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Investigation of the Morphological and Color Changes of Damaged Green Plums During Storage Time Using Digital Image Processing Techniques

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ABSTRACT

The quality of green plums is directly affected by the uniformity of color and morphological characteristics which can be changed during harvest, handling, transportation and storage until they reach consumers. The determination of these characteristics is possible with image processing techniques. The advantages of this technique are being a simple, non-destructive and inexpensive methods that don't require a complex apparatus. In this study, green plums are damaged at different rates (3 mm, 5 mm and 10 mm) by a texture analyzer and images are obtained at different storage periods. Non-damaged fruits were considered as control. Morphological and color features of these images are determined by using image processing technique with Matlab® Image Processing Toolbox and the findings are compared among groups. In particular, the 10 mm damaging rate showed statistically significant differences for most of the morphological and color features ($p<0.05$). Therefore, the results showed that image processing technique is usable to classify the green plums according to damage rate.

Keywords: Green plum, damaging, image processing.

1. INTRODUCTION

Uniformity in color and size is important for green plums, since these properties determine the quality of the fruit. However, undesirable mechanical damages on green plums may occur during harvesting, transportation and storage (Adel and Diane, 2004; Zeebroeck et al., 2007). This damaging is an adverse situation for the consumers and requires sorting of the damaged ones. Computer-based sorting is more effective than manual sorting because it excludes personnel fatigue and loss of attention. Therefore, computer-based sorting systems are highly utilizable for determining fruit quality in large-scale fruit sorting (Nanyam et al., 2012). Image processing provides to identify, analyze, and display a wide variety of the finer details of objects from their digital images owing to the recent developments in hardware and software (Gonzalez and Woods, 2006; Russ, 2011). Otherwise, a computer vision system can provide convenience for long and tedious monitoring processes or ones that require complex apparatus to be performed. Consequently, sorting, classification and identification systems based on image processing techniques are becoming potentially feasible (Cubero et al., 2011; Paliwal et al., 2003).

Image processing techniques give more useful, simple, rapid, and correct data than manual techniques. In previous studies, this method was used to extract color, morphological and texture features of foods such as fish,

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fruit and vegetables. Different pattern recognition methods used for classifying, analyzing, sorting and investigating of foods depend on these features. Therefore, image processing (Blasco et al., 2009; Garrido-Novell et al., 2012; Mendoza et al., 2006; Boldaji et al., 2008) and pattern recognition (Hu et al., 2012; Valenzuela and Aguilera, 2013) were the best methodology for determining quality of crops. In this paper, color and morphological changes of the damaged green plums were investigated by image processing techniques.

2. MATERIAL AND METHODS

2.1. Materials

Green plums (*Prunus cerasifera* L.) were harvested at commercial ripeness and were supplied from a farmer in Canakkale, Turkey. The green plums with uniform size and color were selected and physically damaged plums were discarded. The selected green plums were randomly separated into four equal groups (control, 3 mm, 5 mm and 10 mm damaged). Twenty green plums were used for each group and samples were stored for 7 days at room temperature.

2.2. Damaging the Green Plums

A damaging application was performed on green plums using a Texture Analyzer (TA.XTPlus, Texture Technologies Cor., Scarsdale, N.Y., USA) (Figure 1). Each green plum was punctured from a different distance. The distances were 3 mm, 5 mm and 10 mm. The texture analyzer executed at 3 mm/s constant speed with a compression mode using a 5 mm diameter probe.

Figure 1. An image of damaging application of the green plums

2.3. Determining the Morphological and Color Features by Image Processing

In this study, morphological and color change of green plums are determined with the help of image processing techniques. This process consists of three stages:

Image acquisition system: It contains image acquisition tool and digital camera. Image acquisition tool is prepared size of 40 cm x 40 cm x 15 cm as shown in the Figure (2). Fujifilm FinePix AV100 model digital camera is used to capture and it is placed on a tripod to prevent vibrations that may occur during shooting.

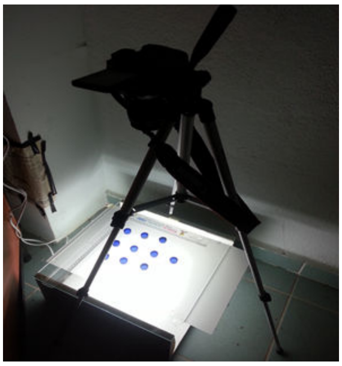

Figure 2. An image of image acquisition unit

Image processing technique: these process was used for labeling of each object.

Phases:

- Captured image of green plumps
- Image was cropped according to specific coordinates for eliminating unnecessary fields
- Image converted into two images (gray image and green channel image)
- Gray image was subtracted from green channel image
- Subtracted image was threshold
- Each object was labeled

Feature extraction: Color and morphological features were extracted from each labeled green plum on the screen. Features of green plums were area, environment, major and minor length, mean intensity and R-G-B values. These features were used for determining of damaging rates.

The segmented images of control and damaged green plums are shown in Table 1.

2.4. Definitions of Morphological Features

Area: The actual number of pixels in the region.

Environment: Determined using environment of bounding box values which is the smallest rectangle containing the region.

Major Length: Specifying the length of the major axis of the ellipse that has the same normalized second central moments as the region.

Table 1. Segmented images of control and damaged samples during storage time

	0. Day 1. Day 3. Day 5. Day 7. Day
Control	
3 mm	
5 mm	
10 mm	

Minor Length: The length of the minor axis of the ellipse that has the same normalized second central moments as the region.

2.5. Definitions of Color Features

RGB: An RGB image is stored as an *m*-by-*n*-by-3 data array that defines red, green, and blue color components for each individual pixel. The color components of an 8-bit RGB image are integers in the range [0, 255] rather than floating-point values in the range [0, 1]. In this study, the RGB values of green plums was separated to R, G and B values.

3. RESULTS AND DISCUSSION

3.1. Morphological Features

There was a linear decrease based on the morphological characteristics over time. All of the determined morphological features (area, environment, major and minor length) displayed similar results and every feature reinforced each other. The results obtained from the morphological characteristics of green plums are shown in Table 2. While damaged samples had lower values than control in all storage periods, statistically significant decreases have occurred after 3 days of storage ($p<0.05$). These reductions are related to water loss of the green plums during storage as reported in the literature (Pérez et al., 2007; Manganaris et al., 2008; Tarazaga and Gago, 2011; Tarhan, 2007; Valero et al., 2003). It was considered that damaging applications have caused more water loss because of the damaging of the green plums' skin and its facilitating effect on dehydration.

Graphs of the percentage changes in morphological features of green plums help to understand more clearly the differences among groups. Percentage reductions were 93.21% (control), 90.36% (3 mm), 90.50% (5 mm) and 90.04% (10 mm) in area; 96.82% (control), 95.38% (3 mm), 95.29% (5 mm) and 95.15% (10 mm) in environment; 96.25% (control), 94.99% (3 mm), 94.52% (5 mm) and 94.60% (10 mm) in major length and 96.44% (control), 95.00% (3 mm), 95.17% (5 mm) and 94.96% (10 mm) in minor length after 7 days (Figure 3). These results have demonstrated that the damaging applications lead to higher water loss. In general, control and damaging applications have showed statistically significant differences in the term of the morphological features ($p<0.05$). However, no statistically significant differences were found between control and 3 mm damaging rate based on major length. 3 mm, 5 mm and 10 mm damaging rates had similar results in all of the morphological features (Figure 3). These results demonstrated that if the skin has been punctured, further damage does not have much effect on the morphological characteristics based on the water loss.

Table 2. Values of morphological features of the green plums during storage time

	Groups	Storage Time (Day) 0.Day	1.Day	3.Day	5.Day	7.Day
Area (mm^2)	**Control**	657.3±44.6	656.8±43.0	638.9±41.0	621.6±44.5	613.0±45.8
	3 mm	649.0±76.8	646.9±74.8	631.1±77.9	604.8±76.1	586.4±75.5
	5 mm	674.6±51.9	671.0±49.8	657.0±53.6	628.2±53.1	610.4±53.7
	10 mm	664.3±47.8	660.9±49.3	644.6±53.1	614.5±52.9	598.1±53.3
		a	a	a	b	b
Environment (mm)	**Control**	114.8±3.8	114.6±3.8	113.2±3.6	111.9±4.2	111.1±4.2
	3 mm	114.3±6.2	113.9±6.1	112.9±6.6	111.0±6.5	109.1±6.7
	5 mm	116.5±4.3	116.1±4.0	115.1±4.4	112.4±4.3	111.0±4.5
	10 mm	115.5±4.0	115.2±4.4	113.9±4.6	111.5±4.8	109.9±4.7
		a	a	ab	bc	c
Major Length (mm)	**Control**	29.6±1.2	29.6±1.1	29.2±1.0	28.7±1.1	28.5±1.2
	3 mm	29.4±1.8	29.4±1.7	29.0±1.8	28.4±1.8	27.9±1.7
	5 mm	30.2±1.1	30.0±1.1	29.6±1.1	28.9±1.2	28.5±1.3
	10 mm	30.0±1.1	29.8±1.1	29.5±1.2	28.7±1.3	28.4±1.4
		a	a	ab	bc	c
Minor Length (mm)	**Control**	28.4±0.8	28.3±0.8	27.9±0.9	27.6±1.0	27.4±1.0
	3 mm	28.1±1.5	28.0±1.5	27.7±1.6	27.1±1.6	26.7±1.7
	5 mm	28.6±1.0	28.6±1.2	28.3±1.3	27.7±1.3	27.3±1.3
	10 mm	28.3±1.1	28.3±1.2	27.9±1.3	27.3±1.3	26.8±1.3
		a	a	a	b	b

a-c: Different letters indicate statistically significant ($p<0.05$) differences.

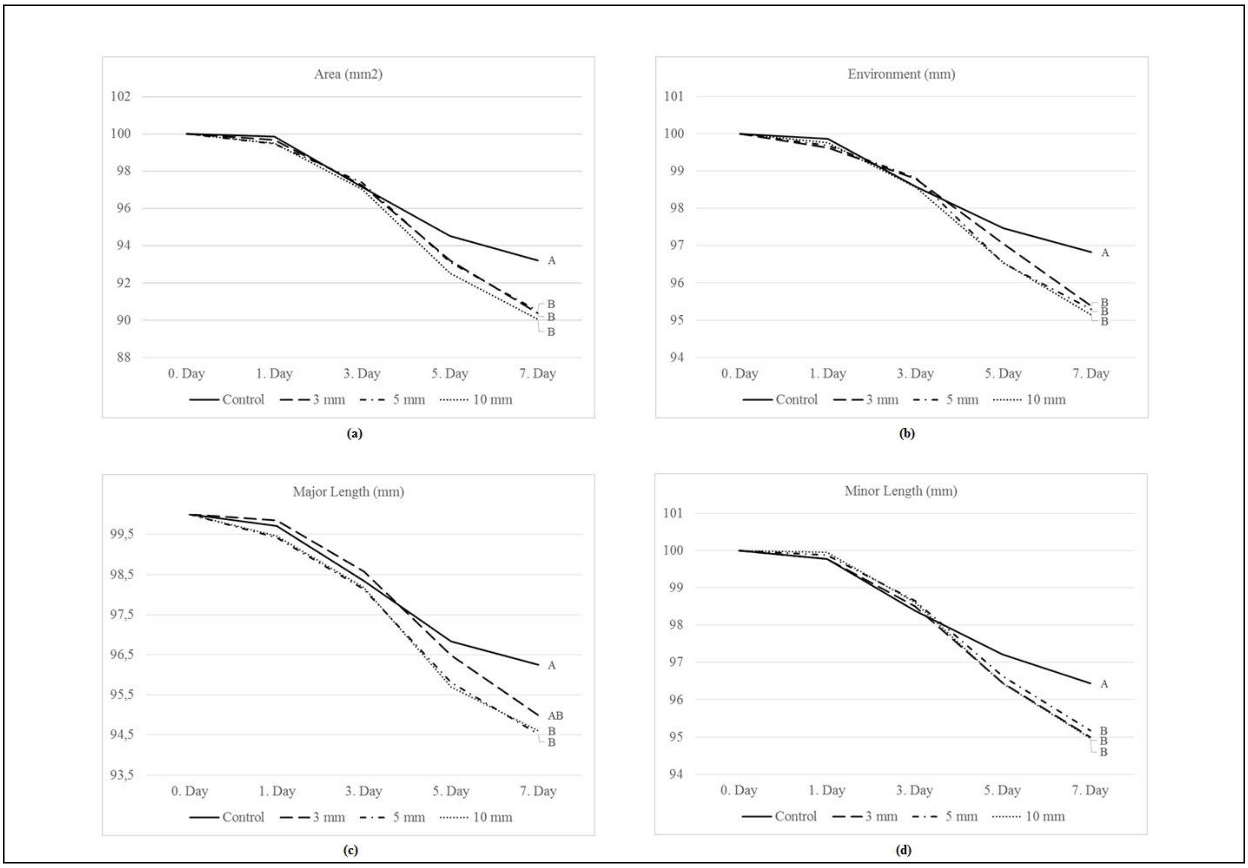

Figure 3. Graphs of the percentage changes in morphological features of green plums and statistically importance level at the end of storage time ((a) area; (b) environment; (c) major length; (d) minor length)

3.2. Color Features

Fruits are appealing and seize attention because of the abundance of color pigments. Protection of color compounds such as green chlorophyll, red to purple anthocyanin and orange to red carotenoid in fruits is vital to maintain the quality of crops (Diane and Elisabeth, 2002).

The results obtained from the color characteristics of green plums are shown in Table 3 and percentage changes are shown in Figure 7. The color of the plums changed from green to red as indicated by the reduction of the G value and increasing of R and B values (Figure 4). Statistical analyses revealed that these alterations were statistically important ($p<0.05$). Chlorophyll (green color) degradation, carotenoid (yellow and orange colors) biosynthesis, anthocyanin (red and blue colors) biosynthesis and phenolic compound (brown color) biosynthesis and oxidation occur during ripening of fruits. The lower O_2 levels slow down these reactions (Adel and Mikal, 2002; Zagory and Kader Adel, 1989). Luo et al. (2009) have mentioned that chlorophyllase is the vital enzyme in the pathway of chlorophyll degradation during the ripening of plums (Luo et al., 2009). Anthocyanins are responsible for much of the red, blue, and purple colors of fruits (Welch and Simon, 2008). Anthocyanins gather relatively late in the ripening of fruits. The lower O_2 levels delay ripening and retard the accumulation of anthocyanin pigments (Zagory and Adel, 1989). For all these reasons, a rapid change from green to red had been observed from the damaged plums (3 mm, 5mm and 10 mm) due to the damaged tissues much more contact with O_2. Particularly, 10 mm damage rate had higher color changes (decrease of G and increase of R and B) based on the loss of chlorophyll and biosynthesis of dark red pigments such as anthocyanin.

Table 3. Values of color features of the green plums during storage time

	Groups	Storage Time (Day)				
		0.Day	1.Day	3.Day	5.Day	7.Day
R values	Control	85.62±7.47	93.17±14.16	93.78±11.08	94.63±9.45	95.04±7.45
	3 mm	81.75±11.98	94.07±8.53	97.65±9.98	109.00±9.39	117.27±8.00
	5 mm	79.17±7.55	88.22±10.83	91.88±10.18	106.69±10.22	115.61±8.72
	10 mm	73.81±8.10	86.93±15.17	88.93±7.77	111.49±11.43	119.12±11.77
		d	c	c	b	a
G values	Control	133.31±7.01	132.88±17.06	132.18±11.19	131.00±10.66	124.38±12.38
	3 mm	129.88±7.61	129.23±8.03	128.78±7.93	123.24±10.09	116.65±16.00
	5 mm	124.49±7.32	123.14±11.26	122.78±8.56	116.85±12.31	109.88±14.74
	10 mm	126.66±14.72	124.97±19.71	119.44±9.03	109.27±18.05	96.66±19.74
		a	a	ab	b	c
B values	Control	83.12±9.99	83.51±14.73	84.12±9.79	84.64±8.88	84.93±6.19
	3 mm	78.94±11.97	81.33±8.91	83.63±9.51	85.57±9.03	88.94±10.08
	5 mm	76.59±10.70	79.44±11.91	81.67±9.17	85.40±10.55	89.19±10.70
	10 mm	73.63±9.00	77.03±12.37	78.79±7.87	84.54±9.51	87.22±9.66
		c	c	bc	ab	a
Mean Intensity	Control	140.9±8.3	135.1±12.3	133.9±9.5	132.8±7.6	132.7±6.1
	3 mm	143.7±10.4	135.6±7.9	132.8±8.8	130.3±9.8	130.6±11.7
	5 mm	150.3±7.6	141.4±13.1	138.6±6.7	135.7±8.8	133.0±8.0
	10 mm	145.7±7.4	139.1±9.1	135.1±7.3	129.2±9.0	124.4±8.8
		a	b	bc	c	c

a-c: Different letters indicate statistically significant ($p<0.05$) differences.

Percentage changes computed for further illustrate of results were 111.01% (control), 143.46% (3 mm), 146.03% (5 mm) and 161.39% (10 mm) in R; 93.30% (control), 89.81% (3 mm), 88.27% (5 mm) and 76.31% (10 mm) in G; 102.19% (control), 112.68% (3 mm), 116.45% (5 mm) and 118.46% (10 mm) in B and 94.14% (control), 90.60% (3 mm), 88.46% (5 mm) and 85.34% (10 mm) in mean intensity after 7 days of the storage (Figure 4). These findings have showed that the damaging applications showed higher color changes throughout the storage period. 10 mm damaging application showed statistically significant differences than other groups based on R and G values and mean intensity ($p<0.05$). While 10 mm displayed higher values for B value, no significant differences were found among other damaging applications (Figure 4).

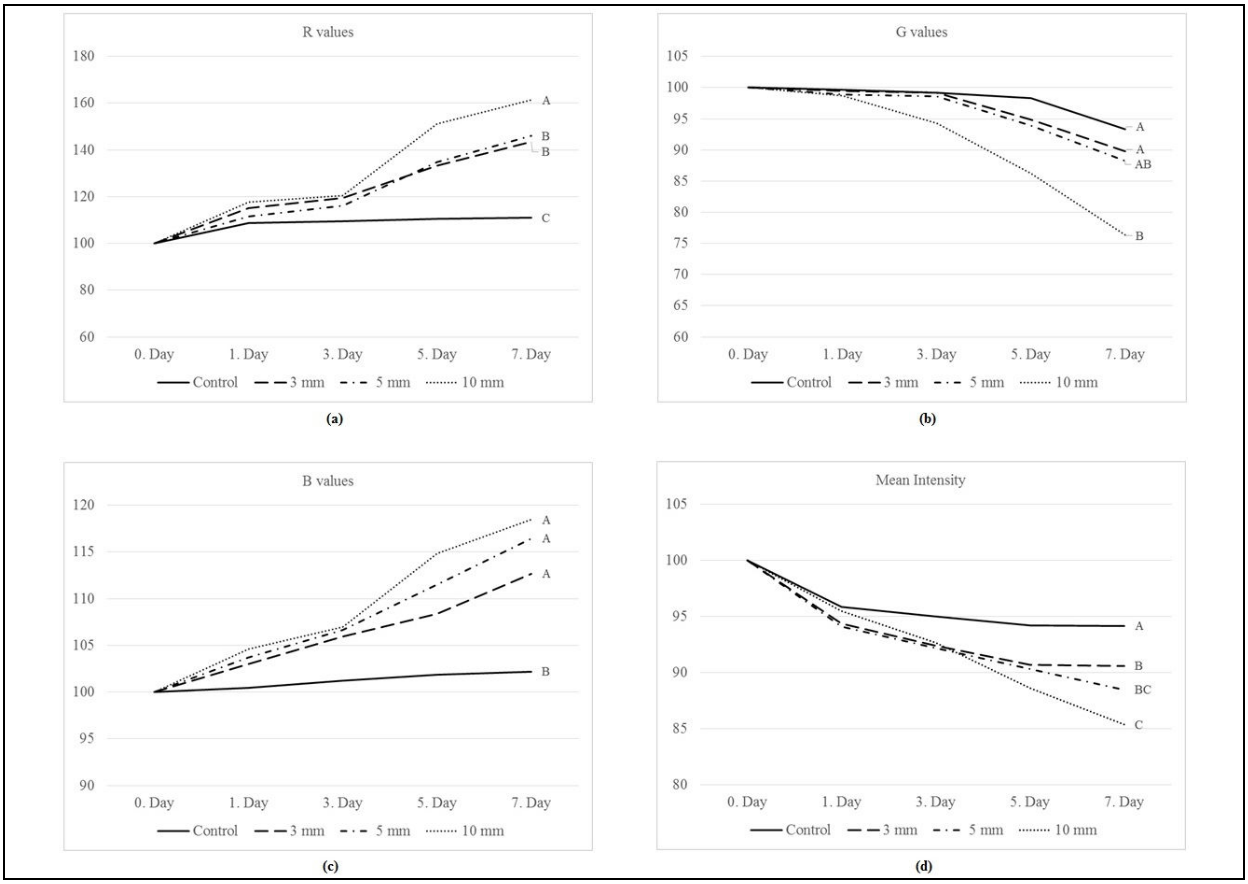

Figure 4. Graphs of the percentage changes in color features of green plums and statistically importance level at the end of storage time ((a) R value; (b) G value; (c) B value; (d) mean intensity)

4. CONCLUSIONS

In this article, morphological and color changes of damaged green plums were investigated during storage time using digital image processing techniques and the findings are compared among groups. Especially, the 10 mm damaging rate which was the most amount of damage had statistically significant differences for most of the features ($p<0.05$). Therefore, the image processing can be used to determine the rate of damage on green plums.

Area, environment, major and minor length showed a similar trend during the storage time. However, the higher damaging rates resulted a greater reduction than lower damaging rates regarding to morphological features. The change in the morphological features of green plums is due to the weight loss during storage time.

When the color properties of green plums were examined, it was observed that R and B values increased, whereas the G values and mean intensity decreased. The change in the color depends on degradation of chlorophyll and biosynthesis of the dark red color pigments (anthocyanin, etc.) during storage time. The chlorophyll degradation caused to reducing of G values, while R and G values increased by anthocyanin biosynthesis. The damaging application was accelerated the color changings owing to the deterioration.

According to the data obtained from plum images, the rate of damage is directly proportional to deterioration of the plums. The using of image processing techniques had provided a rapid, easy, high accuracy and regardless of human error study. In this study, one of the most important issues is that the analysis system was carried out directly without damage namely non- destructive.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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