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Firmness classification of tomato fruits by using colour parameters

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ABSTRACT

In this study, firmness classification potential of tomato fruits was investigated by using colour parameters measured with a colour measuring device. 202 ‘Bandita F1’ greenhouse tomatoes were used as trial material. In damage free colour measurements carried out by Minolta CR-400 colour measurement device, L*, a* and b* colour parameters were considered as main parameters. Other colour parameters (a*xb*, a*2, b*2 and a*/b*) were derived from main colour parameters. These colour parameters were associated with tomato firmness. In tomato firmness measurements, the force value at the skin rupture point was used and this value was expressed as tomato firmness. Tomato samples were grouped according to firmness by using clustering analysis method. In addition, linear discrimination analysis method was used in the classification of tomatoes according to firmness. Classification accuracy was improved by linear discrimination analysis and the number of parameters used was decreased with stepwise regression analysis method. The association between tomato firmness and colour parameters (L*, a*, b*, a*xb*, a*2, b*2 and a*/b*) was determined with Pearson Correlation test. Statistical analysis results showed that the association between tomato firmness and colour parameters was significant (P<0.01). According to linear discrimination analysis results, linear classification accuracy was calculated as 85.64% for main colour parameters approach and as 90.59% for seven colour parameters approach. The results of linear discrimination analysis performed by using the most important three colour parameters determined with stepwise regression analysis method showed that correct classification accuracy of tomatoes was 89.10%. The results showed that firmness classification of tomatoes could be done by using colour parameters and linear discrimination analysis method.

Keywords:
Tomato firmness
Maturity stage
Colour parameters
Clustering analysis
Linear discrimination analysis

Domates meyvelerinin renk parametrelerine göre sertlik sınıflandırması

ÖZET

Bu çalışmada, renk ölçüm cihazı ile ölçülen renk parametreleri kullanılarak domates meyvelerinin sertlik sınıflandırma potansiyeli araştırılmıştır. Deneme materyali olarak 202 adet ‘Bandita F1’ sera domatesleri kullanılmıştır. Minolta CR-400 model renk ölçüm cihazı kullanılarak yapılan hasarsız renk ölçümlerinde, L*, a* ve b* renk parametreleri ana parametreler olarak dikkate alınmıştır. Diğer renk parametreleri (a*xb*, a*2, b*2 ve a*/b*) ana renk parametrelerinden türetilmiştir. Bu renk parametreleri, domates sertliği ile ilişkilendirilmiştir. Domates sertliği ölçümlerinde, kabuk yırtılma noktasındaki kuvvet değeri kullanılmış ve bu değer domates sertliği olarak ifade edilmiştir. Kümeleme analiz yöntemi kullanılarak domates örnekleri sertliğine göre gruplandırılmıştır. Ayrıca, domateslerin sertliğine göre sınıflandırma işlemlerinde, doğrusal ayırma analiz yöntemi kullanılmıştır. Sınıflandırma hassasiyeti doğrusal ayırma analizi ile iyileştirilmiş ve kullanılan parametre sayısı stepwise regresyon analiz yöntemi ile azaltılmıştır. Domates sertliği ve renk parametreleri (L*, a*, b*, a*xb*, a*2, b*2ve a*/b*) arasındaki ilişki, Pearson Korelasyon testi ile belirlenmiştir. İstatistiksel analiz sonuçları, domates sertliği ve renk parametreleri arasındaki ilişkinin önemli olduğunu göstermiştir (P<0.01). Doğrusal ayırma analizi sonuçlarına göre, doğrusal sınıflandırma hassasiyeti ana renk parametreleri yaklaşımı için % 85.64 ve yedi renk parametre yaklaşımı için de % 90.59 olarak hesaplanmıştır. Stepwise regresyon analiz yöntemi ile belirlenmiş olan en önemli üç renk parametresi kullanılarak

Anahtar Sözcükler:
Domates sertliği
Olgunluk safhası
Renk parametreleri
Kümeleme analizi
Doğrusal ayırma analizi

yapılan doğrusal ayırma analizi sonuçları da, domateslerin doğru sınıflandırma hassasiyetinin % 89.10 olarak gerçekleştiğini göstermiştir. Sonuçlar, domateslerin sertlik sınıflandırmalarının renk parametreleri ve doğrusal ayırma analiz yöntemi kullanılarak gerçekleştirilebileceğini göstermiştir.

1. Introduction

The process of fruit ripening in tomato is a key factor for determining physiological and biochemical changes (Giovannoni, 2004). The conversion of tomato fruit from the mature green to fully ripe stage involves dramatic changes in colour, flavour, and texture (Kaur et al., 2006). For fresh tomatoes, the two quality attributes that are most important to buyers and consumers are texture and skin colour (Batu, 2004). Colour change of tomato fruits is the most obvious feature of ripening (Lenucci et al., 2012; Kaur et al., 2006). Fruit firmness is inversely proportional to ripeness and therefore may be used as alternative ripeness index in vegetable and fruit classifications (Mohsenin, 1970; Lesage and Destarin, 1996). While colour is a ripeness parameter in tomato fruit, firmness is also one of the main factors contributing to the quality of tomato fruit.

Degree of fruit firmness has been used as an indicator of fruit quality and for this reason, firmness may be the final index of consumers while making their purchase decision for tomato fruit (Burton, 1982). Ripening continues after the harvest of tomatoes and tomatoes can ripen very quickly. This situation may cause losses in quality and limit the shelf life of tomatoes (Geeson et al., 1985; Wu & Abbott, 2002; Lana et al., 2005). A large number of researchers used colour classification criteria to find out ripening (USDA, 1991) in tomato harvest (Kader et al., 1978; Edan et al., 1997; Lopez Camelo and Gomez, 2004; Batu, 2004; Baltazar et al., 2008; Bui et al., 2010; Sirisomboon et al., 2012).

If tomatoes are to be transported over long distances, they are mostly harvested during colour turning period. On the other hand, tomatoes that will be transported to close distances are harvested during their pink or light red maturity period. In both stages, tomatoes are required not to be below a certain firmness limit value (Edan et al., 1997). Tomato colour and colour change are mostly determined by using instrumental methods. Colour measurement devices (Minolta Chroma and Hunter Lab) are an effective way used to find out colour index (Batu, 2004; Baltazar et al., 2008).

Among the damage free technologies, colourimeters which quantify lightness (L*), green to red (a*), and blue to yellow (b*) of fruit surface have been used extensively because CIELab indices allow objective statistical and quantitative analyses.

Although it has been reported in a large number of studies that there is a positive association between maturity stage and colour development in tomatoes, this association is not fully understood (Hobson et al., 1983; Batu, 1998, 2004; Thai & Shewfelt, 1990, 1991). Except for the method of determining the colour ripening stages specified in the USDA colour catalogue, colour charts and scales have been developed to determine the maturity stages of tomatoes commercially. However, accurate determination of maturity stages of tomatoes is still not possible with these methods (Van Zeebroeck et al., 2007).

There is no specific standard for firmness classification of tomatoes. In tomato firmness classifications carried out by researchers, colour ripeness criteria are taken into consideration and firmness classifications are made accordingly (Bui et al., 2010; Sirisomboon et al., 2012 and Sirisomboon et al., 2012a). As tomato ripens, its texture softens and changes occur in its textural structure. During ripeness, skin rupture force and skin firmness of tomatoes decrease and the fruit flesh softens. Firmness analysis of agricultural products is made using automation-based material testing devices or hand penetrometers. A large number of researchers examine tomato colour and firmness change and while doing this, both spend time and damage the product in firmness measurement. It would be a more accurate approach to estimate the firmness without any damage by using direct colour measurement values instead of this process. The aim of the present study is to classify tomato fruits according to their firmness by using L*, a*, b* colour parameters and separation analysis method.

2. Materials and Method

The present study was carried out by using 'Bandita F1' tomato variety. The tomatoes tested during the trials were provided from a greenhouse in Adana. The tomatoes were harvested in different maturity stages as green, breaking, turning, pink, light red and red ripening periods in order to create different firmness groups and 202 tomatoes were tested during the trials. Mean mass, equatorial diameter and height of the tomatoes used in the trials were measured as 112.51±14.67 g, 58.17±3.45 mm and 46.93±2.01 mm, respectively.

In the first step regarding the colour measurement of tomatoes, CR-400 model (Konica Minolta Chroma Meter, Japan) colour measurement device was used to determine the colours with L*, a*, b* three-point measurement method. Before the measurement, the device was calibrated with a standard white ceramic plaque (Y=88.20, x= 0.3174, y= 0.3222).

Colour measurements (L*, a*, b*) were made at four points on the equatorial region of each tomato sample and the mean of four measurements was recorded to be used in the assessment of maturity. a* value measured with Minolta colourimeter denotes redness and greenness and ranges from -90 to +90. b* value denotes blueness and yellowness and ranges from -90 to +90. In the present study, the redness values and maturity classifications of tomatoes were determined by using a*/b* values proposed by Batu (2004). The a*/b* colour space value ranges used in the determination of tomato maturity are given in Table 1. Colour measurement points of tomatoes were marked and firmness measurements were made from these points after colour measurement. During the trials, a total of 808 colour measurements were made on 202 tomatoes, with 4 colour measurements on each tomato.

Lloyd Universal Test device (Lloyd Instrument LRX Plus Series) was used in the firmness measurements of tomatoes. The device consists of three main parts as moving head, movement system and data transfer system (load cell, computer and connections and NEXYGEN Plus software). 4 mm diameter flat indenter was used in the measurements and 10 mm min-1 loading speed was used (ASAE Standards, 2001). The indenter tip was made to move 10 mm while forming the force-deformation graphs. The force at the skin rupture point was expressed as tomato firmness (F_{max}). Tomato firmness measurements, also called damaged measurement reference test, was carried out at four points where colour measurements were made on 202 tomato samples. A total of 808 firmness measurements were made and the average of 4 values measured in the equatorial region for each tomato sample was taken into account in statistical analyses.

The relationship between tomato firmness (F_{max}) and colour parameters (L*, a*, b*, a*xb*, a*2, b*2 and a*/b*) was determined with Pearson Correlation Test. Parameters such as a*xb*, a*2, b*2 and a*/b* used except for main colour parameters L*, a* and b* measured with Minolta colour measurement device were derived from main colour parameters. Mean firmness values obtained for 202 tomatoes were also subjected to clustering analysis and decision was made about what firmness class ranges should be. Scheffe test was used to compare the significance level of each colour parameter (L*, a*, b*) between different firmness classes. In addition, discriminant analysis method was used to determine the colour parameters which were effective and which were not effective in separating into firmness groups and to test whether the data were classified according to firmness as estimated. SPSS 20.0 program was used in all statistical assessments. Tomato firmness and colour parameters, symbols and units were given in Table 2.

3. Results and Discussion

The change of tomato firmness depending on the maturity stage was given in Figure 1. As can be seen in Figure 1, the difference between the means of firmness values was found to be statistically significant at all maturity stages and took place in different groups (P<0.05). The highest change in firmness values was found to take place in breaking, turning and pink maturity stages. The lowest change was found in light red and red maturity stages.

The changes of tomato colour and maturity index values in six different maturity stages are given in Table 3. According to DUNCAN multiple comparison test results, it was found that a* and a*/b* colour parameters showing the redness degree of tomatoes were in different groups in all maturity stages and the difference between the means was found to be statistically significant at 1% level (P<0.01). Lopez Camelo & Gomez (2004) and Vursavuş & Kesilmis (2017) also found similar results and stated that a* and a*/b* colour parameters were dominantly significant on the colour change of tomatoes at six different maturity stages. Batu et al. (1997) examined Minolta colour changes in different maturity stages of tomato and stated that a* redness values should be taken into consideration while determining colour values. In addition, Ince et al. (2016) found that the relationship between a*/b* colour parameter and tomato skin rupture force was significant at 1% level and there was a positive relationship. These results support the results of our study.

The relationship between tomato firmness (F_{max}) and colour parameters regarding the Pearson correlation test was given in Table 4. As can be seen in Table 4, the correlation between tomato firmness and colour parameters was found to be significant at P<0.01 level. When the correlations between main colour parameters were taken into consideration, the highest correlation was found to be between F_{max} and a* colour parameter (r= -0.904). The highest correlation between colour parameters derived from main colour parameters and F_{max} was between a*/b* (r= -0.930). Similar results were also found by Arias et al., 2000; Bui et al., 2010 and Ince et al., 2016 and these results support the results of the present study.

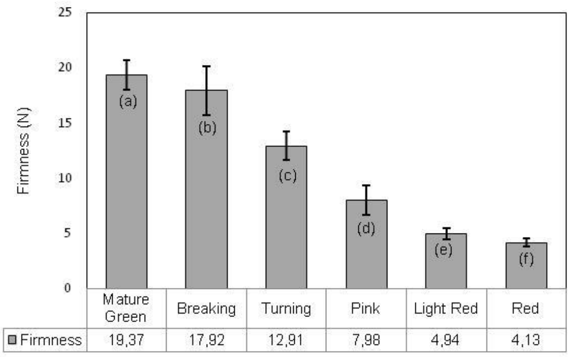

Figure 1. Change of tomato firmness due to maturity stage
Şekil 1. Olgunluk döneminde domateste sertlik değişimi

Table 1. a*/b* values used for maturity classification of tomatoes (Batu, 2004)
Çizelge 1. Domatesin olgunluk sınıflandırmasında kullanılan a/b* değerleri*

Colour stage	a*/b*
Mature green	$-0.59<a^*/b^*\leq-0.47$
Breaking	$-0.47< a^*/b^*\leq-0.27$
Turning	$-0.27< a^*/b^*\leq0.08$
Pink	$0.08< a^*/b^*\leq0.60$
Light red	$0.60< a^*/b^*\leq0.95$
Red	$a^*/b^*>0.95$

Table 2. Colour and firmness parameters
Çizelge 2. Renk ve sertlik parametreleri

Measurement type	Parameter
Colour	L*
	a*
	b*
	a*xb*
	a^{*2}
	b^{*2}
	a*/b*
Firmness	F_{max} (N)

Table 3. Colour parameter values for tomato fruits at different maturity stages
Çizelge 3. Farklı olgunluk dönemlerinde domates için renk parametresi değerleri

Parameters	Mature Green	Breaking	Turning	Pink	Light Red	Red
L*	46.13±1.36^{e}	46.98±1.28^{d}	46.08±1.23^{d}	43.76±1.41^{c}	40.63±1.27^{b}	39.21±0.77^{a}
a*	-7.75±0.82^{a}	-6.74±1.18^{b}	-2.26±1.86^{c}	4.64±2.15^{d}	16.83±3.07^{e}	23.07±1.68^{f}
b*	15.41±1.75^{a}	16.84±1.69^{b}	17.65±2.06^{b}	18.38±1.74^{c}	21.63±1.61^{d}	21.96±1.10^{d}
a*xb*	-120.91±25.12^{a}	-114.61±28.64^{a}	-39.75±34.97^{b}	87.07±43.31^{c}	368.05±87.83^{d}	507.27±52.19^{e}
a^{*2}	60.85±12.29^{c}	46.85±16.19^{bc}	8.42±8.14^{a}	25.98±21.37^{ab}	292.57±100.55^{d}	535.03±77.80^{e}
b^{*2}	240.61±53.42^{a}	286.24±58.45^{b}	315.67±75.85^{b}	340.83±64.29^{c}	470.85±68.34^{d}	483.23±47.84^{d}
a*/b*	-0.50±0.02^{a}	-0.40±0.06^{b}	-0.13±0.10^{c}	0.25±0.11^{d}	0.77±0.10^{e}	1.05±0.07^{f}

The values and ± represent the means and standard deviation values, respectively. The average values with the letters a, b, c, d, e, f are statistically different according to the DUNCAN test ($P\leq0.05$).

Table 4. Correlation coefficients (r) between tomato firmness (F_{max}) and colour parameters
Çizelge 4. Domates sertliği (F_{max}) ile renk parametreleri arasındaki korelasyon katsayıları (r)

Parameter	L*	a*	b*	a*xb*	a^{*2}	b^{*2}	a*/b*
F_{max}	0.808	-0.904	-0.749	-0.874	-0.668	-0.746	-0.930

** Correlation is significant at the 0.01 level.

Table 5. Tomato firmness groups according to cluster analysis results
Çizelge 5. Cluster analizi sonuçlarına göre domates sertlik sınıflandırması

Firmness group	Sample number	Tomato firmness (N)	
		Mean	SD ±
F_{max}≥14.79 N (Hard)	52	18.61	1.91
7.84<F_{max}≤14.78 (Intermediate)	55	11.37	2.04
F_{max}≤7.83 (Soft)	95	4.78	1.29

SD: standard deviation

202 data at different maturity levels used for the firmness classification of tomatoes were first exposed to clustering analysis and it was decided on what the firmness class ranges should be. Clustering analysis results of three different firmness groups were given in Table 5. As can be seen in Table 5, 52 tomato samples were in hard group with a mean value of 18.61±1.91 N, while 55 tomato samples were in the intermediate group with a mean value of 11.37±2.04 N and 95 tomato samples were in the soft classification group with a mean value of 4.78±1.29 N. Class ranges formed with cluster analysis were found as F_{max} ≤7.83 N for soft tomato group, as 7.84<F_{max}≤14.78 N for intermediate tomato group and as F_{max}≥14.79 N for hard tomato group. 202 tomato samples were classified by taking these firmness ranges into consideration.

Main colour parameters can give direct information about the firmness of L*, a* and b* tomatoes. The main colour parameter results in three different firmness groups for tomato samples were given in Table 6. The difference between the mean values of the three firmness group for main colour parameters was analysed by using Scheffe test at P≤0.05significance level. According to analysis results, L* colour parameter mean values were found to show statistically significant differences in three firmness groups. Similar result was also found for a* and b* colour parameters and the difference between hard, intermediate and soft groups was found to be statistically significant at P≤0.05 level.

The results of linear discrimination analysis made separately for each of the main colour parameters were given in Table 7. It was found that L* colour parameter showed low classification for hard tomato group with 36.54% (19/52) value. In intermediate and hard tomato groups, classification success was calculated as 72.73% (40/55) and 74.74% (71/95), respectively. It was found that a* colour parameter could classify all of the 52 tomatoes (52/52= 100%) in hard classification group in the same group. This classification success was calculated as 85.46% (47/55) and 77.89% (74/95), respectively for intermediate and soft tomato groups. Similar to the L* colour parameter, b* colour parameter did not show a high classification success in hard tomato group (44.23%). Success percentages were calculated as 80% and 71.58% for intermediate and soft tomato groups. When evaluated in general, the colour parameter with the highest classification accuracy was a* colour parameter with 85.62%. This was followed by b* (66.83%) and L* (64.36%) colour parameters.

While the difference between the mean values of L* and b* colour parameters was not found to be significant according to Scheffe test results, classification success percentage was found to be lower than the classification success percentage in a* colour parameter. In the classification made by using the main colour parameter a*, classification accuracy was calculated as 85.64% for all firmness groups. Gutierrez et al, (2007) and Lien et al, (2009) stated that classification accuracy should be over 75.00%. Since the classification accuracy of 85.64% was higher than 75.00%, it was found that acceptable results were reached by using only a* main colour parameter.

Table 8 shows the results of linear discrimination analysis using three main colour parameters together (L*, a* and b*). When compared with the results in Table 7 (85.64%), it can be seen in Table 8 that classification accuracy did not differ much with the use of three main colour parameters (84.65%).

In order to increase the classification accuracy determined by using linear discriminant analysis for three main colour parameters, discriminant analysis was performed by using main colours and the other colours derived from these and the results were given in Table 9. As can be seen in Table 9, the percentage of assigning tomatoes to the firmness group they were in was found high for hard and soft tomatoes and calculated as 100% for the hard group and as 90.53% for the soft group. Classification accuracy was increased to 90.59% from 84.65% for three firmness groups. The most unsuccessful classification was found in intermediate firmness group (81.82%) and 6 of the 55 tomatoes in intermediate firmness group were classified as hard, while 4 were classified as soft.

The use of 7 parameters given in Table 7 may cause complexity in real time applications of numerical and logical applications. For this reason, stepwise regression analysis was used to decrease the number of colour parameters. According to stepwise regression analysis results, L*, a*2 and a*/b* colour parameters were found to be statistically the most important parameters. Statistical assessment results of stepwise regression analysis were given in Table 10.

Table 11 shows classification analysis results determined according to linear discriminant analysis by using L*, a*2 and a*/b* colour parameters. By using the three most important colour parameters determined as a result of stepwise regression analysis, it was concluded that the tomatoes could be classified with a classification accuracy of 89.10% for all firmness groups. In addition, the classification accuracy of 90.59% which was calculated by using the seven colour parameters was calculated as 89.10% with a decrease of 1.64%. As can be seen in Table 11, all of the 52 tomatoes in the hard group were classified in their own groups. 8 of the 55 tomatoes in the group with intermediate firmness were classified in the hard group and 5 were classified in the soft group. The lowest classification took place in this group. Of the 95 tomatoes in the soft firmness group, 86 were classified in their own group and 9 were classified in the intermediate firm group. In this case, it can be said that the use of three colour parameters determined with stepwise regression analysis will be more practical in real time applications since it shows similar classification accuracy to seven colour parameter use and for including less colour parameters.

Table 6. Measurements of main colour parameters for three firmness groups of tomatoes
Çizelge 6. Üç domates sertlik grubu için ana renk parametresi ölçümleri

Parameters	Classification group		
	Hard (52)	Intermediate (55)	Soft (95)
L*	46.49±1.37[c]	45.53±1.53[b]	40.80±2.09[a]
a*	-7.34±1.07[a]	-0.85±3.34[b]	17.02±7.34[c]
b*	16.09±1.81[a]	17.40±1.91[b]	21.04±2.09[c]

Values are mean and ± is standard deviation. In the same row, values with different superscripts are significantly different (P<0.05) by Scheffé test.

Table 7. Accuracy of tomato classification according to main colour parameters
Çizelge 7. Ana renk parametrelerine göre domates sınıflandırma doğruluğu

Parameters	Classification group			Total	Accuracy (%)
	Hard (52)	Intermediate (55)	Soft (95)		
L*	19 (%36.54)	40 (%72.73)	71 (%74.74)	130	64.36
a*	52 (%100)	47 (%85.46)	74 (%77.89)	173	**85.64**
b*	23 (%44.23)	44 (%80)	68 (%71.58)	135	66.83

Best accuracy is 85.64%=(52+47+74)/202*100, i.e., 85.64 well classified.
Value in parentheses presents the best response as a quantity percentage of the original class

Table 8. Accuracy of tomato classification for three main colour parameters L*, a* and b* using discriminant analysis
Çizelge 8. Diskriminant analizi ile L, a* ve b*ana renk parametreleri için domates sınıflandırma doğruluğu*

Class of Origin	Class of Test Response			Total
	Hard (52)	Intermediate (55)	Soft (95)	
Hard	48[a](92.31)[b]	4 (7.69)	0 (0.00)	52
Intermediate	5 (9.09)	49[a] (89.09)	1 (1.82)	55
Soft	0 (0.00)	21 (22.11)	74[a] (77.89)	95

[a] Overall accuracy is 84.65% = (48+49+74)/202 x 100, i.e., 84.65% well classified.
[b] Value in parentheses presents the test response as a quantity percentage of the original class.

Table 9. Accuracy of tomato classification for all colour parameters L*, a*, b*, a*xb*, a^{*2}, b^{*2} and a*/b* using discriminant analysis

Çizelge 9. Diskriminant analizi ile L, a*, b*, a*xb*, a^{*2}, b^{*2} ve a*/b*tüm renk parametreleri için domates sınıflandırma doğruluğu*

Class of Origin	Class of Test Response			Total
	Hard (52)	Intermediate (55)	Soft (95)	
Hard	52[a] (100.00)[b]	0 (0.00)	0 (0.00)	52
Intermediate	6 (10.91)	45[a] (81.82)	4 (7.27)	55
Soft	0 (0.00)	9 (9.47)	86[a] (90.53)	95

[a] Overall accuracy is 90.59% = (52+45+86)/202 x 100, i.e., 90.59% well classified.

[b] Value in parentheses presents the test response as a quantity percentage of the original class.

Table 10. Statistical results of the most significant colour parameters by stepwise regression analysis

Çizelge 10. En önemli renk parametrelerini belirlemede Stepwise regresyon analizi sonuçları

Parameters	Partial-R-square	Std Error	t-value	Significant
L*	0.031	0.089	-2.514	0.013
a^{*2}	0.432	0.001	12.247	0.000
a*/b*	0.796	0.519	-27.813	0.000

Table 11. Accuracy of tomato classification for three colour parameters L*, a^{*2} and a*/b* using discriminant analysis

Tablo 11. Diskriminant analizi ile L, a^{*2} and a*/b* ana renk parametreleri için domates sınıflandırma doğruluğu*

Class of Origin	Class of Test Response			Total
	Hard (52)	Intermediate (55)	Soft (95)	
Hard	52[a] (100.00)[b]	0 (0.00)	0 (0.00)	52
Intermediate	8 (14.55)	42[a] (76.36)	5 (9.09)	55
Soft	0 (0.00)	9 (9.47)	86[a] (90.53)	95

[a] Overall accuracy is 89.10% = (52+42+86)/202 x 100, i.e., 89.10% well classified.

[b] Value in parentheses presents the test response as a quantity percentage of the original class.

Conclusion

For practical and quick measurements, skin colour values in the harvest period were used to classify the tomatoes according to their firmness. Tomato skin rupture force was associated with L*, a*, b* and colour parameters derived from these main colour parameters. In the classification of tomato firmness, the use of colour parameters was found as an applicable method in classifying tomatoes of hard, intermediate and soft firmness level and firmness measurements. Main colour parameters gave high level of information about firmness classification of L*, a* and b* tomatoes with a classification accuracy of 84.65%. By using seven colour parameters instead of three main colour parameters, classification accuracy of tomatoes for all firmness groups was increased to 90.59% from 84.65% using linear discrimination analysis method. With stepwise regression analysis applied to seven colour parameters, the most important three colour parameters were determined as L*, a*2 and a*/b*. According to the linear discrimination analysis conducted by using these parameters, classification accuracy was calculated as 89.10 % from 90.59% with a decrease of 1.64% for all firmness groups. In addition, it can be said that classification of tomatoes by using three colour parameters of L *, a *2 and a */b * will be a more accurate approach considering that the numerical analysis complexity resulting from multiple parameter use will be decreased. While three main colour parameter approach was a suitable approach for the classification of hard and intermediate hard tomatoes (92.31% and 89.09%), seven colour parameter approach and three colour parameter approach were found be suitable for hard and soft firmness group (100% and 90.53%). The result that classification accuracy of tomatoes was found to be higher than 75% in all of the three approaches promoted the real time use of this technique. The aim of the present study was the classification of tomatoes according to their firmness and it is thought that it will be appropriate to conduct similar studies to increase classification accuracy for different products by using clustering, linear discriminant and stepwise regression analysis methods.

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