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ASSESSMENT THE EFFECT OF GENOTYPE X MYCORRHIZA INTERACTION ON SOME FRUIT QUALITY TRAITS IN TOMATO

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Abstract

In the context of current concerns regarding sustainable tomato production, the use of arbuscular mycorrhizal fungi (AMF) can represent an important way in order to reduce the use of chemical fertilizers and pesticides and their negative environmental impact. The aim of this study was to assess the qualitative traits of fruits (firmness, titratable acidity, total soluble solids, maturity index, and flavour index) in six tomato genotypes under the effect of mycorrization with Glomus sp. The biological material was composed by five hybrids and one tomato variety developed at ULS Timisoara. The study was carried out using a split-plot design with mycorrhizal treatment as the main factor. The effect of AMF on different quality traits was influenced by the genotype, to a greater extent for fruit firmness and acidity, and associated with an increase of sugar content and firmness of fruits. The obtained results highlighted that the use of AMF in tomato can lead to an improvement in fruit quality, considering that a selection of appropriate genotypes is also necessary.

Key words: *Solanum lycopersicum, arbuscular mycorrhizal fungi, fruit quality.*

INTRODUCTION

Tomato, is one of the highest-value vegetable with an extensive worldwide distribution. Quality is considered an important factor for ensuring higher value of tomato fruits, being influenced by the interaction of genotype with several ecological and technological factors. In tomato production system, the arbuscular mycorrhizal fungi (AMF) can be an effective alternative n order to reduce the input of chemicals and their environmental impact (Toju et al., 2018).

Arbuscular mycorrhizal fungi (AMF) are obligate biotrophs and are the most widespread symbioses with the roots of the majority important crop species (Smith & Read, 2008), and enhance their mineral nutrition by improving the absorption of several nutrients, in exchange for the use of carbon compounds resulted from the photosynthetic process (Bucher et al., 2014; Keymer et al., 2017; Nedorost & Pokluda, 2012).

AMF can modify root hydraulic properties (Bárzana et al., 2012) that will increase the water supply in shoots and tolerance to water stress (Bowles et al., 2016; Chitarra et al., 2016), also the AMF plants can express a higher net photosynthetic rates (Birhane et al., 2012; Bowles et al., 2016; Huang et al., 2011). Inoculation with AMF decreased stem elongation in plants under low light conditions, thus counteracting the plant's reaction to shading (Sahaet al., 2022). The mechanisms that produce benefits of AMF are depend on the stress characteristics, and are mostly regulated by phytohormones (Pozo et al., 2015). The beneficial effects of AMF on plant growth that were frequently observed has stimulated the development of several biostimulant products for agricultural use (Lee Diaz et al., 2021).

Tomato is one of the most important crops which are known to have several benefits from symbiotic relationships with mycorrhizae. The use of AMF provide benefits to the development of tomato plants, improved their health and might be of particular interest for ecological tomato production (Jamiołkowska et al., 2020). The symbiosis between roots and AMF in tomato provides nutrients and water to the host plant, thus stimulating plant growth and increasing yield and fruit quality (González-González et al., 2020; Paskovic et al., 2021; Saia et al., 2019). The colonization of tomato roots with AMF increase the resistance of plants to biotic (Aseel et al., 2019; Song et al., 2015) and abiotic stresses (Liang et al., 2022; Volpe et al., 2018). Mycorrhizal colonization in tomato produce a defense mechanism that induced effective resistance against fungal and bacterial, virulent and avirulent pathogens, insects and necrotrophs (Fujita et al., 2022; Nguvo & Gao, 2019).

Under the inoculation with AMF, the tomato plants were more vigorous having a developed root system (Felföldi et al., 2022). Mycorrhizal inoculated tomato plants flowered earlier (Ortas et al., 2013), produced larger inflorescences and a higher number of flowers (Conversa et al., 2013; Urias-Garcia et al., 2022) and has uniform fruits (Dasgan et al., 2008). As a consequence of early flowering, the AMF treatment increase the first harvest yield and reduce the harvesting time (Candido et al., 2013; Salvioli et al., 2012). The benefits of AMF on tomato growth can be due to the association between the mycorrhizal plants colonization and the quantity and quality of pollen. (Dey & Ghosh, 2022).

The inoculated tomato plants exhibited an increase of sweetness and a reduction of fruit acidity (Chafai et al., 2023; Ullah et al., 2023), and improved quality of nutrients by increasing the citric acid, antioxidants, carotenoids, amino acids (Bona et al., 2017; Di Fossalunga et al., 2012; Miranda et al., 2015). The beneficial effect of AMF symbiosis on the accumulation of bioactive compounds in fruits is dependent on the AMF species, host plant and growing conditions (Horvath et al., 2020).

The previous findings highlighted that the utilization of AMF can be an effective way to obtain yield with high-quality fruits and to reduce the fertilizer doses and their environmental impact. In this context, the aim of this study was to assess the qualitative traits of fruits (firmness, titratable acidity, total soluble solids, maturity index, and flavor index) in six tomato genotypes under the effect of mycorrization with *Glomus* sp.

MATERIALS AND METHODS

The biological material was composed by four F_1 hybrids ('Banato', 'Miruna', 'Sorada', 'USAB29') and one tomato variety ('Tomtim') developed at ULS Timisoara, and 'Ghittia' Romanian variety.

The study was carried out using a split-plot design in three replications, with mycorrhizal treatment (no AMF; with AMF) as the main factor and the genotype as second factor. The 45 old days seedlings were transplanted into the field on May 10, 2021, using a density of 3.33 plants/m^2 (0.7-0.8 m between the rows/0.4 m on the rows).

Inoculation with *Glomus* sp., was done during the transplanting of seedlings into the field, by placing 4.5 g of inoculums consisting of 1 x 10^7 CFU/g (50% *Glomus intraradices* + 50% *Glomus mosseae*), in the planting holes. As a source of mycorrhiza the commercial product Aegis Pastiglia (ITALPOLLINA S.p.A., Italy) was used.

The soil was mulched with black plastic film and the irrigation was done by drip. Cultural practices for tomato field crop were applied. The average monthly temperatures ranged between 21.9ºC in May to 32.5ºC in July, while the average monthly rainfall ranged from 28.4 mm in May to 47.5 mm in July.

Ten representative mature fruits for each mycorrhizal treatment and genotype were randomly selected for analyses. The total soluble solids (TSS) was carried out using a digital refractometer (DR 201-95) and the results were expressed in ºBrix. The fruit firmness was measured using a penetrometer (PCE – PTR 200) and the results were expressed in kg/cm^2.

The titratable acidity (TA) was determined through a titration procedure using a NaOH (0.1 N) solution, and calculated using the formula (Saad et al., 2014):

TA (citric acid %) = (v x N x 100 x 0.064)/m, where: v-volume (mL) of NaOH solution; N - 0.1; 0.0064 - conversion factor for citric acid; m- sample mass (g).

The maturity index (MI) and flavor index were calculated with the following formulas (Hernandez Suarez et al., 2008):

MI = TSS/TA; FI = TA + [(TSS/20) x TA]. The means were compared using ANOVA and Least Significant Difference test (Ciulca, 2006). The genotypes were clustered using the UPGMA algorithm (Neighbor program) of the Phylip package. The basic principles of the biplot technique were used to display in a graph the performance of each genotype for the analyzed traits.

RESULTS AND DISCUSSIONS

Regarding the main effect of mycorrhization (Table 1), the fruits firmness showed amplitude of 0.49 kg/cm^2 with values ranging from 2.52 to 3.01 kg/cm^2. Mycorrhization had a slight positive effect causing a significant increase of 19.44%. Considering the cumulative effect of the genotype, the average values of fruit firmness ranged from 1.99 kg/cm^2 in the Banato hybrid to 3.51 kg/cm^2 in the case of the Ghittia variety. The plants of Ghittia variety and Sorada hybrid have used this year's growing conditions at a higher level, achieving a superior fruit firmness compared to the other genotypes. The fruit firmness of USAB29 hybrid was significantly higher than Tomtim, Miruna and Banato genotypes.

Table 1. The effect of mycorrhization and genotype on tomato fruits firmness (kg/cm^2)

Genotype	Mycorrization		Genotype	
	AMF -	**AMF +**	Mean	CV
Banato	1.82 d	2.16 d	1.99±0.09 D	18.39
Ghittia	3.25 a	3.78 a	3.51±0.16 A	18.85
Miruna	1.83 d	2.33 d	2.08±0.12 D	24.02
Sorada	3.00 ab	3.82 a	3.41±0.15 A	18.19
Tomtim	2.28 c	2.66 c	2.47±0.08 C	14.23
USAB29	2.96 b	3.29 b	3.13±0.12 B	15.68
AMF Mean	2.52±0.09 Y	3.01±0.11 X	2.77±0.08	
CV	28.74	26.33	28.70	

AMF- (non-mycorrhizal); AMF+ (mycorrhizal); Data represents mean ±SE
Genotype LSD 5%=0.21; AMF LSD 5%=0.19; Genotype x AMF LSD 5%=0.26
Different letters (a-d) in the columns indicate significant differences ($p<0.05$) between genotypes.
Capital letters were used for AMF means (X, Y) and genotype means (A-D) comparisons.

The mycorrhization caused a significant increase in fruit firmness at the plants of all genotypes, being associated with increases between 11.15% at USAB29 and 27.33% in Sorada hybrid. The non-mycorrhizal plants (AMF-) of the genotypes achieved fruits firmness values from 1.82 kg/cm^2 for Banato hybrid up to 3.25 kg/cm^2 at Ghittia variety, while in the mycorrhizal plants (AMF+) the amplitude was higher ranging from 2.16 kg/cm^2 in Banato to 3.82 kg/cm^2 in Sorada hybrid. Independent of mycorrhization, it was observed that Ghittia variety and Sorada hybrid have recorded significantly higher values compared to the other genotypes.

Under the effect of AMF, at the level of the whole experience the TSS of the fruits recorded amplitude of 0.36 with limits from 5.98 to 6.34 ^{0}Brix (Table 2). Thus, it was observed that the use of AMF had a positive effect associated with a significant increase in the amount of TSS by 6.02%. Given the unilateral effect of the genotype, it was observed that the TSS showed a variation of 0.46 ^{0}Brix with values between 5.88 in USAB29 and 6.34 ^{0}Brix in Tomtim variety. As such, Ghittia and Tomim varieties have achieved significantly lower values compared to the rest of the genotypes. The four hybrids registered significantly equal values of TSS.

Table 2. The effect of mycorrhization and genotype on TSS (^{0}Brix) of tomato fruits

Genotype	Mycorrization		Genotype	
	AMF -	**AMF +**	Mean	CV
Banato	6.07 ab	6.32 ab	6.19±0.05 A	3.86
Ghittia	5.86 bc	6.16 bc	6.01±0.08 B	5.73
Miruna	6.11 a	6.49 a	6.30±0.09 A	6.01
Sorada	6.02 ab	6.45 a	6.24±0.07 A	4.71
Tomtim	5.65 c	6.10 c	5.88±0.08 B	5.64
USAB29	6.17 a	6.51 a	6.34±0.07 A	4.85
AMF Mean	5.98±0.04 Y	6.34±0.03 X	6.16±±0.03	
CV	5.26	4.58	5.70	

AMF- (non-mycorrhizal); AMF+ (mycorrhizal); Data represents mean ±SE
Genotype LSD 5%=0.16; AMF LSD 5%=0.1; Genotype x AMF LSD 5%=0.22
Different letters (a-c) in the columns indicate significant differences ($p<0.05$) between genotypes.
Capital letters were used for AMF means (X, Y) and genotype means (A-B) comparisons

Based on the genotype x mycorrization interaction, it was observed that in the AMF- plants the amount of soluble solids varied from 5.65 in Tomtim variety up to 6.17 ^{0}Brix for USAB29 hybrid, with amplitude of 0.52 ^{0}Brix. The USAB29 and Miruna hybrids achieved significant increases than Ghittia and Tomtim varieties.

Under the effect of AMF the variation of TSS was associated with amplitude from 6.1 in Tomtim variety up to 6.51 ^{0}Brix for USAB29 hybrid. In the AMF+ plants, the fruits of Miruna, Sorada and USAB29 hybrids were highlighted, which presented a significantly higher TSS compared to Ghittia and Tomtim varieties. Regarding the effect of mycorrization on the TSS in each genotype, it was found that generally AMF+ plants recorded significant relative increase from 4.12% in Banato to 7.96% in Tomtim.

Regarding the main effect of mycorrhization (Table 3), the fruits titratable acidity (TA) showed amplitude of 0.086 with values ranging from 0.46 to 0.546 citric acid %. Overall, the mycorrhization had an negative effect causing a significant relative decrease of 15.75%.

Given the cumulative effect of the genotype, average values of TA from 0.447 in Sorada to 0.593 citric acid % in Tomtim variety, were found. The fruits of Tomtim and Banato achieved a significantly higher acidity by 9.5-47.1% than the rest of the genotypes. The acidity of Miruna fruits was significantly lower to the other genotypes.

Table 3. The effect of mycorrhization and genotype on titratable acidity (citric acid %) of tomato fruits

Genotype	Mycorrization		Genotype	
	AMF -	**AMF +**	Mean	CV
Banato	0.602 ab	0.530 a	0.566±0.023 A	17.34
Ghittia	0.573 bc	0.450 b	0.512±0.024 B	19.80
Miruna	0.437 e	0.370 c	0.403±0.014 D	14.73
Sorada	0.487 d	0.407 b	0.447±0.019 C	18.75
Tomtim	0.623 a	0.563 a	0.593±0.026 A	18.76
USAB29	0.553 c	0.440 b	0.497±0.028 B	24.37
AMF Mean	0.546±0.014 X	0.460±0.015 Y	0.503±0.011	
CV	19.34	23.95	23.01	

AMF- (non-mycorrhizal); AMF+ (mycorrhizal); Data represents mean ±SE
Genotype LSD 5%=0.031; AMF LSD 5%=0.024; Genotype x AMF LSD 5%=0.042
Different letters (a-e) in the columns indicate significant differences (p<0.05) between genotypes.
Capital letters were used for AMF means (X, Y) and genotype means (A-D) comparisons.

The mycorrization significantly influenced the TA of fruits for all genotypes, being associated with decreases between 9.63% in Tomtim and 21.47% in Ghittia variety. The AMF- plants registered an TA of the fruits with values from 0.437 for Miruna to 0.623 citric acid % in Tomtim, while in the AMF+ plants the amplitude was between 0.370 and 0.563 citric acid %. In the absence of mycorrization the fruits of the Tomtim variety had a significantly higher TA to the other genotypes, while under the effect of mycorrization the fruits of Banato next to the Tomtim fruits, recorded a high TA. Independent of mycorrization, the fruits of Banato hybrid showed a significantly lower acidity.

Table 4. The effect of mycorrhization and genotype on maturity index of tomato fruits

Genotype	Mycorrization		Genotype	
	AMF -	**AMF +**	Mean	CV
Banato	10.40 cd	12.11 d	11.26±0.48 E	17.99
Ghittia	10.36 cd	14.14 c	12.25±0.68 D	23.57
Miruna	14.25 a	17.76 a	16.00±0.65 A	18.08
Sorada	12.65 b	16.51 ab	14.58±0.84 B	24.44
Tomtim	9.32 d	11.34 d	10.33±0.59 F	24.41
USAB29	11.45 bc	16.23 b	13.84±1.04 C	35.11
AMF Mean	11.40±0.34 Y	14.68±0.55 X	13.04±0.36	
CV	22.04	27.56	29.63	

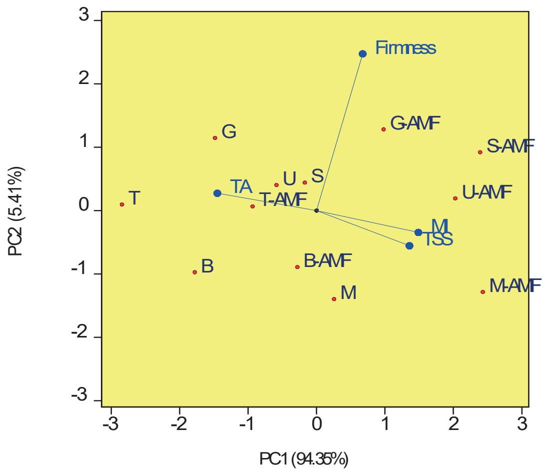
AMF- (non-mycorrhizal); AMF+ (mycorrhizal); Data represents mean ±SE
Genotype LSD 5%=0.98; AMF LSD 5%=0.66; Genotype x AMF LSD 5%=1.34
Different letters (a-d) in the columns indicate significant differences (p<0.05) between genotypes.
Capital letters were used for AMF means (X, Y) and genotype means (A-E) comparisons.

Under the effect of AMF, at the level of the whole experience the maturity index (MI) of the fruits recorded amplitude with limits from 11.4 to 14.68 (Table 4). Thus, it was observed that the use of AMF had a positive effect associated with a significant increase of MI by 28.77%.
Given the main effect of the genotype, it was observed that the MI shoved a variation of 5.67 with values from 10.33 in Tomtim to 16 in Miruna hybrid. As such, the fruits of Miruna have achieved significantly higher value compared to the rest of the genotypes, being followed by those of Sorada and USAB29.
Based on the genotype x mycorrization interaction, it was observed that in the AMF- plants the MI varied from 9.32 in Tomtim up to 14.25 for Miruna. As such, the fruits of Miruna achieved significant increases of flavor and taste, while the fruits Sorada have been highlighted by a superior aroma against Banato, Ghittia and Tomtim fruits. Under the effect of mycorrization the variation of MI was associated with amplitude from 11.34 in Tomtim up to 17.76 for Miruna. Also, in the AMF+ plants, the fruits of Miruna and Sorada hybrids were highlighted, by a higher flavor and taste. Regarding the effect of mycorrization on the MI in each genotype, it was found that generally AMF+ plants recorded significant relative increase from 16.44% in Banato to 41.75% in USAB29 hybrid.

Table 5. The effect of mycorrhization and genotype on flavour index of tomato fruits

Genotype	Mycorrization		Genotype	
	AMF -	**AMF +**	Mean	CV
Banato	0.785 a	0.697 a	0.741±0.03 A	17.33
Ghittia	0.742 a	0.588 b	0.665±0.031 B	19.72
Miruna	0.570 b	0.490 c	0.530±0.017 C	13.93
Sorada	0.632 b	0.537 bc	0.585±0.024 C	17.60
Tomtim	0.799 a	0.735 a	0.767±0.033 A	18.32
USAB29	0.723 a	0.582 b	0.653±0.036 B	23.47
AMF Mean	0.709±0.018 X	0.605±0.019 Y	0.657±0.014	
CV	19.04	23.39	22.38	

AMF- (non-mycorrhizal); AMF+ (mycorrhizal); Data represents mean ±SE
Genotype LSD 5%=0.06; AMF LSD 5%=0.012; Genotype x AMF LSD 5%=0.078
Different letters (a-c) in the columns indicate significant differences ($p<0.05$) between genotypes.
Capital letters were used for AMF means (X, Y) and genotype means (A-C) comparisons.



B - Banato; G - Ghittia; M - Miruna; S - Sorada; T - Tomtim; U - USAB29

Figure 1. Biplot (PC 1, 2) for fruits quality traits of tomato genotypes

The mycorrization significantly influenced the FI of fruits for most of the genotypes, being associated with decreases between 11.21% in Banato and 20.75% in Ghittia variety (Table 5). The FI of Tomtim variety fruits was not significantly affected by the mycorrization.
The AMF- plants registered an FI of the fruits with values from 0.57 for Miruna to 0.799 in Tomtim,

while in the AMF+ plants the amplitude was between 0.49 and 0.735. In the absence of mycorrization the fruits of Miruna and Sorada hybrids have had a significantly lower flavour to the other genotypes, while under the effect of mycorrization the fruits of Banato next to the Tomtim fruits, recorded the highest flavour.

The PCA biplot from Figure 1 expresses 99.76% of the variability of the four fruit quality traits in the six tomato genotypes. Depending on the position of the genotypes towards the vectors of the different traits, it was observed that overall the AMF+ plants achieved higher MI and TSS, associated with low TA. The AMF+ plants of Sorada and USAB29 hybrids achieved fruits with the highest flavour and aroma according to MI and TSS, associated with lower TA and firmness above the mean, while the fruits of AMF+ Miruna plants shoved high TSS, MI, low TA and firmness. In the case of AMF+ plants for Tomtim variety the fruits recorded the high TA, low TSS, MI and average firmness. Under the mycorrization the fruits of Banato and Ghittia shoved similar TA, TSS and MI, but different firmness, higher in Ghittia, respectivelly. Regarding the AMF- plants, the fruits of Miruna hybrid achieved the higher taste and flavour and lower firmness.

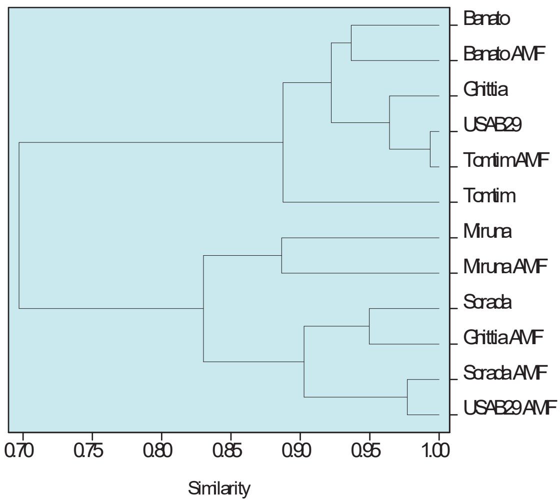


Figure 2. UPGMA clustering of tomato genotypes based on fruits quality traits

According to the hierarchical classification (Figure 2), it has been observed that at AMF- plants, the fruits highest similarity for quality traits was recorded for the genotypes: USAB29 and Ghittia (96.45%); USAB29 and Sorada (95.88%); Banato and Tomtim 93.67%). The highest diversity of fruits quality traits, was presented by the AMF- plants: Miruna and Tomtim (35.35%); Miruna and Ghittia (28%).

Considering the AMF+ plants, the highest similarity was observed between the fruits of the following genotypes: Sorada and USAB29 (97.71%); Banato and Tomtim (96.637%); Ghittia and Sorada 95.02%), while the genotypes Tomtim and Miruna (40.44%), Tomtim and Sorada (33.36%), genotypes showed a high fruits diversity. Thus, generally under the effect of mycorrization, an decrease of the similarity for the fruits quality traits between different genotypes was observed, which indicates a different reaction of them. The AMF- plants of Banato, Ghittia, Tomtim, USAB29 and AMF+ plants of Banato, Tomtim, are clustered togheter in a main group, showing a 90% similarity of the fruits quality traits. The fruits of these plants are characterised by high acidity, low soluble solids content and maturity index. The AMF+ plants of Miruna, Ghittia, Sorada, USAB29, and AMF- plants of Miruna, Sorada, constitute a second major group characterized by a similarity of 83%.

Regarding the significant negative impact of mycorrhization on titrable acidity of fruits Bona et al. (2017) reported similar results, while Regvar et al. (2003) found an association of low acidity with a slight decrease in electrical conductivity.

The beneficial effect of mycorrhiza symbiosis on the increase of total soluble solids as an indicator of dissolved, sucrose, and fructose, which reflects fruit sweetness, aligns with previous research (Chafai et al., 2023; Ullah et al., 2023). Our finding are in accordance with that of previous studies (Horvath et al., 2020; Huang et al., 2013; Subramanian et al., 2006) who found higher content of sugar in fruits of mycorrhizal plants under different stresses.

The positive effect of mycorrhization on fruit firmness and sugar content previous reported by Felfoldi et al. (2022), has been confirmed in our study. The increased fruit yield and quality of mycorrhizal tomato plants was also reported by previous studies (Di Fossalunga et al., 2012; Giovanetti et al., 2012; Miranda et al., 2015).

CONCLUSIONS

The mycorrhiza treatment expressed the highest effect on the variability of sugar content and a lower effect on the fruits firmness, being associated with an increase of firmness, sugar content and maturity index, and a decrease of acidity and flavour index, respectively.

The fruits firmness shoved the highest variability between genotypes, while the variation of sugar content was lesser influenced by the genotype.

Under the effect of genotype x mycorrhiza interaction, the acidity of fruit recorded the highest variability, in opposite with the low influence on fruit firmness.

In the case of fruits from Tomtim hybrid and Ghittia variety the highest effect of mycorrhiza treatment were observed, while the influence on the fruits from Banato hybrid was lower.

The mycorrhizal plants of Sorada and USAB29 hybrids achieved fruits with the highest sugar content, flavour and aroma associated with lower acidity and a good firmness, while the quality of Miruna fruits were associated with a low firmness.

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