# Effects of maturity stages on textural mechanical properties of tomato

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**Abstract:** The textural mechanical properties of Jadelo F1 variety tomato were evaluated at three different mature stages (green, pink and red) which were classified according to the colors of the fruit. The compression and the puncture tests were applied on samples. The cycling and relaxation tests showed that indexes of average firmness, energy absorption and deformation ratio were more sensitive parameters to maturity stages than others. The puncture tests indicated that maturity stages were effective on initial and average firmness and skin rupture force. Since the rigidity and the firmness of the fruit reduced, it was more prone to mechanical damage in the process of mature. The initial firmness values obtained fromcompressiontest and average firmness values from puncture tests had the highest correlation with each other which indicates that they can be used as representative parameter for tomato. Moreover, it was found that a*/b* color parameter can be good indicator for evaluating mechanical properties of tomato.

**Keywords:** maturity, textural properties, mechanical properties, color

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## 1 Introduction

The quality for agricultural products is generally evaluated under three attributes: texture, color and taste. Among these, texture and color are important factors to qualify the tomato. Considering that low quality depends on the damages occurred during harvest and postharvest processes, it is quite important to know textural properties of tomato for offering to the market with minimum damage. Texture is influenced by flesh firmness and skin strength[1]. During operation after harvest, the agricultural products remain under the effect of compression and puncture forces. While compression forces affect the whole fruit surface and cause bruising, puncture forces are effective on a single point and increase deterioration by wound respiration[2].

Many studies focused on textural properties of tomato have been published and different methods have been used such as image processing, nuclear magnetic resonance, ultrasonic technique, visible/near infrared and near infrared spectroscopy which cannot measure the food texture directly[2,3]. Therefore, many researchers preferred destructive methods for determining textural properties[4-8].

In Turkey, annual tomato production is approximately 11 500 000 t and 8.5% of this production comes from Çukurova region. Tomato is ranked first among Turkey's fresh fruit/vegetable export in terms of both quantity and value. The export ratio of its total production is around 4% per year[9]. One of the reasons for such a low ratio is the quality. Because it is early maturing variety and has long shelf life, Jadelo F1 tomato cultivars commonly grow under protection in the region.

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The market distance plays an important role to determine the harvesting time. If the market is closer, tomato can be harvested in red color; in the contrarily, they must be harvested at early matured stage. From this point of view, the color is preferential determination component. However, changes of Jadelo F1 tomato cultivar's textural properties depending on maturity stage must be known.

This study was carried out to help the growers knowing textural properties of Jadelo F1 tomato cultivar so that they can prevent damages during harvest and storage. For this aim, puncture test, relaxation test, cycling test were performed on the tomatoes harvested at different times, and initial firmness, average firmness, deformation ratio, degree of elasticity, energy absorption, mechanical hysteresis, deformation energy, penetration energy and apparent modulus of elasticity values were determined. Moreover, a relationship between color and textural properties was also tried to be established.

## 2 Materials and methods

### 2.1 Sample preparation

The tomatoes used in the tests were harvested by selecting with naked eyes according to their color from a greenhouse in the Cukurova region. After having been stored one day under laboratory conditions, the unhealthy and damaged tomatoes were separated.

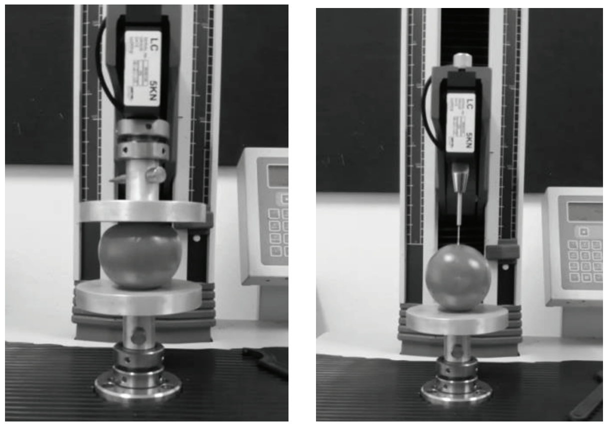
The maturities of tomatoes were categorized as green, pink and red according to their colors. For this purpose, Minolta CR-100 Chromometer color measurement device was used. Classification was based on a*/b* values representing the red color, and is provided in Table 1[2,10]. Thirty tomatoes in each color group were numbered and their lengths, widths, thicknesses and weights were measured by using digital caliper and sensitive scale.

**Table 1 Color stage classification**

| Color stages | Description | a*/b* |
|---|---|---|
| Green | Completely light to dark green, but mature | -0.59<a*/b*≤-0.47 |
| Breaker | Green to tannish-yellow, pink or red, not more than 10% | -0.47<a*/b*≤-0.27 |
| Turning | Over 10% but not more than 30% green to tannish-yellow, pink, red or combination | -0.27<a*/b*≤0.08 |
| Pink | Over 30% but not more than 60%pinkorred | 0.08<a*/b*≤0.60 |
| Light red | Over 60% but not more than 90% red | 0.60<a*/b*≤0.95 |
| Red | Over 90% red | 0.95<a*/b*≤1.21 |

### 2.2 Test procedure

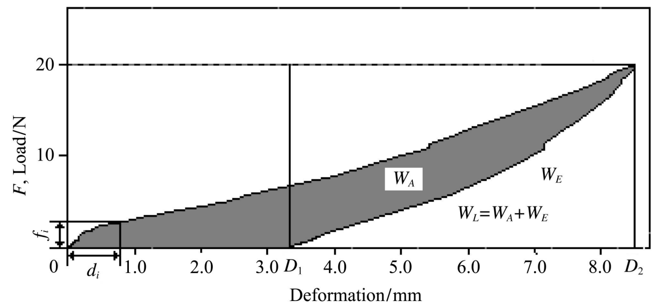
Relaxation, cycling and puncture tests were applied on the tomatoes by using Lloyd Instrument LRX Plus universal test device connected to a computer. The load-cell admits a maximum force of 5 kN[3,4] (Figure 1).



a. Compression test b. Puncture test

Figure 1 View of the plate compression and puncture test

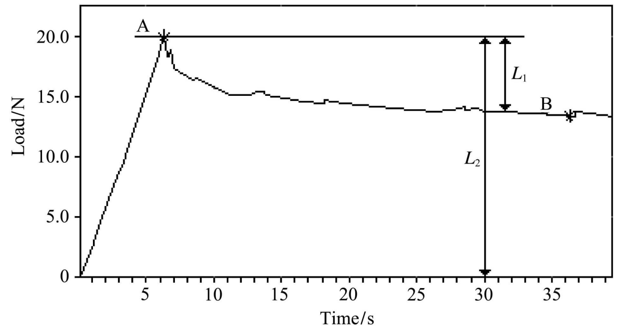
In the cyclingtest, 20 N force with a speed of 8 mm/min was applied on the samples ata single point (middle) between two flat plates of 100 mm diameter, and it was removed again with the same speed. A typical force-deformation curve obtained as the result of test is given in Figure 2. Depending on the force and deformation values obtained from this test, initial firmness, average firmness, deformation ratio, degree of elasticity, energy absorption and mechanical hysteresis values were calculated as shown in Figure 2. Initial firmness value was calculated withthe force of 2.45 N suggested by Sirisomboon et al.[2]




Note: $F$ or $f_i$: force, N; $D$ or $d_i$: deformation, mm; Initial firmness, N/mm $=\frac{f_i}{d_i}$; Average firmness, N/mm $=\frac{F}{D_2}$; Deformation ratio $=\frac{D_2}{\text{initial diameter of tomato}}$; Degree of elasticity $=1-\frac{D_2}{D_1}$; Energy absorption (N·mm), $W_A = W_L - W_E$ [Loading energy, $W_L=\frac{1}{2}FD_2$; Elastic energy, $W_E=\frac{1}{2}F(D_2-D_1)$]; Mechanical histerisis $=\frac{W_A}{W_L}$.

Figure 2 Typical force-deformation curve obtained from cycle test

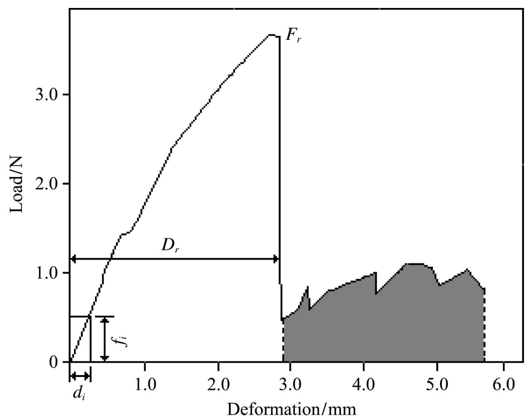
In relaxation test, 20 N force was applied on the samples, which were kept under this load for 30 s. The decrease of load at the end of holding period was recorded, and the relaxation ratio of the samples were determined (Figure 3).




Note: $L_2$: maximum force, N; $L_1$: decline in force, N; Relaxation ratio $=\frac{L_1}{L_2}$.

Figure 3 Typical force-time curve obtained for relaxation test

In puncture test, the samples were placed on a flat surface as shown in Figure 1a, and they were punctured with a speed of 10 mm/min by a plunger with a diameter of 2 mm. As shown in Figure 4, a typical force-deformation curve was obtained as the result of puncture test. By using the data obtained from this test, initial firmness, average firmness, deformation energy, penetration energy and apparent modulus of elasticity values were determined. Since the texture of the tomato flesh under the skin is not homogeneous, the penetration force in the flesh was not uniform, as shown in Figure 4. Therefore the penetration energy was calculated through multiplying the depth of the penetration by the average penetrating force in the flesh.




Note: $F$ or $f$: force, N; $D_r$ or $d_i$: deformation, mm; Initial firmness, N/mm $=\frac{f_i}{d_i}$; Deformation energy $=\frac{1}{2}F_rD_r$ Apperant modulus of elasticity, N/mm$^2$ $=\frac{F_i(1-\mu^2)}{dD_r}$ ($d$: diameter of plunger, mm); Penetration energy=shaded area calculated by the sum of the areas every 0.5 mm up to 5 mm.

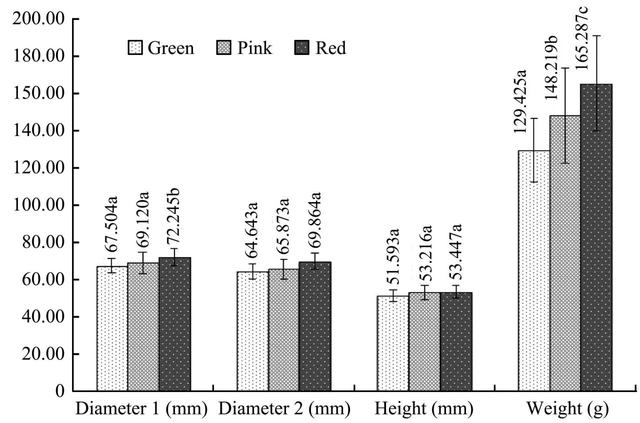
Figure 4 Typical force-deformation curve obtained from puncture test

### 2.3 Statistic treatment

For statistical analysis, the average value of the measurements was taken. These data were subjected to variance analysis by using SPSS 20.0 for Windows. Also, results were compared at 5% significant level by using Duncan's Multiple Range Test. In order to investigate the relationship between a*/b* color parameter and mechanical properties obtained from both cyclingand puncture test, Pearson's correlation matrix method was used. The regression equations between color and textural parameters were developed by using Microsoft Office Excel 2010.

## 3 Results and discussion

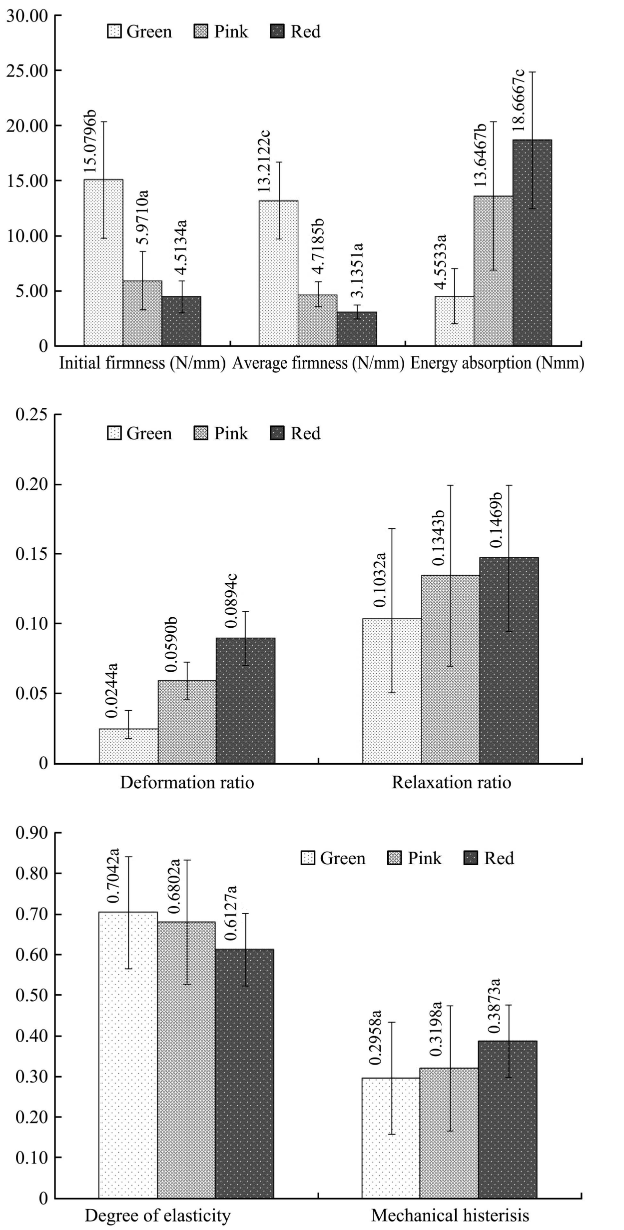
Due to been directly harvested from the field, the physical properties of samples showed small differences. As seen in the Figure 5, while green and pink colored tomatoes were statistically within the same group for Diameter 1 and Diameter 2 values, the red colored tomatoes showed difference. No difference was found among color groups in respect of height at 5% probability level. When the relation in respect of weight among color groups was examined, each three groups were found to be statistically different with a significance level of 5% depending on the maturation of flesh.




Note: Data are the mean value of 30 fruits. Error bars indicate the standard deviation.

Figure 5 Physical properties of tomatoes at different maturity stages

The results obtained from cycle test are given in Figure 6. Initial firmness, average firmness and degree of elasticity are indicators of the hardness of fruits. As seen in the Figure 6, these parameters decreased as the maturity of fruit increased. This result verified the softening of the fruit. Initial firmness was found higher than the average firmness for all the maturity stages. While initial firmness values for pink and red maturity stages were in the same group statically, average firmness values were found different at 5% probability level for all the maturity stages. However, the degree of elasticity did not show any difference for all maturity stages statically.

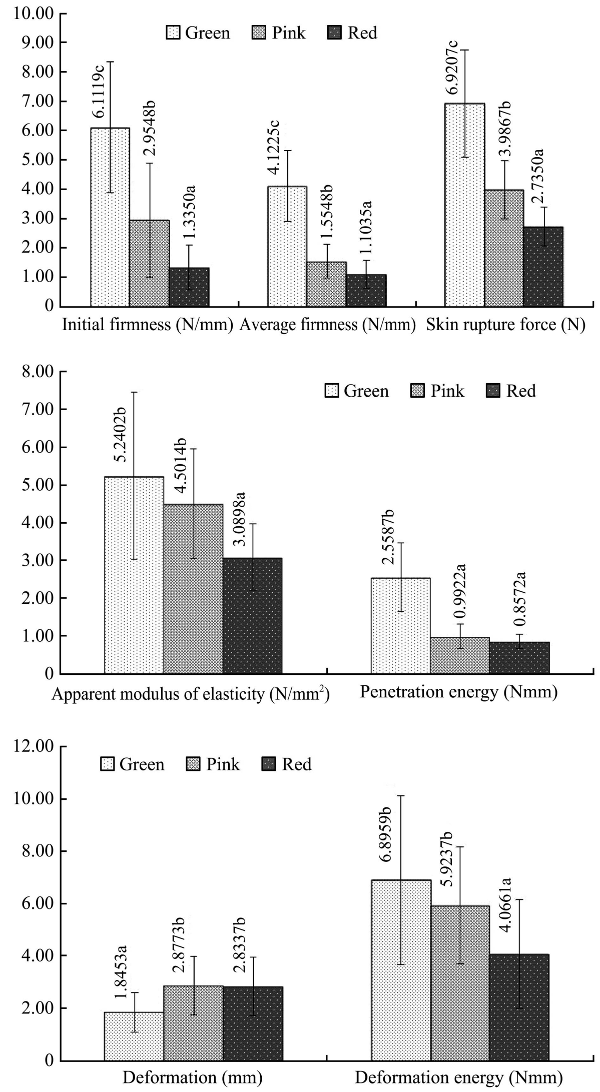



Note: Values with different letters are significantly different according to the Duncan multiple range test at 5% probability level.

Figure 6 Textural parameters of tomato obtained by cycle and relaxation test

On the contrary, energy absorption, deformation ratio, relaxation ratio and mechanical hysteresis values increased with the increase of the maturity of fruit. Energy absorption specified the energy amount required for the fruit to change form, and deformation ratio is related to its deformation. In other words, ripe fruit mightbe damaged more due to its soft texture compared to unripe fruit under the same force. Also in this study, energy absorption and deformation ratio showed an increase with the increase of the maturity of fruit, and this change was found statistically significant for all the maturity stages. Relaxation ratio is related to visco-elastic behavior of the fruit. Ripe fruits show more elastic behaviors compared to less mature ones, and they are more prone to be damaged. Change of relaxation ratio was not found statistically different for the pink and red maturity stages. A similar result had also been obtained by Sirisomboon et al.[4] who applied same research on Japanese pear. Despite the increase in mechanical hysteresis, another indicator of sensitivity against getting damaged was obtained with the increase of maturity, no statistically significant difference was observed between these changes. The results of compression test showed that average firmness, energy absorption and deformation ratio were more sensitive textural parameters related tothe maturity stage comparing with the other parameters for Jadelo F1 variety tomato.

In Figure 7, the results of puncture test, by which the behaviors of skin and pulp under force were determined and provided. Initial firmness, average firmness, skin rupture force, apparent modulus of elasticity, penetration energy and deformation energy decreased with the increase of maturity. Initial firmness was found higher than the average firmness in the cycle test. It was determined that the difference between maturity periods for both values was statistically significant. The skin rupture force is one of the most important textural parameters which indicating the strength of the peel. The measured values showed that the skin rupture resistance of the fruit was 39.5% higher at the beginning of maturity period, and this difference was found statistically significant. Similar results have also been reported by Bui et al.[11]. This condition shows that the fruit in late maturity period is more sensitive getting damaged compared to the fruits in early maturity period.




Note: Values with different letters are significantly different according to the Duncan multiple range test at 5% probability level.

Figure 7 Textural parameters of tomato obtained by puncture test

Apparent modulus of elasticity refers to the resistance of fruit against deformation. The results of this study also showed that the fruit in early maturity period was more resistant against getting damaged. While the apparent modulus value did not show a statistically significant difference in green and pink stages, it was found significant in red stages. Penetration energy indicates the resistance of the flesh. While the penetration energy values were determined very close in the pink and red stages, it was found three times than that in green stage. Deformation energy is found high at early maturity periods. Moreover, this value did not show a statistical difference for the green and pink stages and it decreased 40% in the late maturity period. The deformation values tended to increase in the late maturity stages. As seen in Figure 7, the deformation was found almost same in the pink and red stages. Also in these stages, higher standard deviations which indicated that the flesh texture under the peel was more varied were obtained. According to the puncture test results, initial firmness, average firmness and skin rupture force are sufficient indicators for tomato maturity stages.

The Pearson's correlation coefficients between parameters obtained from compression and puncture tests are given in Table 2. As can be seen in the table, the plate compression parameters indicating the elasticity of tomato donot show well correlation with the parameters from the puncture test. As a sample, energy absorption is correlated with the average firmness obtained from the puncture test ($r$=–0.58, significance level=0.01). This indicated that the average firmness could be used as a firmness representative parameter. From the compression tests, initial firmness is correlated with the relaxation ratio with a very low $r$ value ($r$ = –0.31, significance level=0.05). This parameter has shown high correlations with an$r$ of 0.88 and –0.76 for average firmness and energy absorption, respectively.

Referring to the results of the compression test (cycle and relaxation test), degree of elasticity and mechanical hysteresis of the three maturity stages were not significantly different, but the deformation ratio of the three stages were different. Among the parameters from the puncture tests, the initial firmness had the highest correlation with average firmness ($r$=0.74) and was followed by the puncture energy and rupture force ($r$=0.71).

The parameters from compression test are IFC (initial firmness), AFC (average firmness), DRC (deformation ratio), DEC (degree of elasticity), EAC (energy absorption), MHC (mechanical hysteresis), RRC (relaxation ratio). The parameters from puncture test are RFP (rupture force), DRP (deformation at rupture), IFP (initial firmness), AFP (average firmness), AEMP (Apparent modulus of elasticity), DEP (deformation energy), PEP (penetration energy).

Pearson's correlations between a*/b* color parameter and mechanical properties obtained by the cycling test are presented in Table 3. The best fit was found between a*/b* and average firmness ($r$=0.883) followed by initial firmness ($r$=0.804). As listed in Table 3, the correlation coefficients of a*/b* and mechanical properties obtained by the cycle test were significant at the 1% level except degree of elasticity and mechanical hysterisis. In Table 4, Pearson's correlations aregiven for puncture test results. The a*/b* color parameter was closely related to average firmness. Thus, the best relationship to estimate the mechanical properties was found between a*/b* and average firmness. Correlations of a*/b* and deformation, apparent modulus of elasticity and deformation energy were lower but also statistically significant (1% level). The results showed that a*/b* color parameter was also an important indicator for changing of mechanical properties changing of tomato. Camelo and Gomez[12] has also accented same result in their work.

The analysis of variance results showed that maturity stages of the tomato samples significantly affected the a*/b* color parameter. Duncan's multiple range test performed to determine the differences among the maturity stages isgiven in Figure 8. The results showed that the difference among the green, pink and red stages was significant at 5% level.

**Table 2 Pearson's correlation coefficients between parameters obtained from compression and puncture tests**

| | Compression | | | | | | | Puncture | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IFC | AFC | DRC | DEC | EAC | MHC | RRC | RFP | DRP | IFP | AFP | AEMP | DEP | PEP |
| IFC | 1 | $0.88^{**}$ | $-0.79^{**}$ | $0.41^{**}$ | $-0.76^{**}$ | -0.41 | $-0.31^{*}$ | $0.39^{**}$ | -0.23 | 0.19 | $0.31^{*}$ | 0.14 | 0.14 | 0.12 |
| AFC | | 1 | $-0.86^{**}$ | 0.28 | $-0.75^{**}$ | -0.28 | $-0.36^{*}$ | $0.47^{**}$ | -0.29 | 0.19 | $0.41^{**}$ | 0.14 | 0.14 | 0.18 |
| DRC | | | 1 | $-0.30^{*}$ | $0.82^{**}$ | $0.30^{*}$ | $0.45^{**}$ | $-0.56^{**}$ | $0.39^{**}$ | $-0.38^{**}$ | $-0.55^{**}$ | -0.12 | -0.12 | $-0.41^{**}$ |
| DEC | | | | 1 | $-0.69^{**}$ | $-1.00^{**}$ | -.0.10 | -0.13 | $-0.36^{*}$ | 0.20 | $0.42^{**}$ | -0.11 | -0.11 | 0.22 |
| EAC | | | | | 1 | $0.69^{**}$ | $0.36^{*}$ | $-0.37^{*}$ | $0.46^{**}$ | $0.36^{*}$ | $-0.58^{**}$ | 0.04 | 0.04 | -0.29 |
| MHC | | | | | | 1 | 0.01 | -0.13 | $0.36^{*}$ | -0.20 | $-0.42^{**}$ | 0.11 | 0.11 | -0.22 |
| RRC | | | | | | | 1 | $-0.35^{**}$ | 0.05 | -0.18 | $-0.24^{*}$ | $-0.23^{*}$ | $-0.23^{*}$ | $-0.22^{*}$ |
| RFP | | | | | | | | 1 | -0.08 | $0.47^{**}$ | $0.63^{**}$ | $0.71^{**}$ | $0.71^{**}$ | $0.56^{**}$ |
| DRP | | | | | | | | | 1 | $-0.56^{**}$ | $-0.67^{**}$ | $0.59^{**}$ | $0.59^{**}$ | $-0.38^{**}$ |
| IFP | | | | | | | | | | 1 | $0.74^{**}$ | -0.07 | -0.07 | $0.53^{**}$ |
| AFP | | | | | | | | | | | 1 | -0.02 | -0.02 | $0.71^{**}$ |
| AEMP | | | | | | | | | | | | 1 | $1.00^{**}$ | 0.17 |
| DEP | | | | | | | | | | | | | 1 | 0.17 |
| PEP | | | | | | | | | | | | | | 1 |

Note: * Correlation is significant at 0.05 probability level; ** Correlation is significant at 1% probability level.

**Table 3 Correlation coefficients between a*/b* color parameter and mechanical properties obtained by cycle test**

| Parameter | Initial firmness | Average firmness | Deformation ratio | Degree of elasticity | Energy absorption | Mechanical hysterisis | Relaxation ratio |
|---|---|---|---|---|---|---|---|
| a*/b* | −0.804** | −0.883** | −0.838** | −0.257 | 0.724** | 0.257 | 0.284** |

Note: ** Correlation is significant at the 1% level.

**Table 4 Correlation coefficients between a*/b* color parameter and mechanical properties obtained by puncture test**

| Parameter | Skin rupture force | Deformation | Initial firmness | Average firmness | Apparent modulus of elasticity | Deformation energy | Penetration energy |
|---|---|---|---|---|---|---|---|
| a*/b* | −0.775** | 0.373** | −0.669** | −0.802** | −0.304** | −0.304** | −0.757** |

Note: ** Correlation is significant at the 1% level.

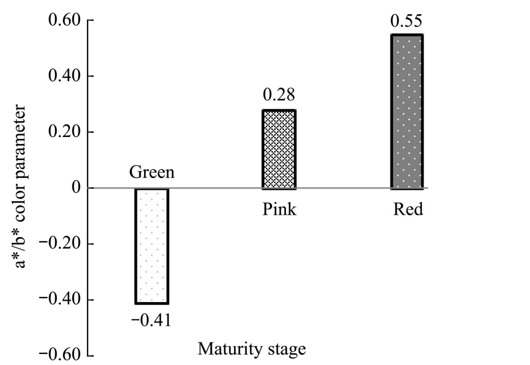



Figure 8 The changing of a*/b* color parameter *vs.* tomato maturity stage according to Duncan Multiple Range Test result

## 4 Conclusions

The compression and puncture tests were applied on Jadelo F1 variety tomato to obtain the effects of maturity stages on textural mechanical properties. According to the test results, initial firmness, average firmness, skin rupture force, energy absorption and deformation ratio are more sensitive textural mechanical parameters related tothe maturity stage. It was observed that especially firmness and skin rupture force decreased after green maturity stages remarkably which means starting softening rapidly. Since the initial firmness and average firmness were correlated well with the other parameters, they can be used as determining parameters for ripening. Also it was found that a*/b* color parameter was a good indicator for the changing of the mechanical properties. When the firmness values varied between 1.55 N/mm and 2 N/mm, tomato reaches breaker and turning color stages and can be harvested easily.

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