was added to 5 ml of crude extract. Substrate and extract were mixed in a viscosimeter (Cannon 200, United States), based on the principle that viscosity can be determined by recording the time needed for the solution to pass through a narrow calibrated glass column in the viscosimeter. Measurements were taken every 2 rein, and the activity was expressed as the time needed for a 50% decrease in the initial viscosity.

Pigment analysis. Pigments were analyzed by weighing pericarp discs 11 mm in diameter and extracting each disk with 5 ml of 4 acetone : 5 hexane (v/v). After centrifugation, the optical density of the supernatant was read at several wavelengths with a Kontron UNIKON 810 spectrophotometer (Hager and Meyer-Bertenrath, 1967).

Chemical analyses. Fruit tissue (10 g) was homogenized with 5 ml of water in a Virtis homogenizer, the homogenate centrifuged in a Sorvall RC2-B centrifuge (12000 × g, 10 rein), and the supernatant solution analyzed. Both pH and electrical conductivity were recorded using El-Hama Instruments PBS 710 and TH 250 (Tel Aviv), respectively. The amount of reducing sugars was measured according to the method of Sumner (1921) with dinitro-salycilic acid reagent. Acidity was estimated by titration with NaOH standardized against a KOH volumetric solution (BDH lg104 3u, Dorset, England). The analyses were performed on individual fruits from the ethylene evolution studies 10 days after the last of the tomatoes had entered the stage of ethylene evolution. The experiment was performed on three occasions several months apart, with essentially the same results, and all data were pooled.

Sensory tests. Flavor was estimated using fresh fruits under red light (to avoid effect of color on taste estimation). Several fruits of each line were cut so that each slice contained pericarp and jelly and the slices were mixed together. Evaluations were requested to rate the samples as: 1 (worst), 2 (medium), or 3 (4 in one test) (best) (Kopeliovitch et al., 1982). Average flavor scores were calculated.

Results

Self-pollination failed to produce fruits on the triploid plants, as expected, while auxin application induced development of fruits that were 50% larger than their diploid counterparts (Table 1). This difference was maintained independently of season. Fruits of the female parent of 'FC121' were smaller and those of the male parent larger than those of their diploid hybrid, whereas the triploid fruits were the largest. Time from anthesis to first color was the same for triploid and diploid hybrids, closely approximating that of the male parent. Percentage of fruit set was similar for all lines (Table 1). Fruit of triploids were seedless and appeared to be as juicy as fruit of the diploids.

Table 1. Effect of ploidy level and mode of fruit-set on fruit size and time from set to first color in hybrid tomatoes and their parent lines.

Ploidy and generation	Mode of fruit induction[z]	Time from anthesis to first color (days)	Set (%)	Average fruit wt[y] (g)
		Summer crop		
2n hybrid	Selfing	37.0	94	61.7 a
	NOA[y]	37.5	91	60.2 a
3n hybrid	Selfing	---	---	---
	NOA	37.9	93	93.3 c
LSD (5%)		---	---	6.6
		Winter crop		
2n hybrid	Selfing	78	96	77.0 b
	NOA	75	98	78.5 b
3n hybrid	Selfing	---	---	---
	NOA	75	96	117.5 d
Female parent	Selfing	62	94	58.3 a
Male parent	Selfing	76	95	89.4 bc
LSD (5%)		3.0	---	12.8

[z]NOA = 0.1 g β -naphthoxy-acetic acid/liter. The averages include > 30 fruits per parental line and at least 60 fruits per hybrid line.
[y]Mean separation by Duncan's multiple range test.

Dry matter content was significantly higher in the triploids: 5.8 ± 0.005 vs. 5.3 ± 0.008 for diploids, a difference of ≈10%. There was no significant difference in fruit cell size between triploid and diploid lines (hybrid and parent). DNA content was ≈50% higher in the triploid and protein content only ≈30% to 35% higher (Table 2).

Ethylene evolution rate reached a higher level in the self-pollinated and auxin-treated 'FC121' fruits than in triploid fruits (Fig. 1) but peaked on the same day. The experiment was carried out three times at different seasons, each yielding the same typical peak for each line. The female and the male parent peaks were higher than and similar to, respectively, the peak level recorded for the triploids (data not shown). The ethylene evolution surge was accompanied by an increase in CO_2 evolution rate showing the same pattern (data not shown).

Polygalacturonase activity was similar in all the hybrid fruits, although those treated with auxin had a wider range of variation. Fruit shelf life was also the same for all lines (Table 3). Fruit -quality, as expressed in terms of chemical composition, was not significantly different between triploid and diploid hybrid fruit (Table 4). Pigment levels were highest in the triploid fruits, but, probably due to a high variability level, the difference between triploid and diploid hybrids was not significant (Table 5).

In contrast with the above results for the chemical components, sensory tests repeatedly revealed a marked preference for the triploid fruits on the part of the tasters, while no difference was found between auxin-treated and selfed diploid fruits (Table 6). To differentiate between the effect of the male parent (the double complement donor) and of triploidy itself, fruits of parent lines were compared with fruits of hybrid lines (Table 7). The male parent was awarded the lowest score, while the triploids again achieved the highest. No significant difference was found between the diploid hybrid and the female parent.

Discussion

Triploid tomato plants do not bear fruits spontaneously (Jorgensen, 1928; Nilsson, 1950; Rick, 1945). We embarked upon

Table 2. Cell size, DNA, and protein contents of tomato fruits as affected by ploidy.

Fruit type[z]	Cell vol ($\mu m^3 \cdot 10^{-6}$)	DNA content ($\mu g \cdot g^{-1}$ fresh wt)	DNA ratio	Protein content ($mg \cdot g^{-1}$ fresh wt)	Protein ratio
3n(NOA) F_1 (a)	1.6	6.8		3.7	
2n(self) F_1 (b)	1.4	4.6	a/b = 1.48	2.7	a/b = 1.35
Female parent (c)	1.4	5.0	a/c = 1.36	2.9	a/c = 1.28
Male parent (d)	1.3	4.4	a/d = 1.54	3.0	a/d = 1.22
LSD (5%)	0.3	0.79		0.41	

[z]NOA = β -naphthoxy-acetic acid at 0.1 $g \cdot liter^{-1}$.

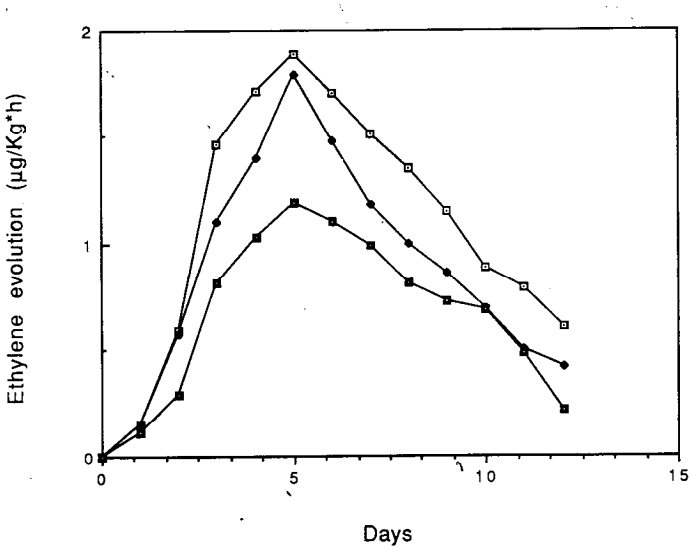

Fig. 1. Ethylene evolution rate in triploid and diploid hybrid 'FC121' tomato fruits.—□— 2n, selfed. –◆ – 2n, NOA-treated.–■— 3n, NOA-treated.

Table 3. Polygalacturonase activity and shelf life in diploid and tripleid tomato fruits of the 'FC121' hybrid[z].

Hybrid fruit type[y]	PG[x] ($t_{1/2}$ min.)	Shelf life (days)
3n(NOA)	31.3	26.8
2n(NOA)	29.2	25.0
2n(self)	34.6	24.1
LSD (5%)	11.2	4.4

[z]For shelf life estimation, at least 70 fruits were harvested 5 days after first color appearance.
[y]NOA = b -naphthoxy-acetic acid at 0.1 g·1iter[-1].
[x]Polygalacturonase activity was tested on fruits at the same physiological stage, 10 days after onset of ethylene surge.

Table 4. Fruit characteristics in diploid and triploid tomato hybrids[z].

Hybrid fruit type[y]	Reducing sugars ($mg \cdot g^{-1}$ fresh wt)	Electrical conductivity ($dS \cdot m^{-1}$)	pH	Titratable acidity ($meq \cdot g^{-1}$ fresh wt)
3n(NOA)	38.4	4.3	3.96	0.093
2n(NOA)	39.3	4.3	3.96	0.090
2n(self)	32.9	4.6	4.08	0.081
LSD[y] (5%)	4.65	0.61	0.04	0.0081

[z]Results are average of four tests. Ten fruits were taken for each test.
[y]NOA = β -napthoxy-acetic acid at 0.1 g·1iter[-1].

our work hoping that accumulated scientific knowledge concerning tomato fruit set and development (Bunger-Kibler and

Table 5. Pigment level, expressed as optical density, in diploid and triploid tomato hybrid fruits (± SE)[z].

Hybrid fruit type[y]	Wavelength 503 nm	476 nm	446 nm
		Optical density	
3n(NOA)	11.35 ± 2.6	11.95 ± 2.3	10.65 ± 2.3
2n(NOA)	8.51 ± 0.9	10.51 ± 1.1	8.00 ± 0.8
2n(self)	7.46 ± 0.2	9.30 ± 0.3	7.20 ± 0.3
LSD[y] (5%)	5.26	4.65	4.85

[z]Results are average of four tests. Ten fruits were taken for each test. Values are optical density for 1 g fresh weight pericarp disks at the various wavelengths.
[y]NOA = b -naphthoxy-acetic acid at 0.1 g·liter[-1].

Table 6. Organoleptic test scores of tomato fruits as affected by ploidy.

Hybrid fruit type[z]	Flavor score	Distribution of evaluators Grade 3 (best)	Grade 2	Grade 1 (worst)
3n(NOA)	2.5	42	23	7
2n(NOA)	1.7	12	28	32
2n(self)	1.8	19	21	32
LSD (5%)	0.2			

[z]NOA = b -naphthoxy-acetic acid at 0.1 g·liter[-1].

Table 7. A taste test comparing hybrid lines (triploid and diploid) with their parents.

Hybrid fruit type[z]	Flavor score	Distribution of evaluators Grade 4 (best)	Grade 3	Grade 2	Grade 1 (worst)
3n(NOA) F_1	2.95	10	2	5	3
2n(self) F_1	2.55	3	8	6	3
Female parent	2.55	3	7	8	2
Male parent	1.55	0	4	3	13
LSD (5%)	0.38				

[z]NOA = β -naphthoxy-acetic acid at 0.1 g·liter $^{-1}$

Bangerth, 1982/3; Mapelli et al., 1978; Varga and Bruinsma, 1976, 1988) would enable us to induce fruiting in triploids. Indeed, when applied manually to the ovary or style, auxin treatment in the concentrations recommended for routine use in tomato greenhouses resulted in > 90% setting and yielded well-developed fruits 50% larger than the corresponding diploid hybrid fruits (Table 1). This success was not a seasonal effect, because the same difference was observed in summer and winter crops. Also, the difference in fruit size cannot be attributed to hormone treatment alone, since hormone-treated diploid fruits were no larger than self-pollinated diploid fruits. An effect of the double contribution of the male parent on fruit size cannot

be ruled out, since the male parent plants bore larger fruits than the female, though with much variability (Table 1). Nonetheless, it seems that the greater size of the triploid fruits may be attributed to triploidy.

Both diploid and triploid hybrids followed the male parent in time elapsed between set and first color appearance, while the female parent had a shorter development time, suggesting male dominance in this characteristic (Table 1). The triploid' fruits lacked seeds, as expected both from their parthenocarpic origin (Varga and Bruinsma, 1976) and from the gamete imbalance associated with triploidy. The fruits did contain jelly and were juicy. Thus, triploid tomato plants could bear commercially valuable fruits.

Leaf cell volume was ≈50% larger in the triploids than in diploid lines–hybrids as well as parents–and so was leaf DNA per cell, is expected (unpublished data). Fruit cell volume, however, was similar in all lines checked. This means that the enhanced fruit size was due to the presence of more-numerous, rather than larger, cells. Fruit DNA content was 50% higher in the triploids and protein content only ≈30% higher (Table 2). Dry matter, however, was only ≈10% higher in the triploid, suggesting that the elevated DNA and protein content were not entirely reflected in all cellular activities. The same trend toward elevated protein content occurred in tomato tetraploid plants (Tal, 1979). Since Albuzio et al. (1978) have already demonstrated lack of correlation between ploidy level and enzymatic activities (because the various controls involved in cellular activities may be affected differently by the same events) discrepancies in overall behavior between DNA and protein are to be expected.

Ethylene evolution rate during ripening was lower in the triploids than in the diploid hybrid (Fig. 1). This finding is probably unrelated to triploidy, but was due to the influence of the male parent, which donated the double chromosome number (Kagan-Zur et al., 1991). Indeed, the male parent displayed an ethylene evolution rate similar to that of the triploid, while the peak rate of the female parent was the highest of all lines (data not shown); In spite of the difference observed in peak level of ethylene evolution, almost all characteristics usually thought to be related to ethylene level (Rhodes, 1980) were similar.

The triploid fruits were decidedly preferred to the diploid hybrid fruits (Tables 6, 7). The superior flavor did not stem from parental contribution, for the female parent and the diploid hybrid were judged similar, while the male parent rated the lowest (Table 7). Thus, triploidy by itself can affect flavor independently of reducing sugar level, electrical conductivity, or acidity and pH (compare Tables 6 and 4). We have long maintained that these attributes are only indirectly connected to flavor in tomato (Kopeliovitch et al., 1982; Kagan-Zur and Mizrahi, 1987).

Triploids in general and, at the least, the particular triploid studied here, probably can be developed into commercial tomato lines. Not only does the latter bear juicy fruit larger and more flavorful than its diploid counterpart, but it is also seedless, a quality increasingly in demand in European markets. Moreover, for seedless tomatoes, it maybe possible to obtain breeder rights.

Triploid plants have to be propagated through cuttings or tissue culture; the first method results in disease accumulation, and both are considered too expensive. In fact, use of cuttings is already being contemplated for diploid tomato hybrids as a means of countering high seed costs. Propagation by cuttings is also common practice among Israeli flower growers who overcome the probable disease accumulation by renewing the cuttings from a stock of sterile material every few years.

The overall yields of triploids and diploids were not compared in this study. Yields should be assessed in the course of field trials planned for testing the commercial potential of the 'FC121' triploid.

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