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EFFECTS OF RIPENING STAGES AND STORAGE DURATIONS ON RESISTANCE PARAMETERS OF BEEF TYPE TOMATOES: PART 1: SPRING PERIOD

EFEITOS DE ESTÁGIOS DE MATURAÇÃO E DURAÇÕES DE ARMAZENAMENTO EM PARÂMETROS DE RESISTÊNCIA DE TOMATES CORAÇÃO DE BOI: PARTE 1: PERÍODO DE PRIMAVERA

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ABSTRACT: Following the harvest, agricultural products are subjected to various negative impacts throughout the way to consumers. Mechanical damages such as color darkening, abrasion, cuts, or punctures over the fruit surface are irreversible damages and such damages ultimately end up in significant quality and economic losses. In modern production systems, only a certain portion of the products directly reach from producer to consumers. The majority of these products are subjected to mechanical damages through the crush, squeeze, vibration, and similar impacts during the harvest and postharvest processes. In this study, Tybeef tomato cultivar grown over the experimental greenhouses of Bati Akdeniz Agricultural Research Institute (BATEM) (control) and 14-193 and 14-206 coded candidate cultivars developed through breeding programs of BATEM were used as the plant material. Resistance parameters of tomato cultivars were determined at 4 different ripening stages (green, turning, pink, and red) and 4 different storage durations (4, 8, 12, and 16 days). Resistance parameters decreased with the progress of ripening and storage durations. All measurements and assessments revealed that 14-193 coded candidate cultivars were prominent for resistance parameters.

KEYWORDS: Damage. Harvest Date. Quality. Sensitivity**.** Vegetable.

INTRODUCTION

There are intense labor and input in agricultural commodities. Therefore, pre and postharvest processes should continuously be monitored to minimize yield losses, to have products complying with certain standards, to supply high-quality products to markets, and to improve the allure of the products. Physiological and biological deteriorations during the production, harvest, and postharvest processes result in [illegible] economic losses for both the producers and the country (KABAS, 2002). Insufficient infrastructure and organization generate about 25% losses in productions and only 7-8% of total production is exported just because of losses in the quality of the products. Since standard and desired commodities are not able to be produced, it is quite hard to compete with other exporter countries in international markets. It should always be kept in mind that “quality at the table is more significant than the quality at the branch”. Thus, all the processes from the field to consumers should be performed in the uppermost appropriate manner. High-quality products should preserve quality attributes for a long time and marketed abroad on demand. Such cases will automatically improve both the producer and the country's economy.

Postharvest losses are generally generated through mechanical damages. Such damages result from crash, impact, puncture, vibration, and similar mechanical processes. About 6.1 million tons of [illegible] are produced in the [illegible] About 75% of this production (4.6 million tons) is constituted by vegetables and tomato alone constitutes about 55% of vegetable production of the province. About 62% of under-cover tomato production and 20% of open-field production of Turkey come from Antalya. About 3 million tons of fresh vegetables and fruit are exported from Turkey and, from those, 490 thousand tons are exported from Antalya alone (ANONYMOUS, 2018).

Mechanical damages may result in 30-40%

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losses throughout different processes from the field to consumers (PELEG; HINGA, 1986). Such damages are generally encountered through static and dynamic external forces like a crash, impact, squeeze, and vibration. Mechanical damages on agricultural products may vary with the physical and biological structure of the product and type of external forces. The damage is generally encountered as smash and fracture with the impact of crash forces and excessive deformations. Since agricultural products are living organisms, they are highly sensitive to mechanical damages. Damages during the transportation of agricultural products reduce their market values and make these products perishable and unstable for diseases and deteriorations (KARA; TURGUT, 1988). Therefore, the mechanical characteristics of agricultural products should be known to minimize such damages and losses accordingly.

Several researchers have conducted studies on different agricultural products (GEZER et al., 2000) investigated dimensional attributes, mass, removal force, mass/removal force ratio, total dissolved solids, fruit flesh firmness, and modulus of elasticity of tomato, pepper, eggplant and cucumbers and reported modules elasticity value of 1006 kPa for tomato and 632 kPa for cucumber (MOHSENIN, 1986) and (SITKEI, 1986) conducted studies on external damages generated by static and dynamic forces and identified various types of external damages. Desmet et al. (2004) investigated the mechanical characteristics of tomato and pointed out that genotypes with lower punching sensitivity should be used for direct measurements of mechanical characteristics. Bentini et al. (2009) investigated the effects of potato cultivars and storage durations on the physio-mechanical characteristics and indicated that mechanical characteristics of the different cultivars were significantly different from each other. Eraltan (2005) stored Dixired and Earlyred peaches in cold storage at 0 ºC temperature and 90% relative humidity for 28 days to investigate the effects of cultivars and storage durations on mechanical attributes and reported decreasing peal tearing force, tearing energy, and firmness index with increasing storage durations. Garcia et al. (1995) investigated the effects of irrigation, moisture content, harvest time, and storage on fruit firmness peel characteristics, and damaging sensitivity of apple and pear species and put forth the relationships between fruit physical attributes and damaging. Schoorl and Holt (1983) studied the effects of storage durations and temperatures on the damaging sensitivity of Jonathan, Delicious, and Granny Smith apples.

Identification of resistance parameters of agricultural products constitutes valuable information for machine and equipment design, on one hand, aids in finding out the resistance of different agricultural products against mechanical forces and thus taking relevant measures accordingly on the other hand. In this study, the effects of 4 different fruit ripening stages (green, turning, pink, and red) and 4 different storage durations (4, 8, 12, and 16 days) on some resistance parameters of tomato were investigated.

MATERIAL AND METHOD

In this study, 3 different tomato cultivars (1 commercial cultivar - Tybeef and 2 candidate cultivars developed in tomato breeding programs of Bati Akdeniz Agricultural Research Institute (BATEM - 14-193, 14-206) were used as the plant material (Figure 1).

Figure. 1. Tybeef, 14-193,14-206 variety

Experiments were conducted at 4 different ripening stages and 4 different storage durations. The texture analysis test device was used to determine resistance parameters and a color measurement device was used to determine color parameters.

Experiments were conducted in two stages. The physical characteristics of tomatoes were determined in the first stage and resistance parameters were determined in the second stage of the study. All measurements were performed at 4 different ripening stages (green, turning, pink, and red) and 4 different storage durations (4, 8, 12, and 16 days at 12ºC temperature and 90% relative humidity).

For dimensional and shape characteristics, fruit length and diameters were measured with a digital caliper (±0.01 mm). The following equations were used to calculate the geometric mean diameter and sphericity of the fruits (MOHSENIN, 1986) and (HACISEFEROGULLARI et al., 2005).

$$Dg = (LD^2)^{1/3} \quad (1)$$

Dg = Geometric mean diameter (mm)
L = Length (mm)
D = diameter of tomato (mm)

Sphericity was calculated dependent on geometric mean diameter using the following equation (MOHSENIN, 1986) and (HACISEFEROGULLARI et al., 2005).

$$\Phi = (Dg/L) *100 \quad (2)$$

Φ = Sphericity index (%),
Dg = Geometric mean diameter (mm),
L = Length (mm)

Also, the surface areas of tomato samples were determined by using the following formula (MOHSENIN, 1986).

$$S = Dg^2 \quad (3)$$

S = Surface area (mm^2),
Dg = Geometric mean diameter (mm)

A texture analysis device (probe diameter: 2 mm, probe penetration rate: 10 mm min^{-1}) was used to determine puncture force, maximum puncture strain, deformation, firmness, and modules of elasticity of tomato fruits (Figure 2).

Figure 2. Texture analysis device

The tomato samples were placed on the base plate and pressed by the moving 2 mm diameter probe until the fruit punctured, and the force–deformation curve was recorded in real-time for each experiment (Figure 3). Afterward, some resistance parameters such as deformation, force, and strain were extracted from each recorded curves.

For each cultivar, 50 fruits were used in experiments. Modules of elasticity and firmness were calculated with the aid of the following equations (NELSON; MOHSENIN, 1968; MOHSENIN, 1986; KABAS et al., 2008).

$$E = \frac{F(1-\gamma^2)}{D.\Delta L} \quad (4)$$

E = Modules of elasticity (Nmm^{-2})
F = Force (N)
γ = Poisson ratio
D = Diameter of the cylindrical probe (mm)
ΔL = Deformation (mm)

$$Q = F/D \quad (5)$$

Q = Firmness (Nmm^{-1}),
F = Maximum force (N),
D = deformation in maximum force (mm)

The Peel color of tomatoes was measured with Minolta CR-100 chronometer (Minolta CR-100, Osaka, Japan) device in accordance with L*, a*, b* color space. Measurements were performed from 6 different sections of previously numbered

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tomato fruits and averages of these measurements were taken. CIE L, a*, b*, chroma (C), and hue angle (ho) components of fruit color were analyzed with the aid of Minolta CR 400 (Konica Minolta) device (Figure 4). Measurements were made under the D65 light source. The device was calibrated with a calibration plate (CR A43) before the measurements (OZDEMIR, 2001). Minolta White color standard was used in calibrations. L* indicates the changes in brightness of color. L* gets maximum values as approached to 100 and such a value indicates a 100% reflection of the light sent to the color. The a* indicates the color change from green to blue and the b* value indicates the color change from blue to yellow. Positive a* values indicate red and negative a* values indicate green color; positive b* values indicate yellow and negative b* values indicate blue color. Increasing negative or positive values indicate color darkening.

RESULTS AND DISCUSSION

Experiments were set up with 1 commercial tomato cultivar (Tybeef) and 2 candidate tomato cultivars of BATEM (14-193 and 14-206) in the spring period in a greenhouse in randomized blocks design. Fruit physical characteristics including weight, diameter, length, geometric mean diameter (GMD), sphericity, and surface area are provided in Table 1.

Table 1. Physical characteristics of the cultivars

	Tybeef	**14-193**	**14-206**
Weight (g)	334.40 ± 8.190	248.90 ± 4.163	282 ± 2.865
Diameter (mm)	88.92 ± 0.651	85.21 ± 0.732	88.60 ± 0.867
Length (mm)	75.84 ± 0.673	63.30 ± 0.349	68.84 ± 0.549
GMD (mm)	80.60 ± 0.420	73.86 ± 0.483	77.85 ± 0.430
Sphericity (%)	106.58 ± 0.911	116.73 ± 0.656	113.45 ± 1.135
Surface area (mm^2)	20425.61 ± 215.784	17162.90 ± 220.419	19058.45 ± 207.046

Tybeef was the heaviest cultivar with a fruit weight of 334 g and it was followed by 14-206 (282 g) and 14-193 (248 g) cultivars. The same order of cultivars was also valid for surface area, length, and geometric mean diameter. The order of cultivars for sphericity was 14-193 > 14-206 > Tybeef. Ponjičan et al. (2012) used hybrid industrial and table tomato cultivars and reported a sphericity value of 108% for table tomatoes and 83% for industrial tomatoes. Color analyses of cultivars were performed at 4 different ripening periods (green, turning, pink, and red) (Table 2).

Table 2. Color analysis of tomato variety according to ripening periods

Variety	**Ripening period**	**L***	**a***	**b***	**C***	**h**
Tybeef	Green	56.59583	-14.1792	26.955	30.45833	117.7483
	Turning	49.51288	12.50303	28.86887	31.86461	67.5616
	Pink	46.44112	21.59205	31.21651	38.18437	55.63898
	Red	42.88548	27.99544	33.51827	41.14655	49.0069
14-206	Green	61.0003	-13.8225	27.5175	30.79583	116.6958
	Turning	53.9038	9.222059	32.01636	33.5309	74.24977
	Pink	48.80256	22.19618	32.24586	43.48071	59.36307
	Red	42.01052	27.89648	30.58708	41.42207	47.68977
14-193	Green	64.8925	-13.8708	28.955	32.10917	115.6192
	Turning	51.03345	16.67125	35.25025	39.40221	65.74004
	Pink	42.55084	28.08351	31.65187	42.45265	48.23326
	Red	40.42044	29.75215	28.65868	41.31484	43.91488

Color graphs for different ripening stages were presented in the order of red, pink, turning, and green. Mean a* value of Tybeef F1 was 27.995 for red tomatoes, 21.592 for pink tomatoes, 12.503 for turning tomatoes, and -14.179 for green tomatoes. Mean a* value of 14-206 cultivar was 27.896 for red tomatoes, 22.196 for pink tomatoes, 9.222 for turning tomatoes, and -13.822 for green tomatoes. Mean a* value of 14-193 cultivar was 29.752 for red tomatoes, 28.083 for pink tomatoes, 16.671 for turning tomatoes, and -13.870 for green tomatoes. The greatest and the lowest a* values (27.995 and -14.179) were observed in the Tybeef F1 cultivar. Ye and Zhang (2018) reported the greatest a* value as 31.240 and the lowest a* value as -12.62. Present findings revealed that a*/b* ratio was also an important indicator for changing resistance parameters. Similar findings were also reported by Camelo and Gómez (2004).

The data were analyzed based on ripening stages. There were significant differences in the puncture force of the cultivars at a 5% level. The data on the puncture force are provided in Table 3.

Table 3. Variance table for puncture force (N)

Source of Variance	Sum of Squares	Mean Squares	F value	
Cultivar	123.5493	44.8428	< 0.0001	**
Replicate	23.6189	8.5726	0.0003	**
Ripening	4174.2611	1010.044	< 0.0001	**
Storage	975.1566	176.9687	< 0.0001	**
Cultivar*Storage	21.5991	1.9599	0.0574	ns
Cultivar*Ripening	38.4993	4.6578	0.0003	**
Ripening*Storage	263.8993	15.9639	< 0.0001	**
Cultivar*Ripening*Storage	48.6798	1.4724	0.0905	ns

*: 0.05, **: 0.01, ns: Not-significant

Variance analysis revealed that cultivars, ripening stages, and storage durations had significant effects on puncture forces at a 1% level. Cultivar*ripening stage and storage duration*ripening stage interactions had also significant effects on puncture forces ($p < 0.01$), but the effects of cultivar*storage duration*ripening stage triple interactions were not found to be significant. There were interactions between the cultivars and varieties in the turning phase of tomatoes. Interaction data are provided in Table 4.

Table 4. Cultivar*ripening stage interaction table for puncture force (N)

Cultivar	Green	Turning	Pink	Red	Mean
Tybeef	21.25 c	12.85 b	10.77 b	9.72 b	13.65 **C**
14-193	24.62 a	14.54 a	12.24 a	11.3 a	15.68 **A**
14-206	22.58 b	12.63 b	11.65 a	11.41 a	14.57 **B**
Mean	22.82 **A**	13.34 **B**	11.55 **C**	10.81 **D**	

CV (%) = 8.02 ; Cultivar LSD (0.05) =0.42; Ripening stage LSD (0.05) =0.49; Cultivar*Ripening Stage interaction LSD (0.05) = 0.848

The greatest puncture force (24.62 N) was observed in the green ripening stage of 14-193 cultivar and the lowest puncture force (9.72 N) was observed in the red ripening stage of the Tybeef cultivar. Considering the ripening stages, the greatest puncture force was observed in green tomatoes. With regard to cultivar*ripening stage interactions, 14-193 cultivar was prominent in all ripening stages.

The greatest puncture forces were observed in green tomatoes and the lowest values were observed in red tomatoes since fruit firmness decreased with the progress of ripening. Similar findings were also reported by Sirisomboon et al. (2012) indicating decreasing firmness values from green to red tomatoes.

There were interactions between storage durations of the cultivars and the ripening stage. Interaction data are shown in Table 5.

Considering the storage duration*ripening stage interactions, the greatest puncture force (26.76 N) was observed in the green ripening stage of 0-day storage and the lowest puncture force (9.06 N) was observed in the turning ripening stage of 16-day storage. Considering the storage durations, the greatest puncture force was observed in 16-day storage. Puncture resistance decreased with the progress of ripening and storage durations. Similar findings were also reported for tomatoes by Yurtlu and Erdogan (2005) and Bui et al. (2010). Such a case indicated that fruits were more sensitive to physical damages at early ripening stages.

Table 5. Ripening stage*storage duration interaction table for puncture force (N)

Storage Duration	Green	Turning	Pink	Red
0 day	26.76 a	20.39 a	13.56 a	12.77 a
4 days	25.09 b	13.93 b	12.29 b	11.47 b
8 days	22.89 c	12.58 c	11.39 c	10.83 b
12 days	21.20 d	10.75 d	10.8 c	9.81 bc
16 days	18.08 e	9.06 e	9.73 cd	9.17c

CV (%) = 8.01; Storage duration LSD (0.05) = 0.54; Storage duration*Ripening stage interaction LSD (0.05) = 1.089

The variance table for strain values is provided in Table 6. There were significant differences in strain values of the cultivars at a 5% level.

Table 6. Variance table of strain (Nmm^{-2})

Source of Variance	Sum of Squares	Mean Squares	F value	
Cultivar	7.72183	44.8428	<.0001	**
Replicate	1.47618	8.5726	0.0003	**
Ripening	260.89132	1010.044	<.0001	**
Storage	60.94729	176.9687	<.0001	**
Cultivar*Storage	2.40621	1.9599	0.0574	n. s
Cultivar*Ripening	1.34994	4.6578	0.0003	**
Ripening*Storage	16.49371	15.9639	<.0001	**
Cultivar*Ripening*Storage	3.04248	1.4724	0.0905	n. s

*: 0.05, **: 0.01, ns: Not-significant

Variance analysis revealed that cultivars, replicates, ripening stages, and storage durations had significant effects on strain values at a 1% level. Considering the interactions, cultivar*ripening stage and storage duration*ripening stage interactions were also found to be significant ($p<0.01$), but cultivar*storage duration and cultivar*storage duration*ripening stage triple interaction did not have significant effects on strain values.

There were interactions between the cultivars and storage durations in turning the ripening stage. Interaction data are provided in Table 7.

Table 7. Cultivar*Ripening stage interaction table for strain (Nmm^{-2})

Cultivar	Green	Turning	Pink	Red	Mean
Tybeef	5.31 c	3.21 e	2.69 h	2.43 ı	5.31 c
14-193	6.15 a	3.64 d	3.06 ef	2.83 gh	6.15 a
14-206	5.65 b	3.16 e	2.91 fg	2.85 fgh	5.65 b
Mean	5.71 A	3.34 B	2.89 C	2.70 D	

CV (%) = 8.02; Cultivar LSD (0.05) =0.42; Ripening stage LSD (0.05) =0.49; Cultivar*Ripening Stage interaction LSD (0.05) = 0.848

The greatest strain value (6.15 Nmm^{-2}) was observed in the green ripening stage of 14-193 cultivar and the lowest strain value (2.43 Nmm^{-2}) was observed in the red ripening stage of the Tybeef cultivar (Table 7). Considering the strain values of ripening stages, the greatest value was observed in green tomatoes. Considering the cultivar*ripening stage interactions, 14-193 was prominent in all ripening stages. The greatest strain values were observed in green tomatoes and the lowest values were observed in red tomatoes since initial fruit firmness decreased with the progress of ripening. Similar findings were also reported by Sirisomboon et al. (2012). There were interactions between the ripening stage and storage durations. Interaction data are provided in Table 8.

Table 8. Ripening stage*storage duration interaction table for strain (Nmm^{-2})

Storage duration	Green	Turning	Pink	Red	Mean
0 day	6.69 a	5.10 d	3.39 fg	3.19 gh	4.59
4 days	6.27 b	3.48 f	3.08 hı	2.87 ıj	3.93
8 days	5.72 c	3.15 gh	2.85 ıj	2.71 jk	3.61
12 days	5.32 d	2.69 jkl	2.70 jkl	2.46 klm	3.29
16 days	4.52 e	2.29 m	2.43 lm	2.27 m	2.88

CV (%) = 8.01; Storage duration LSD (0.05) = 0.14; Storage duration*Ripening stage LSD (0.05) = 0.55

Considering the storage duration*ripening stage interactions, the greatest strain value (6.69 Nmm^{-2}) was observed in the green ripening stage of 0-day storage and the lowest strain value (2.27 Nmm^{-2}) was observed in the red ripening stage of 16-day storage. Considering the storage durations, the lowest puncture force was observed in 16-day storage. The resistance of tomatoes decreased with the progress of ripening stages and storage durations. Yurtlu and Erdogan (2005) also reported similar findings for tomatoes. Ciupak et al. (2012) investigated the effects of ripening on tomato cultivars and indicated that damaging strain decreased with the progress of ripening.

The variance table for deformation values is provided in Table 9. A separate analysis was performed for each ripening stage and differences in deformation values of the cultivars were not found to be significant at a 5% level.

Table 9. Variance table for deformation (mm)

Source of Variance	Sum of Squares	Mean Squares	F value	
Cultivar	2.83794	2.9150	0.0581	*
Replicate	30.41596	31.2420	<.0001	**
Ripening	162.67909	111.3981	<.0001	**
Storage	125.66719	64.5401	<.0001	**
Cultivar*Storage	2.33291	0.7988	0.5728	**ns**
Cultivar*Ripening	3.61340	0.9279	0.4963	**ns**
Ripening*Storage	19.37272	3.3165	0.0004	**
Cultivar*Ripening*Storage	10.67492	0.9137	0.5834	**ns**

*: 0,05, **: 0,01, ns: Not-significant

However, there were significant differences in deformation values of the storage durations at a 5% level. Interaction data are provided in Table 10.

Table 10. Ripening stage*storage duration interaction table for deformation (mm)

Storage Duration	Green	Turning	Pink	Red	Mean
0 day	3.93 j	5.43 fgh	5.31 gh	5.69 efg	5.09 E
4 day	4.26 ij	5.61 efg	5.81 efg	6.03 ef	5.43 D
8 day	4.42 ij	6.01 ef	6.16 de	6.69 c	5.90 C
12 day	4.65 i	6.80 cd	6.99 cd	7.16 c	6.40 B
16 day	4.86hi	7.84 b	8.46 ab	8.70 a	7.47 A
Mean	4.42 C	6.34 B	6.55 B	6.85 A	

CV (%) = 11.54; Ripening stage LSD (0.05) =0.29; Storage duration LSD (0.05) = 0.32; Storage duration*Ripening

Variance analysis revealed that replicates, ripening stages, and storage durations had significant effects on deformation at a 1% level, but the effects of cultivars were not found to be significant. Considering the interactions, cultivar*ripening stage, storage duration*ripening stage, and cultivar*storage duration*ripening stage interactions were not found to be significant, but ripening stage*storage duration interaction was found to be significant ($p < 0.01$).

With regard to deformation values of storage duration*ripening stage interactions, the lowest value was observed in the green ripening stage of 0-day storage (control) and the greatest value was observed in the red ripening stage of 16-day storage. Considering the storage durations, the greatest deformation was observed in 16-day storage. Deformation increased with the progress of ripening stages and storage durations. Yurtlu and Erdogan (2005) also reported similar deformation values for tomatoes in their study.

The variance table for firmness values is provided in Table 11. There were significant differences in the firmness values of the cultivars at a 5% level.

Table 11. Variance table for firmness (Nmm^{-1})

Source of Variance	Sum of Squares	Mean Squares	F value	
Cultivar	2.55469	8.1044	0.0005	**
Replicate	2.69858	8.5609	0.0003	**
Ripening	386.49221	817.3983	<.0001	**
Storage	94.39840	149.7335	<.0001	**
Cultivar*Storage	1.50794	1.5946	0.1547	ns
Cultivar*Ripening	2.17381	1.7240	0.0997	ns
Ripening*Storage	14.51595	7.6750	<.0001	**
Cultivar*Ripening*Storage	3.57555	0.9452	0.5421	ns

*: 0,05, **: 0,01, ns: not-significant

Variance analysis revealed that cultivars, replicates, ripening stages, and storage durations had significant effects on firmness values at a 1% level. Considering the interactions, cultivar*ripening stage, storage duration*ripening stage, and cultivar*storage duration*ripening stage interactions were not found to be significant, but ripening stage*storage duration interaction had significant effects on firmness values (p<0.01).

There were interactions between the cultivars and the ripening stage. Interaction data are provided in Table 12.

Table 12. Cultivar*Ripening stage interaction table for firmness (Nmm^{-1})

Cultivar	Green	Turning	Pink	Red	Mean
Tybeef	5.01	4.52	3.48	3.16	**5.28 B**
14-193	5.56	4.88	3.96	3.44	**5.84 A**
14-206	5.24	4.08	3.72	3.36	**5.40 B**
Ort.	**5.26 A**	**4.48 B**	**3.72 C**	**3.32 D**	

CV (%) = 14.36; Cultivar LSD (0.05) = 0.07; Ripening stage LSD (0.05) = 0.08; Cultivar*Ripening Stage interaction =n. s

There were interactions between the ripening stage and storage durations. Interaction data are shown in Table 13.

Table 13. Ripening stage*Storage duration interaction table for firmness (Nmm^{-1})

Storage Duration	Green	Turning	Pink	Red	Mean
0 day	6.87 a	3.80 a	2.60 a	2.30 a	3.89 A
4 days	5.97 b	2.52 b	2.12 b	1.93 b	3.14 B
8 days	5.19 c	2.15 c	1.86 c	0.82 c	2.71 C
12 days	4.60 c	1.60 d	1.56 d	1.38 d	2.29 D
16 days	3.74 d	1.17 e	1.15 e	1.06 e	1.78 E
Mean	5.26 A	2.24 B	1.86 C	1.66 D	

CV (%) = 14.36; Ripening stage LSD (0.05) =0.08 Storage duration LSD (0.05) =0.09; Storage duration*Ripening stage interaction.

With regard to firmness values of storage duration*ripening stage interactions, the greatest value was observed in the green ripening stage of 0-day storage and the lowest value was observed in the red ripening stage of 16-day storage. Considering the storage durations, the lowest deformation was observed in 16-day storage. Fruit firmness decreased with the progress of ripening. Similar results were also reported by Kaynas and Surmeli (1995). Puncture test data revealed that ripening stages had significant effects on firmness values. Olorunda and Tung (1985) reported fruit firmness of tomatoes as 0.549 kg mm^{-1} in their research. Such a value was similar to the values for the present red ripening stage. Ince et al. (2016) indicated that the easiest harvest was performed when the tomatoes had firmness values of between 1.55 – 2.00 Nmm^{-1}.

Data on the modulus of elasticity are provided in Table 14. There were significant differences in modulus of elasticity values of the cultivars at a 5% level.

Table 14. Variance table for modulus of elasticity (Nmm^{-2})

Source of Variance	Sum of Squares	Mean Squares	F value	
Cultivar	0.159668	8.1044	0.0005	**
Replicate	0.168661	8.5609	0.0003	**
Ripening	24.155763	817.3983	<.0001	**
Storage	5.899900	149.7335	<.0001	**
Cultivar*Storage	0.094246	1.5946	0.1547	ns
Cultivar*Ripening	0.135863	1.7240	0.0997	ns
Ripening*Storage	0.907247	7.6750	<.0001	**
Cultivar*Ripening*Storage	0.223472	0.9452	0.5421	ns

*: 0,05, **: 0,01, ns: not-significant

Variance analysis revealed that cultivars, replicates, ripening stages, and storage durations had significant effects on the modulus of elasticity values at a 1% level. While cultivar*ripening stage and cultivar*storage duration*ripening stage interactions were not found to be significant, ripening stage*storage duration interactions had significant effects on the modulus of elasticity ($p<0.01$).

There were interactions between the cultivars and the ripening stage. Interaction data are provided in Table 15. Sirisomboon et al. (2012) reported the modulus of elasticity of ripe tomatoes as 0.90 Nmm^{-2} and Kabas and Ozmerzi (2008) reported modules of elasticity of cherry tomatoes as between 0.16 – 0.28 Nmm^{-2}.

Table15. Cultivar*ripening stage interaction table for modulus of elasticity (Nmm^{-2})

Cultivar	Green	Turning	Pink	Red	Mean
Tybeef	1.25	0.56	0.44	0.39	0.66 B
14-193	1.39	0.61	0.49	0.43	0.73 A
14-206	1.31	0.51	0.46	0.42	0.68 A
Mean	1.32 A	0.56 B	0.46 C	0.41 D	

CV (%) = 14.30; Cultivar LSD (0.05) =0.0035 / Ripening stage LSD (0.05) =0.04; Cultivar*Ripening stage interaction = ns

There were interactions between the ripening stage and storage durations. Interaction data are provided in Table 16. Considering the storage duration*ripening stage interactions, the greatest modulus of elasticity was observed in the green ripening stage of 0-day storage (control) and the lowest value was observed in the red ripening stage of 16-day storage (Table 16). Considering the storage durations, the lowest modulus of elasticity was observed in 16-day storage. Yurtlu and Erdogan (2005) reported modules of elasticity of tomatoes as between 0.18 – 0.13 Nmm^{-2} for EF49 cultivar and as between 0.14 – 0.40 Nmm^{-2} for the Joker cultivar. Yurtlu and Erdogan (2005) investigated the effects of ripening on tomato cultivars and reported decreasing modulus of elasticity with the progress of ripening.

Table 16. Storage durations*ripening stage interaction table for modulus of elasticity (Nmm^{-2})

Storage Duration	Green	Turning	Pink	Red	Mean
0 day	1.71 a	0.95 e	0.65 f	0.57 fgh	0.97 A
4 days	1.49 b	0.63 fg	0.53 hi	0.48 ij	0.78 B
8 days	1.30 c	0.54 ghi	0.46 ij	0.41 jk	0.68 C
12 days	1.15 d	0.40jkd	0.39 jk	0.34 kl	0.57 D
16 days	0.93 e	0.29 l	0.29 l	0.26 l	0.44 E
Mean	1.32	0.56	0.46	0.41	

CV (%) = 14.33; Ripening stage LSD (0.05) =0.04 Storage duration LSD (0.05) =0.05; Storage duration*Ripening stage interaction

CONCLUSIONS

Present experiments conducted for spring harvests revealed that cultivars, ripening stages, and storage durations had significant effects on puncture forces at a 1% level. The greatest puncture forces were observed in green tomatoes and the lowest puncture forces were observed in red tomatoes. The greatest puncture force was observed in the green ripening stage of 14-193 cultivar and the lowest value was observed in the red ripening stage of the Tybeef cultivar. Considering the storage durations, the lowest puncture force was observed in 16-day storage. The resistance decreased with the progress of ripening stages and storage durations.

Cultivars, replicates, ripening stages, and storage durations had also significant effects on strain values at a 1% level. The greatest strain value was observed in the green ripening stage of 14-193 cultivar and the lowest value was observed in the red ripening stage of the Tybeef cultivar. Considering the ripening stages, the greatest strain value was observed in green tomatoes. The greatest strain values were observed in green tomatoes and the lowest strain values were observed in red tomatoes since fruit firmness decreased with the progress of ripening. Considering the storage durations, the lowest strain values were observed in 16-day storage. Again, fruit resistance decreased with the progress of ripening and storage.

Ripening stages, replicates and storage durations had significant effects on deformation at a 1% level, but cultivars did not. The lowest deformation was observed in the green ripening stage of 0-day storage (control) and the greatest deformation was observed in the red ripening stage of 16-day storage. Considering the storage durations, the greatest deformation was observed in 16-day storage. Deformations increased with the progress of ripening and storage.

Cultivars, replicates, ripening stages, and storage durations had significant effects on firmness values at a 1% level. The greatest firmness was observed in the green ripening stage of 0-day storage (control) and the lowest firmness was observed in the red ripening stage of 16-day storage. Puncture tests revealed that ripening had significant effects on fruit firmness.

As compared to commercial cultivar (Tybeef), 2 candidate cultivars developed by BATEM (14-193 and 14-206), 14-193 as being better, had superior resistance parameters against mechanical damages. It was concluded that harvest at the green ripening stage might minimize potential losses and improve fruit resistance against transportation conditions.

RESUMO: Após a colheita, os produtos agrícolas estão sujeitos a diversos impactos negativos ao longo do caminho até os consumidores. Danos mecânicos como escurecimento da cor, abrasão, cortes ou perfurações na superfície da fruta são irreversíveis e acabam resultando em perdas significativas de qualidade e econômicas. Nos sistemas de produção modernos, apenas uma determinada parte dos produtos chega diretamente do produtor ao consumidor. A maioria desses produtos está sujeita a danos mecânicos por meio de esmagamento, compressão, vibração e impactos semelhantes durante os processos de colheita e pós-colheita. Neste estudo, a cultivar de tomate Tybeef cultivada em estufas experimentais do Bati Akdeniz Agricultural Research Institute (BATEM) (controle) e as cultivares candidatas codificadas 14-193 e 14-206 desenvolvidas por meio de programas de melhoramento do BATEM foram utilizadas como material vegetal. Os parâmetros de resistência dos cultivares de tomate foram determinados em 4 diferentes estágios de maturação (verde, pintado, rosado e vermelho) e 4 diferentes durações de armazenamento (4, 8, 12 e 16 dias). Os parâmetros de resistência diminuíram com o progresso do amadurecimento e durações de armazenamento. Todas as medições e avaliações revelaram que 14-193 cultivares candidatas codificadas eram proeminentes para os parâmetros de resistência.

PALAVRAS-CHAVE: Data de colheita. Vegetal. Danificar. Qualidade. Sensibilidade.

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