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Research Article

Tomato Fruit Yield and Quality as Affected by Grafting and Shading

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Abstract

In the present study, tomato (grafted and nongrafted) was grown in the soil under net-house cover by pearl and red nets (50% shade index) or un-shade condition (open field-control). Commercial tomato cultivars (‘Optima F1’ and ‘Big Beef F1’) were used to determine whether grafting (Maxifort rootstock) could prevent decrease of fruit weight and quality under light stress conditions. Nongrafted ‘Optima F1’ and ‘Big Beef F1’ was used as a control plants. Total yield of grafted plants was higher (51.0%) than non-grafted only in ‘Optima F1’. Shading maintained 30-40% higher marketable yield (reduced the amount of pysiological disorders) than plants from non-shaded conditions in both cultivars. Among the fruit components, lycopene, ascorbic acid, phenols, total sugar and citric acids concentrations and ratio of sugar and acid content were examined. In every case the values of these parameters were lower in the fruits from grafted plants than those from ungrafted ones, meaning that the increase of the yield quantity caused the decrease of main fruit components. The decrease of bioactive compounds had a similar trend and intensity, though some inter-color shade variation was observed. Fruits from shading plants under red nets obtained highest lycopene content in both grafted and non-grafted plants.

Keywords: Grafting; Quality; Shading; Tomato; Yield

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Introduction

Tomato (*Lycopersicum esculentum* Mill.) is one of the most important vegetable species, produced and consumed worldwide, grown in both open-field and protected conditions, in soil or soilless media [1], with regard to both economic and health aspects. The growth, yield and fruit quality of tomato can be influenced by their genetic potential and environmental factors, such as temperature, radiation and grafting [2-6].

High temperatures during the growing season have been reported to be detrimental to growth, reproductive development and yield of tomato. The high market price during the summer period motivates farmers to adopt additional cultural practices to overcome production constraints, such as shading and grafting. Low-cost protected cultivation, such as net houses, has the potential to reduce various biotic and abiotic challenges during summer open field production, creates a microclimate which affects productivity and quality [7]. Photo-selective, coloured, shade nets provide diverse mixtures of natural, unmodified light and scattered spectrally modified light [8]. Spectral modification promotes physiological responses [9], while scattering improves penetration of spectrally modified light into the inner plant canopy [10].

Grafted commercial cultivars (scions) onto selected tolerant rootstocks could be a promising method for producing tomato at suboptimal conditions [11]. Grafting is the union of two or more pieces of living plant tissue [12,13], which are forced to develop vascular connection and grow as a single plant [14]. The root system of grafted plants is stronger and more efficient in uptake of water and nutrients which indirectly improves yield [13,15-17]. In this context, the use of adequate rootstocks through grafting provides an alternative strategy to reduce the losses in production caused by environmental stresses [18], such as the excess of radiation and temperature in the late cropping season [15,19]. Grafting is becoming a common practice in several European countries, such as Spain, Italy, Turkey, Greece and Israel [12].

Regarding the changes in fruit quality by grafting, there are several conflicting reports whether grafting effects are advantageous or disadvantageous [20,21]. A negative effect of tomato grafting was observed regarding fruit yield per plant, number of fruits per plant and total yield [17], but organic acid and lycopene content was significantly higher when the eggplant was used as a rootstock. The overall results showed that tomato grafting on suitable rootstocks elicited positive effects on cultivation performance, but decreased tomato nutritional quality [22]. Obtained similar results with respect to vitamin C reduction because of grafting.

The effect of rootstocks on the amount of TSS was found not statistically significant [23-26], although some researchers have observed that soluble solid content was lower in grafted compared to non-grafted plants [27-29].

According to several authors, lycopene concentration in tomato fruits tends to decrease with grafting [30-33]. The effect of rootstocks on titratable acidity has been found to be significant [25], but in some studies [23,24,27,28], found no effect of grafting on the titratable acidity. Gajc-Wolska et al. [34] and Turhan et al. [28], found decreasing sugar contents in fruits of grafted tomatoes too.

Genetic (cultivar differences) and environmental factors modulate the physiology and metabolism of tomato plants, but it is not clear how technological factors (grafting) combined with abiotic stress (environmental factors-light, temperature) affect tomato's natural metabolic composition. The objective of our research was to evaluate grafting dependent differences in the response of shades.

Material and Methods

Plant material and cultivation

The experiments were performed in a net-house experimental plot located in the village of Moravac near Aleksinac (longitude 21°42' E, latitude 43°87 30' N, altitude 159 m) in the central area of south Serbia from March to September 2017.

The cultivar 'Optima F_1' is characterized by medium early maturing, with round shape and with high quality flesh. The cultivar 'Big Beef F_1' belong to *Solanum lycopersicum* L., beef type group, medium maturing with round and oblate shape, respectively and with fine beef quality. Interspecific hybrid 'Maxifort' (*Solanum lycopersicum* L. × *Solanum habrochaites* S. De Ruiter, Bergshenhoek, The Netherlands), were used as rootstock.

In our experiment, the seeds of scions were sown on 15th March in a seedling tray filled with peat-based substrate. Seeds of the rootstocks were sown two days prior to the sowing of scion seeds. Seedlings were grafted on 28th April. Seedlings were produced in the plastic tunnel with heating. Until the emerging of the tomato plants temperature was maintained at the 25-26°C, and after decreased at 21°C. Seedlings were grafted 25 to 30 days after emerging of the rootstocks and scions, when the stem diameter was 2 mm. Grafting was done by hand using cleft grafting method. During the grafting process it is very important to increase temperature at the 24°C. After the grafting, plants are placed in germination chamber, where the temperature of 20°C and relative humidity of 95% is maintained for 3 days. In next 5 days relative humidity is slowly decreased and temperature was set at 22°C, until the transplanting time. Grafted plants were transplanted in net-house 29th May. The experiment was set as randomized block system with three replications, each replication consists of 30 plants. Plants were transplanted at the distance 80 cm between the rows and 40 cm in the row. This spacing gave the density of 3 plants m^{-2}.

Normal cultural practices for the experiment were followed for irrigation, fertilization and pesticide application. The experiment was terminated on 11.09.2017. The following measurements were recorded: (a) number of plants which survived until the transplanting date; (b) fruit yield (g $plant^{-1}$) and (c) total number of fruits harvested per plant. Yield measurements were recorded on ripe fruits, which were gently hand-harvested and transported to the laboratory, where they were counted and weighed.

Characteristics of the nets

In order to test the effect of shading nets, two shading nets were used: Red and pearl nets with shading intensity of 50% relative shading, were compared to the open field production. The coloured shade-nets were obtained from Polysack Plastics Industries (Nir-Yitzhak, Israel) under the trade mark ChromatiNet. These nets are unique in that they both spectrally modify as well as scatter the transmitted light. The shading nets were mounted on a structure about 2.2 m in height over the plants (tunnel nethouse).

Light interception by nets

The effect of nets on the interception of light was measured annually as a percentage of total Photosynthetically Active Radiation (PAR) above canopy, using a Ceptometer mod. Sun scan (SS1-UM-1.05; Delta-T Devices Ltd, Cambridge, UK) with a 64-sensor photodiode linearly sorted in a 100 cm length sword. Readings are in units of PAR quantum flux (μmol $m^{-2}s^{-1}$). The Solarimeter-SL 100 (KIMO, France) is an easy-to-use portable autonomous solarimeter that measures solar irradiation ranging from 1 Wm^{-2} to 1300 Wm^{-2}.

β-Carotene and lycopene content

For β-carotene content measurements, the dry extract obtained according to the procedure at 40°C described above, was dissolved in a 4:6 mixture of acetone:hexane in a 10 cm^3 volumetric flask. The absorbance was measured at 663, 645, 505 and 453 nm in a 1.0 cm quartz cell (VARIAN UV-Vis Cary-100 spectrophotometer). The β-carotene concentration (mg/100 ml) was calculated from the equation proposed by [35]:

$$\beta\text{-Carotene (mg/100 ml)} = 0.216 \times A_{663} - 1.22 \times A_{645} - 0.304\ A_{505} + 0.452 \times A_{453}$$

$$\text{Lycopene (mg/100 ml)} = -0.0458A_{663} + 0.204A_{645} + 0.372_{A505} - 0.0806A_{453}$$

The results were expressed in µg/g fresh weight.

For determination of total phenol contents, the average sample obtained by mixing the axial cut outs from 9 fruits from each treatment block was used. Extraction was performed from 2 g of homogenized fresh plant material with 40 cm^3 of 70% v/v ethanol during 4.5 h at 25°C. The obtained extracts were filtered under vacuum and the solvent was removed by evaporation at 50°C. The extracts were dried in the vacuum dryer at 40°C till constant mass and the content of total extractive matter (TEM, dry extract) was calculated on the basis of dry residue content. TEM were expressed in g/100 g of fresh plant material.

Ascorbic acid content was determined by spectrophotometric methods using potassium permenganate as a chromogenic reagent. Standard calibration curve of ascorbic was established by graphing concentrations versus absorbance of ascorbic standard solutions by taking 10 mL of each of standard solutions and put in a test tube, then 1 mL of $KMnO_4$ solution (100 µg/mL) was added. This solution was let to stand for 5 minutes. The absorbance of this standard solutions were read at 530 nm against blank.

Each of the five of fruit samples were accurately taken as 10.0 mL for each sample, and then transferred into a test tube, and 1.0 mL of $KMnO_4$ (100 µg/mL) was added for each. The contents of each test tube were mixed well and stand for 5 minutes. The prepared solutions were read at 530 nm against blank by spectrophotometer using a suitable concentration for the analysis.

Total Phenol Content (TPC) was determined according to the Folin-Ciocalteu method Singleton et al. [36]. In brief, to 1 mL of extract, 7 mL of water and 0.5 ml of Folin-Ciocalteu reagent diluted with water (1:1; v:v) were added. After 10 minutes of equilibration, 1.5 mL Na_2CO_3 solution (20%; w/v) was added. Following 30 minutes, the absorbance was recorded at 730 nm (Cintra 303, GBC). The results were calculated from the calibration obtained using gallic acid as the reference standard.

Sugars and organic acids content

For determination of sugar and organic acid compositions, a weight sample was dissolved in three-fold higher volume of demineralized water. The supernatant was separated by centrifugation for 5 minutes at 10.000 rpm and and an aliquot was diluted with two-fold higher volume of acetonitrile and kept at -18°C until analysis. A High-Performance Liquid Chromatographic (HPLC) method (Agilent 1200 series) was applied to determine sugar (fructose, glucose and sucrose) and acid (citric, malic and succinic) contents in lettuce extracts. Prior to HPLC analysis, prepared samples were filtered through 0.45-µm pore size filters.

For sugar determinations the liquid chromatograph was equipped with Evaporative Light Scattering Detector (ELSD) and Agilent, Zorbax Carbohydrate 4.6 × 250 mm, 5 µm column (Agilent Technologies). Solvent system of acetonitrile and water (75:25 v/v) at a flow-rate of 1.1 mL min^{-1} with total running time of 12 minutes was used. Injection was performed automatically with injection volume of 10 µL.

For organic acids analysis liquid chromatograph was equipped with Diode Array Detector (DAD) and nucleogel sugar 810 H (MACHEREY-NAGEL) column. 5 mmol H_2SO_4 was used for elution at a flow-rate of 0.6 mL min^{-1} at 65°C, and total running time was 25 min. Peaks were recorded at 210 nm. The injected volume of samples and standards was 5 µL and injection was performed automatically.

Standard solutions of sugars (glucose, fructose and sucrose) and organic acids (citric, malic and succinic) were used for development of calibrations. Peaks were identified based on retention time comparisons, and the concentrations were quantified from developed linear regressions.

Statistical Methods

Significance of effect of different color shade nets on tomato was determined by two way ANOVA followed by Duncan's multiple range test. Multivariate principal component analysis was used for explanatory data analysis. For all calculations STATISTICA 13 software was used (Dell Inc. (2016). Dell Statistica (data analysis software system), version 13. software.dell.com.).

Results and Discussion

Light modification by photo-selective nets

Light has been known to be fundamental in plant growth and development. Shade nets have the potential to modify light quality by reducing radiation intensity and the microclimate thermal properties. Our data show that during a sunny day in July the maximum solar radiation measured is 889 Wm^{-2} (Figure 1). The net radiation is strongly correlated to the incoming solar radiation, in analogy to what is known to occur over open ground.

Results from figure 1 show that the reduction of net radiation is mediated by the colour nets. Compared to control, solar radiation was significantly reduced by the 50% shadow intensity. The incoming solar radiation for red and pearl colour-nets was 563 Wm^{-2} and 469 Wm^{-2}, respectively.

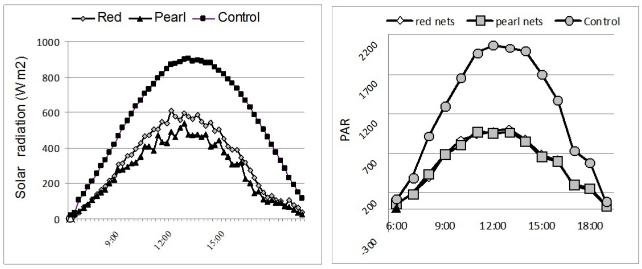

Figure 1: Solar radiation (W m^{-2}) and PAR-Photosynthetically Active Radiation (µmol $m^{-2}s^{-1}$) measured under different colour nets (average day in July).

The solar radiation registered on sunny days resulted in high PAR values (maximum 1600 to 2000 µmol $m^{-2}s^{-1}$), which are common in southern Europe arid conditions. On cloudy days (complete cloud cover), the maximum PAR values ranged from 800 to 900 µmol $m^{-2}s^{-1}$. The photosynthetically active radiation was halved in comparison to open field under all used shade nets. The maximal level photosynthetically active radiation under the red nets was 1004 µmol $s^{-1}m^{-2}$, while the maximum intensity of photosynthetically active radiation in the open field reached 2034 µmol $s^{-1}m^{-2}$ (Figure 1).

Parameters of yield

Comparing the averages of the grafting to the controls (non-grafting), it was seen that grafting caused increases in the yield per plant and total yield in cultivar 'Optima F_1' for 51.0%. At same time, total yield of grafted plants was smaler for 37.2% in cultivar 'Big Beef F_1' than non-grafted ones. In this case, probably one of the reason for reduction of yield was less compatibility between the rootstock (Maxifort) and scion.

Shading effect changes total and market yields of tomatoes. Shading maintained 30-40% higher marketable yield (reduced the amount of pysiological disorders) than plants from non-shaded conditions in both cultivars. The greater fruit yield produced from shaded plants may be explained by the assumption that during summer, high temperature increases shedding of tomato flower and reduces fruit set. It is also possible that the increase in tomato yield is due to larger number of branches and flowers per plant. Since the nets are composed of holes, in addition to the translucent photo-selective plastic threads, shade nets actually create mixtures of natural, unmodified light, which is passing through the holes, together with the diffused, spectrally modified light, which is emitted by the photo-selective threads [37].

The reduced total and marketable yields of non-shaded plants were probably due to high heat stress. However, grafted cv. Optima F_1 did not significantly affect leaf biomass but increased the total and marketable fruit yield.

The difference in marketable fruit yield between grafted and non-grafted plants was 4-16%. A shading of tomatoes may be an option to reduce heat stress conditions and extend the summer season toward September. A possible cause of the decrease of cracked fruit by shading is a decrease in fruit temperature by the shading treatments [38].

Similarly, it was reported that marketable yield increased in tomatoes with rootstock use [23,25,26]. For example, tomato cv. Florida 47 grafted on 'Beaufort' and 'Multifort' rootstocks, increased the marketable fruit yield by up to 41% [39].

Similarly, the 'El Cid' tomato grafted onto interspecific hybrid rootstock 'Multifort' obtained a 12.9% increase in fruit yield [40]. Significant decrease of the yield and number of fruits was observed when eggplant rootstock was used [41].

Average fruit weight was similarly in both cultivars. Grafted 'Optima F_1' un-shaded plants, produce fruits with significant highest weight (222.9 g) than non-grafted plants (173 g). Shading havent effects in increasing fruits weight in grafted 'Optima F_1' plants, but non-grafted shade plants produce fruits with significantly highest weight than fruits from unshade plants (173 g). Grafted cv. 'Big Beef F_1' (193 g) obtained significantly highest fruit weight than nongrafted plants. Shading with red and pearl nets has possitive effect in production of highest fruit weight in nongrafted plants in both cultivar. In same time, grafting plants under shading no effect in cv 'Optima F_1' or decrease fruit weight in cv 'Big Beef F_1' (Table 1).

Under shading, Krumbein et al. [11], reported that tomato yield was significantly reduced thus, the commercial rootstocks were not able to enhance the yield reduction. Grafting tomato often results in significant increase in fruit weight and consequently in fruit diameter and size compared with non or self-grafted plants [16,42]. However, yield gain may be also attributed to an increase in the number of fruits rather than an increase in mean fruit weight [24]. The effect of grafting on fruit weight and size depends on grafting combinations [43-45]. Some studies have reported that the average fruit weight increases with rootstock use [23,25,27,28], while some have reported that rootstocks have no effect on the fruit weight [24,46].

Fruit composition

Fruit quality is defined as a combination of visual stimuli like size, shape and color, and sensory properties like sweetness, acidity and aroma [47,48]. Fruit quality can increase or decrease, depending on the scion-rootstock combination [48].

Fruits of grafted tomato plants from both cultivars have higher water content than fruits from non-grafted plants, resulting in a dilution effect of compounds. In fact, the dry matter content of fruits from 'Optima' grafted onto 'Maxifort' (5.6%) was lower compared to non-grafted Optima (6.9%) fruits, supporting an inverse relationship between sugar and water content [28]. Statistically significant differences in water content was observed between cultivars and grafting x cultivars. Shading no influence on fruit water content (Figure 2).

The content of lycopene depends on the tomato cultivar. Red-ripe fruits of most high-lycopene lines showed commercially suitable soluble solids and titratable acidity, in addition to increased levels of lycopene (up to 440 mg/kg fw) and other bioactive phytochemicals (mainly flavonoids and vitamin C) compared to their near isogenic conventional counterparts [49]. In our study, between cultivars in non grafted plants from open field no differences in lycopene content (~210 mg/100g FW). Lycopene content can be influenced by grafting, but it is subject to significant rootstock-scion interaction which indicates that graft combination plays an important role. Thus, lycopene content in grafting cv. Big Beef F_1 was significantly lower (158.6 mg/100g FW) than fruits from non grafting plants with tends to decreased with shading condition. Combination shading x grafting characterized by the significant lower lycopene content in both cultivars (Figure 3).

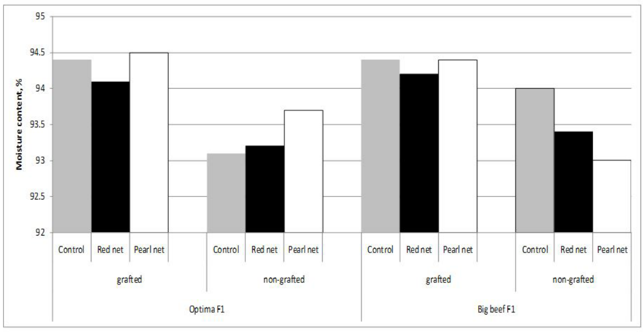

Figure 2: Tomato moisture content as affected by grafting and shading.

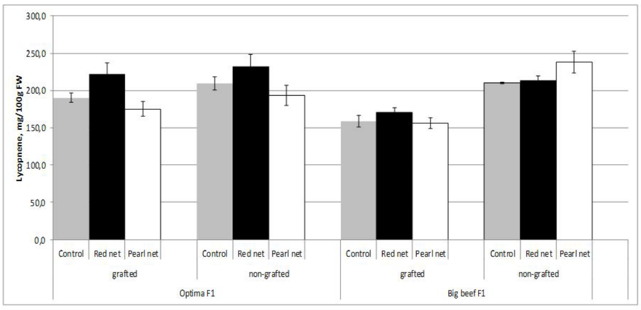

Figure 3: Tomato lycopene content as affected by grafting and shading.

Lycopene is the pigment principally responsible for the characteristic deep-red color of ripe tomato fruits and tomato products. According to Brandt et al. [50], significantly higher lycopene content was observed in glasshouse-grown tomato compared to field grown, at different harvesting times. According to Farkas [51], lycopene production is inhibited when environmental temperature is above 32°C. Lycopene content changed significantly during maturation and accumulated mainly in the deep red stage [52].

According to several authors, lycopene concentration in tomato fruits tends to decrease with grafting [31-33], e.g. most out of 15 rootstocks investigated, including 'Maxifort,' 'Beaufort,' and 'King Kong,' decreased the fruit lycopene concentration of tomato scion 'Jeremy' and 'Jack' [41,42]. Similar results have been reported for tomato scion 'Cecilia' grafted onto 'Beaufort' and 'Heman' [30], for scion 'Macarena' grafted onto 'Maxifort' [34], as well as for 'Classy' grafted onto 'Brigeor' [11,45]. Lycopene in tomato fruits decreased in grafting treatments in soilless cultivation [31]. However, their concentrations were increased or unaffected by grafting in soil cultivation due to the fact that plants grown in soilless culture were not under salt stress, unlike those grown in soil [46].

Tomato fruit contains significant amounts of Ascorbic Acid (AA), and these content strongly depend of cultivar origin. Although light is not essential for the synthesis of AA in plants, the amount and intensity of light during the growing season have a definite influence on the amount of AA formed. AA is synthesized from sugars supplied through photosynthesis in plants. Outside fruit exposed to maximum sunlight contain higher amount of vitamin C than inside and shaded fruit on the same plant. In our experiment fruits from non grafting and open field plants cv. Optima F_1 has double more AA content (22.5 mg/100g FW) than cv. Big Beef F_1 (11.3 mg/100g FW) from same conditions.

In our study we found that AA contents (11.3-22.5 mg/100g FW) depends of cultivar decreased by 21.2-29.3% in the fruits from grafted plants in comparison with the fruit from non-grafted plants. AA content in both cultivars decreased under shade nets exept in non grafting cv. Big Beef F_1 were AA content increased in both shade nets. In terms of AA content specifically react to different color nets, thus both cultivars under pearl nets lower contents of AA were recorded. Statistical differences in AA content was observed inside grafting x cultivar combination (Figure 4).

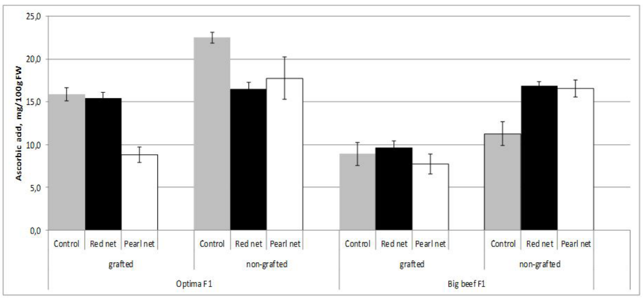

Figure 4: Tomato ascorbic acid content as affected by grafting and shading.

Several studies showed that AA content strongly reduced by grafting both in greenhouse and field studies [39,42,53-55]. However, in a different study, Di Gioia et al. [54], found that vitamin C contents decreased by 14-20% in the fruits of plants grafted onto 'Beaufort' F_1 and 'Maxifort' F_1, in comparison with the non-grafted treatment. The lower ascorbic acid content could be explained by the higher plant/shoot biomass in grafted plants compared with non-grafted ones or by the fact that grafted plants were initially subjected to stress following the grafting operation. Ascorbic acid is known to control cell differentiation [56], and to promote callus division and growth [57]. The decreased total vitamin C content of the fruits from grafted plants could therefore be a resultant of redistribution or accumulation of vitamin C in other parts of grafted plants [58].

The choice of cultivar as well as grafting and shading as agronomic factors are major contributing factors to the total content of phenolics in tomato. Total phenolics showed the greatest variations between grafted and non-grafted plants in cv. Optima F_1.

Under standard growth conditions applied in these experiments, grafting significantly reduced the total phenolics content of fruits only in cv. Optima F_1. Total phenol content decreased in grafting plants under shading in both cultivars. It is interesting to note that no significant differences were found in non grafted cv. Big Beef F_1 among the shading (Figure 5).

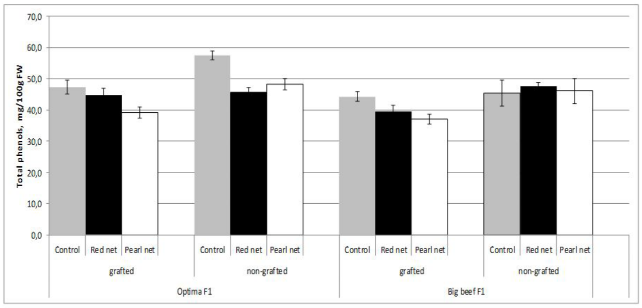

Figure 5: Tomato total phenols content as affected by grafting and shading.

		Yield g/Plant	Total Yield t/ha	% Marketable Yield*	Number of Fruit/Plant	Fruit Weight g
Optima F_1						
Grafted	Control	5443a	150.7a	70b	24.0a	222.9a
	Red net	5640a	156.2a	89a	28.6a	196.9b
	Pearl net	5430a	150.4a	91a	25.2a	214.9a
Non grafted	Control	3602b	99.8b	61b	19.7b	173.0c
	Red net	3462b	95.9b	85a	17.3b	199.5b
	Pearl net	3406b	94.3b	86a	17.7b	192.1b
Big Beef F_1						
Grafted	Control	3275b	90.7b	66b	17.6b	193.0b
	Red net	4570ab	126.6ab	83a	23.1a	198.1b
	Pearl net	5062a	140.2a	84a	25.0a	202.5b
Non grafted	Control	4490ab	124.4ab	57b	26.6a	168.0c
	Red net	4569ab	126.6ab	81a	22.4a	203.5b
	Pearl net	5007a	138.7a	80a	26.7a	187.5b

.**Table 1:** Influence of grafting and shading on parameters of tomatoes yield

Note: *Marketing yield is reduced from total yield by the presence of physiological disorders of tomato fruits (cracking; sun scald; blossom and root; puffiness; .(irregular shape

However, total phenolics content changes significantly among the scions-cultivars used in our experiment as well as between cultivars under different shade nets. The results obtained confirm those of Vinkovic-Vrcek et al. [55], who found that grafting significantly reduced the total phenolics content and antioxidant activities of tomato fruits. Changes in light intensity through the utilisation of shade nets were able to change the synthesis of phenolic compounds in plants. Different shade levels, with the resultant changes in plant morphology and physiological characteristics, affected the secondary metabolites such as phenolic compounds in plants. However, different plants had diverse reactions to shade levels, which alter the production of Total Phenolics (TP). Previous studies showed that change in light intensity was able to modify the production and accumulation of TP in lettuce [8].

Sugars, mainly glucose and fructose, account for about half of the dry matter or 65% of the soluble solids of a ripe tomato fruit. The sugar content of fruit fresh weight depending on cultivar and growing method (grafting and shading). The sugar content ranges from 3.52% in grafting unshading cv. Optima F_1 to 5.62% in nongrafting plants under red shade nets. Improvement of fruit sweetness related to grafting is rather seldomly reported. Grafting decreased sugar concentrations in both cultivars whereas sugar concentrations were influenced by both cultivar and shading. Shading increased sugar content in fruits from nongrafting plants, thus in cv. Optima F_1 the highest sugar content was recorder under red nets (5.62%) and in cv. Big Beef F_1 under pearl nets (5.40%), figure 6.

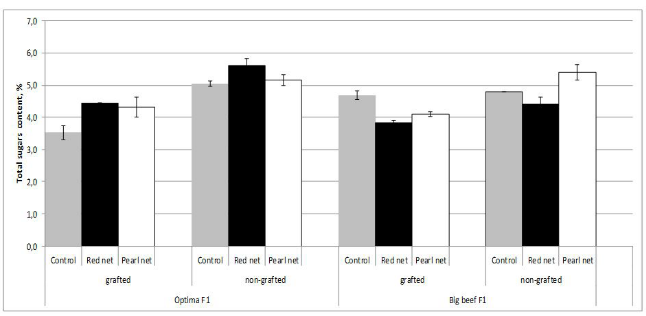

Figure 6: Tomato total sugars content as affected by grafting and shading.

In our study, sugar decreased caused by grafting were relatively minor (2.3%) in cv. Bef Beef F_1 to very high (30.3%) in cv. Optima F_1. For examples, Pogonyi et al. [27], reported a decreased sugar concentration in tomato fruits by up to 25% for tomato plants (Lemance F_1) grown in a soil culture and grafted on 'Beaufort' compared to ungrafted plants.

The decline in sugars incurred with grafting is reported to account for approximately not more than 16% [59], which does not exceed the range of maximum decline proposed for consumer acceptability [60,61]. In this respect, grafting may be considered a high-input production method, with a prevalent tendency for increasing crop load and potentially suppressing fruit sugar content [20,62].

The reasons for a lower carbohydrate content in grafted tomato may stem indirectly through rootstock effect on scion vigor, timing of flowering, fruit load, yield and, ultimately, fruit maturation, as fruit sugar concentration is highly dependent on fruit maturity at harvest [6,62]. It seems that beside photosynthesis, changes in dry matter content could be responsible for the reduced sugar concentration in grafted plants [11]. Alternatively, water uptake-efficient rootstocks may increase fruit water content even if sufficient assimilates are available, thus, leading to a reduced fruit sugar concentration [11,28].

Total organic acids in tomato fruit are usually in the range of 0.2 to 1.7 g/kg^{-1} fresh mass, with citric and malic acid being the main components of sourness. The highest Citric Acid (CA) values (1.0%) were found in nongrafted cv. Big Beef F_1 tomato plants, whereas the lowest (0.67%) were found in grafted cv. Optima F_1 tomato plants. Grafting accounts for an decrease in CA up to 25.6% reported under a range of different shading which indicates a direct rootstock effect (Figure 7).

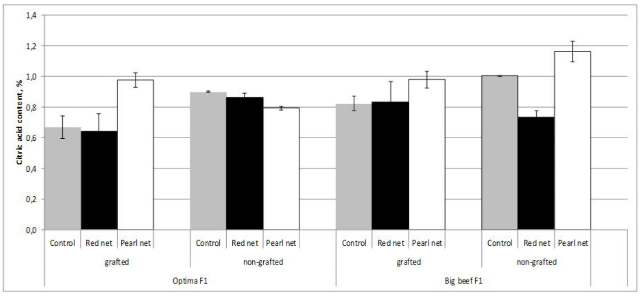

Figure 7: Tomato citic acid content as affected by grafting and shading.

Shading, special pearl nets significantly increased CA content in tomato fruits from grafting and nongrafting plants exept in nongrafting cv. Optima F_1 plants. The decrease of sugar content was not in relation to the loss of acid content on grafted plants compared with ungrafted ones [27]. Because of the decrease of sugar content was much higher than that of acids, their rates were markedly different for the two shading methods. Grafting may have positive effects on the decreased acidity of the tomato fruit produced. Fernández-Garcia et al. [53], stated that TA values were the most important chemical quality parameters for tomato and were not affected by grafting.

The mechanisms involved in grafting-elicited decrease of fruit CA have not been thoroughly investigated; however, organic acids constitute a direct substrate for respiratory demands and their increased *de novo* synthesis in developing fruits might be a plausible mechanism for coping with the sugar deficit incurred on the heavy crop load supported by vigorous rootstocks.

Sugars, acids and their interactions are important in relation to sweetness, sourness, and flavour intensity in tomatoes. Much sugar and relatively high concentration of acids are required for the best flavour. High concentration of acids and low sugar content will produce a tart tomato, while high sugar content and low concentration of acids will result in a bland taste. When both sugar and total acid contents are low, the result is a tasteless, insipid tomato. It is supposed the best if the ratio of sugar to acid ranges from 9 to 10 [63].

Sugar to CA ratio in our study rages from 4.6 in cv. Big Beef F_1 grafted under red nets to 6.8 in cv. Optima F_1 grafted and grown under red nets. This ratio in case of our exploration was lowest because we acidity expressed through citric acid rather than through total acid whose values are slightly higter. Differences in this ratio between cultivars also confirm by Krumbein et al. [11], demonstrated that the flavor compounds (sugars, acids, and aroma volatiles) in tomato fruits grown under shaded condition depends on rootstock-scion combinations. In summary, the quality characteristics of grafted tomato fruits are greatly influenced by rootstock-scion combinations and shading conditions.

Conclusion

Grafted plants offer increased yield and consequently higher profits. In tomato plants cv. Optima F_1, yield is positively affected by grafting due to the increase in fruit yield, number of fruits/truss and fruit weight. We consider these benefits to be of value to farmers. In same time grafted plants under shading, incresed significantly tomato yield only in cv. Big Beef F_1. Although fruit quality values, such as lycopene content, vitamin C content, total sugar and citric acid content were lower in grafted plants, these values were still satisfactory and lied within the adequate ranges. However, lycopene content was slightly increased by shading under red nets. Total phenols remained unchanged depending on the grafting and shading in cv. Big Beef F_1, but in cv. Optima F_1 total phenols was lower in grafted plants and slight decreased with shading. Grafting decrease citric acid in fruit from both cultivars. In same time, shading increased citric acid only in fruits from grafted plants. Sugar content depend of cultivar and shading condition. Total sugar content is higher in fruits from non grafted and shade plants. Therefore, grafting had no harmful effects on fruit quality, but additional research is needed to determine whether grafting is economically feasible to the producer.

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