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COLOR TEXTURE FEATURE ANALYSIS FOR ESTIMATION OF MELON INTERNAL QUALITY

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ABSTRACT The net rind pattern and color of melon surface are important for a high market value of melon fruits. The development of the net and color are closely related to the changes in shape, size, and maturing. Therefore, the net and color characteristics can be indicators for assessment of melon quality as melon fruits develop. The goal of this study was to explore the possibility of estimating melon soluble solids content (SSC) and firmness by analyzing the net and color characteristics of fruit surface. The true color images of melon surface obtained in the equatorial region were analyzed with 18 color features and 9 texture features. Partial least squares (PLS) method was used to estimate melon internal quality using the color and texture features. In the prediction of melon SSC, the coefficients of determination of validation (R_v^2) of the models using the color and texture features were 0.84 (root mean square error of validation, RMSEV: 1.92 °Brix) and 0.96 (RMSEV: 0.60 °Brix), respectively. The R_v^2 values of the models for predicting melon firmness using the color and texture features were 0.64 (RMSEV: 4.62 N) and 0.79 (RMSEV: 2.99 N), respectively. In general, the texture features were more useful for estimating melon internal quality than the color features. However, to strengthen the usefulness of the color and texture features of melon surface for estimation of melon quality, additional experiments with more fruit samples of different varieties need to be conducted.

Keywords: melon, soluble solids content (SSC), firmness, image color feature, image texture feature.

INTRODUCTION Melon (*Cucumis melo* L.) is one of the most consumed crops with high marketability in the world. Internal quality of melon fruit is determined by complicated biochemical and developmental processes that result in changes in flavor, texture, and color (Li et al., 2006). Many researchers have studied assessment of melon fruit quality using various technologies: NIR spectroscopy, dielectric characteristics, multi-spectral imaging, acoustic vibration. Guthrie et al. (2006) used near infrared spectroscopy for on-line assessment of soluble solids content of rockmelons. Nelson et al. (2006) studied the correlations between the dielectric properties of Honeydew melons and their soluble solids contents for nondestructive sensing of maturity. Sugiyama (2009) visualized sugar content of melons with spectral absorption images captured by a multi-spectral imaging system. Taniwaki et al. (2010) determined the ripeness of melons with their resonance frequency by an acoustic vibration.

The rind of muskmelon fruits contains a network of suberized tissue, referred to as the 'net' (Keren-Keiserman et al., 2004). The net pattern is important for a high market value and therefore is one of factors that determine melon quality. The net is a shallow, greenish, non-dried tissue that protrudes only slightly above the fruit surface in an immature stage. As it becomes mature, it changes to a dry, white material that extends above the fruit surface (Gerchikow et al., 2008). The development of the net is related to the changes in shape, size, and maturing (Keren-Keiserman et al., 2004). Therefore, the net characteristics can be indicators for assessment of melon quality. The objective of this study was to explore the possibility of estimating melon soluble solids content (SSC) and firmness by analyzing the net and color characteristics of fruit surface.

MATERALS AND METHOD

Melon samples

A total of 45 muskmelon (*Cucumis melo* L. var. *reticulates*) samples were obtained from a greenhouse in Naju, Korea during March and April in 2009. Fifteen melons were harvested each 40, 44, and 52 day after pollination. Melons were placed at room temperature (23°C) for about 20h before measurements were started. The fruit weight, diameter, which was measured around the fruit equator with a tape measure, firmness, and SSC were measured.

Image acquisition system

A single charge coupled device (CCD) digital color camera (Imaging Source, DFK-31BF03, USA) with a zoom lens (F1.4 and focal lengths of 1.4-11mm) was used to acquire melon skin images. A light chamber was illuminated uniformly with 12 circular fluorescent lamps. The surface images of a melon were acquired in the equatorial region at 6 locations about 60° apart around the perimeter of the melon. The image size was 1024*768 pixels that corresponded to the size of about 4.5*3.5 cm on the surface of the melon.

Color feature analysis

The original color images captured by the CCD camera were transformed to the hue-saturation-intensity images which consisted of hue (H), saturation (S), and intensity (I) images. The true-color images were also divided into red (R), green (G), and blue (B) images. Otsu's threshold method (Gonzalez and Woods, 2002) was applied to each R, G, B, H, S, I image to mask netted rind pixels of the melon surface images. After segmentation processing, adaptive median filter was applied to remove impulse noise that still existed in the segmented images. Histogram of pixels in each image was made. The highest frequency, the intensity value that showed the highest frequency, and the average intensity of pixels were calculated from each R, G, B, H, S, I image. Therefore, 18 color features were obtained from a true-color image.

Texture feature analysis

The true-color images were transformed to the gray scale images. Through Otsu's threshold method and adaptive median filter that were used for color feature analysis, the gray scale images were processed to net-rind-segmented images. The ratio of the area of the net rind to the area of the melon surface image from which the net rind was removed was calculated. The intensity histogram of the gray scale image was obtained. Six statistical features of the intensity histogram, average intensity (m), standard deviation (σ), relative smoothness (R), third moment (μ3), uniformity (U), entropy (e), were obtained (Gonzalez and Woods, 2002).

$$m = \sum_{i=0}^{L-1} z_i \, p(z_i) \tag{1}$$

$$\sigma = \sqrt{\sum_{i=0}^{L-1} (z_i - m)^2 \, p(z_i)} \tag{2}$$

$$R = 1 - \frac{1}{1 + \sigma^2(z)} \tag{3}$$

$$\mu_3(z) = \sum_{i=0}^{L-1} (z_i - m)^3 \, p(z_i) \tag{4}$$

$$U = \sum_{i=0}^{L-1} p^2(z_i) \tag{5}$$

$$e = -\sum_{i=0}^{L-1} p(z_i) \log_2 p(z_i) \tag{6}$$

Where, z_i is a random variable indicating intensity (i=0, 1, 2, …, L-1), L is the number of distinct gray levels, and p(z) is the histogram of the intensity levels in a region.

The Fourier spectrum is suited for describing the directionality of periodic patterns in an image. These global texture patterns are distinguishable as concentrations of high-energy bursts in the spectrum. Interpretation of the spectrum can be simplified by expressing the spectrum as a function S(r,θ), where r is frequency and θ is direction. We considered three features of the Fourier spectrum: the total energy of frequency for each direction (F_r), the total energy of direction for each frequency (F_θ), the maximum energy of frequency at each direction (F_{max}).

$$F_r = \sum_{r=1}^{R_0} \sum_{\theta=0}^{\pi} S_\theta(r) \tag{7}$$

$$F_{\max} = \max_{r=1}^{R_0} \sum_{\theta=0}^{\pi} S_\theta(r) \tag{8}$$

$$F_\theta = \sum_{\theta=0}^{\pi} \sum_{r=1}^{R_0} S_r(\theta) \tag{9}$$

Where R_0 is the radius of a circle centered at the origin.

Internal quality measurement by destructive method

For melon firmness on melon flesh and SSC measurement, an equatorial slice about 2cm thick was cut with a sharp knife from the center of the melon perpendicular to the top-to-bottom axis. From this slice, firmness was measured at 6 locations where the surface images were acquired around the center of the slice using a material testing machine (Multi-Test 1-i, Mecmesin, UK) at a loading speed of 24 mm/min. Fruit skin in the area measured was removed and a cylindrical probe with a diameter of 8 mm was moved down into the fruit flesh to a depth of 15 mm. The maximum force was recorded as the fruit firmness. When the probe pressed the flesh tissue, juice squeezed was taken using a syringe and the SSC of the juice was measured with a digital refractometer (PR-32α, Atago Co. Ltd., Japan). The flesh samples close to the 6 locations where the firmness and SSC were measured were taken for sensory evaluation. The aroma, sweetness, texture, and overall taste of the flesh samples were evaluated in a scale of 1 (bad) to 5 (good) by 5 panelists.

Model development

Partial least squares (PLS) method was used to develop models for predicting SSC, firmness, and sensory taste (aroma, sweetness, texture, and overall taste) from the color and texture features of the surface of melon fruits and the sensory test results. The 45 samples were divided into two data sets: a calibration data set of 30 samples and a validation data set of 15 samples. Five statistical parameters, the number of principle component (#PC), coefficient of determination of calibration (R_c^2), coefficient of determination of validation (R_v^2), root mean square error of calibration (RMSEC), and root mean square error of validation (RMSEV), were used to investigate the performance of the models. PLS analysis was carried out using Matlab PLS Toolbox (ver. 4.2, Eigenvector Research Inc., USA).

RESULTS

Weight, diameter, SSC, and firmness of fruit samples

The weight and diameter of fruit samples increased about 16% and 4%, respectively, from 40 to 52 days after pollination (table 1). They were about 2 kg and 52 cm at the full development stage (52 days after pollination), respectively. The SSC increased from 9.75 °Brix to 15.90 °Brix during the fruit development of 12 days. However, the firmness decreased about 43% (31 N to 22 N) from 40 to 52 days after pollination. The standard deviations of 4 fruit features tended to be lowered with fruit development. Especially, the standard deviations of the SSC and firmness values were reduced linearly with fruit development and were lowest at the full development stage. This indicates that fruit SSC and firmness can be highly variable depending on growing environment during fruit development. But the values of SSC and firmness seem to approach to saturated levels as fruit matures so that the variability of SSC and firmness at the full development stage is lowest.

Table 1. Weight, diameter, SSC, and firmness of the fruit samples (mean±standard deviation of 15 samples at each fruit development stage).

Fruit feature parameter	Days after pollination		
	40	44	52
Weight (kg)	1.83±0.16	1.95±0.21	2.13±0.11
Diameter (cm)	49.51±1.50	50.65±1.88	51.49±0.74
SSC (°Brix)	9.75±0.80	12.18±0.52	15.90±0.37
Firmness (N)	31.32±2.54	29.50±2.40	21.87±1.95

Prediction of fruit quality with image color features

The fruit color features were well correlated with SSC, firmness, and sensory evaluation of aroma, sweetness, texture, and overall taste in general (table 2). The R_c^2 values for calibration of all fruit quality parameters were in the range of 0.836 to 0.914. For prediction of SSC and firmness, the R_v^2 values were 0.84 (RMSEV: 1.92 °Brix) and 0.64 (RMSEV: 4.62 N) respectively. The R_v^2 value for estimation of overall taste based on sensory evaluation was 0.82 (RMSEV: 0.45). As shown in table 1, the variability of fruit SSC and firmness were distinct at different fruit development stages. The correlation result of table 2 indicated that the fruit color features also might be different at each fruit development stage so that the variation of the fruit color features might represent the variation of the fruit SSC and firmness.

Table 2. Performance of PLS models based on the color features of fruit surface.

Fruit quality parameter		#PC	R_c^2	RMSEC	R_v^2	RMSEV
SSC (°Brix)		9	0.914	0.7671	0.836	1.9232
Firmness (N)		10	0.897	1.5029	0.637	4.6235
Sensory evaluation	Aroma	5	0.863	0.2260	0.599	0.4745
	Sweetness	8	0.879	0.3611	0.706	0.9456
	Texture	4	0.853	0.3734	0.833	0.4175
	Overall taste	4	0.836	0.4271	0.818	0.4549

Prediction of fruit quality with image texture features

Table 3 shows that the texture features of fruit surface images can be good indicators for estimation of SSC, firmness, and sensory evaluation of aroma, sweetness, texture, and overall taste. The R_c^2 values for calibration of all the fruit quality parameters were higher than 0.85. For prediction of SSC and firmness, the R_v^2 values of 0.96 (RMSEV: 0.60

°Brix) and 0.79 (RMSEV: 2.99 N), respectively, using the fruit texture features were higher than those using the fruit color features. The R_v^2 value of 0.94 (RMSEV: 0.36) for estimation of overall taste using the fruit texture features was also higher than that using the fruit color features. In comparison to the test results of tables 2 and 3, the texture features of fruit surface may be more useful for estimation of fruit quality than the color features.

However, we need to address that a small number of samples (35 samples for calibration and 15 samples for validation) were used in this study. Therefore, additional experiments need to be conducted using more fruit samples of different varieties to strengthen the usefulness of the color and texture features for estimation of fruit quality.

Table 3. Performance of PLS models based on the texture features of fruit surface.

Fruit quality parameter		#PC	R_c^2	RMSEC	R_v^2	RMSEV
SSC (°Brix)		3	0.928	0.7001	0.962	0.5955
Firmness (N)		6	0.847	1.8284	0.786	2.9923
Sensory evaluation	Aroma	4	0.924	0.1683	0.884	0.2582
	Sweetness	5	0.978	0.1529	0.944	0.3667
	Texture	4	0.962	0.1901	0.949	0.2710
	Overall taste	4	0.970	0.1843	0.940	0.3564

CONCLUSION

The true color images of melon surface obtained in the equatorial region were analyzed with 18 color features and 9 texture features. Partial least squares (PLS) method was used to estimate melon internal quality using the color and texture features. In the prediction of melon SSC and firmness, the coefficients of determination of validation (R_v^2) of the models using the color features were 0.84 (root mean square error of validation, RMSEV: 1.92 °Brix) and 0.64 (RMSEV: 4.62 N) respectively. The R_v^2 values of the models using the texture features were 0.96 (RMSEV: 0.60 °Brix) and 0.79 (RMSEV: 2.99 N), respectively. In general, the texture features were more useful for estimating melon internal quality than the color features. However, we need to address that a small number of samples (35 samples for calibration and 15 samples for validation) were used in this study. Therefore, additional experiments need to be conducted using more fruit samples of different varieties to strengthen the usefulness of the color and texture features for estimation of fruit quality.

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