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Melon Surface Color and Texture Analysis for Estimation of Soluble Solids Content and Firmness

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Abstract

Purpose: 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 used indicators for assessment of melon quality. The goal of this study was to investigate the possibility of estimating melon soluble solids content (SSC) and firmness by analyzing the net and color characteristics of fruit surface. **Methods:** The true color images of melon surface obtained at fruit equator were analyzed with 18 color features and 9 texture features. The partial least squares (PLS) method was used to estimate SSC and firmness in melons using their color and texture features. **Results:** In sensing melon SSC, the coefficients of determination of validation (R_v^2) of the prediction 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. **Conclusions:** 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 need to be conducted.

Keywords: Firmness, Fruit color feature, Fruit texture feature, Melon, Soluble solids content (SSC)

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, and 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. These technologies mainly measure physical and chemical attributes of internal flesh of fruits. Therefore, appearance features of fruits, which are also important factors to grade fruits, cannot be considered.

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 can be 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

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(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, along with fruit surface color, the net characteristics can be indicators for assessment of melon quality. However, there is no report for estimating melon internal quality by analyzing the net and color characteristics of fruit surface. The objective of this study was to investigate the possibility of estimating melon soluble solids content (SSC) and firmness by analyzing the net and color characteristics of fruit surface.

Materials and Methods

Melon samples

A total of 45 muskmelon (*Cucumis melo* L. var. *reticulates*) samples were obtained from a greenhouse in Naju, Korea during March through April in 2009. A set of fifteen melons was harvested on the 40th, 44th, and 52nd day after pollination, respectively. The melons were kept at room temperature (23℃) for 20h before measurements were started. The fruit weight and diameter were measured before taking images of fruit surfaces. The SSC and firmness were measured by a destructive method right after taking images of fruit surfaces.

Image acquisition system

A single charge coupled device (CCD) digital color camera (DFK-31BF03, Imaging Source, USA) with a zoom lens (F1.4 and focal lengths of 1.4-11 mm) was used to acquire melon surface images. A light chamber was illuminated uniformly with 12 circular fluorescent lamps. Each fruit sample was put in the light chamber manually. The surface images of a melon were acquired at evenly distributed 6 points on the fruit equator. The values of color and texture features that were obtained by analyzing the images were averaged and the mean values were used as the representatives of each sample. The acquired image was 1024 × 768 pixels that corresponded to the size of 4.5 × 3.5 cm on the surface of a 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 (Fig. 1). Histograms of pixels in each image ware plotted. The highest frequency in the histograms, 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. The mentioned image processing for color feature analysis was conducted using Matlab(Ver. 7.6, The MathWorks, USA) with the functions provided by Matlab Image Processing Toolbox(Ver. 6.1, The MathWorks, USA).

Texture feature analysis

The true-color images were transformed to the gray scale images. Through the Otsu's threshold method and adaptive median filter 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

(a) (b) (c)

Figure 1. Processing of fruit surface image: (a) color image, (b) binary image, and (c) net-rind-segmented image obtained by applying adaptive median filter to the binary image.

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 et al., 2004).

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

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

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

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

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

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

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.

The Fourier spectrum is suited for describing the directionality of periodic patterns in an image(Gonzalez et al., 2004). 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 and SSC measurement, an equatorial slice with a 2 cm thickness was cut with a sharp knife. The firmness of the flesh was measured by a texture analyzer (MultiTest 1-i, Mecmesin, UK) at the 6 points where the surface images were acquired. A cylindrical probe (8 mm O.D.) equipped at the texture analyzer was moved down into the flesh at a loading speed of 24 mm/min to a depth of 15 mm (ASABE Standards s368.4). The maximum force was recorded as the fruit firmness. When the probe pressed the flesh tissue for firmness measurement, the squeezed juice was taken using a syringe and then the SSC of the juice was measured using a digital refractometer (PR-32α, Atago Co. Ltd., Japan). The SSC and firmness measured at the 6 points of each sample were averaged and the mean value was used as the representative SSC and firmness of each sample. The flesh samples close to the 6 points 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

The 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 melon surface color and texture features 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. The PLS analysis was carried out using Matlab PLS Toolbox (Ver. 4.2, Eigenvector Research Inc., USA).

Results and Discussion

Properties of fruit samples

The weight and diameter of fruit samples increased almost 16% and 4%, respectively, when the day after pollination was changed from 40 to 52 (table 1). They were about 2 kg and 52 cm at the full development stage (the 52nd day after pollination). The SSC increased from 9.75 °Brix to 15.90 °Brix during the fruit development of the 12 days. However, the firmness decreased about 43% (31 N to 22 N) when the day after pollination was changed from 40 to 52. The standard deviations of all 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 approach to saturated levels as fruit matures so that the variability of SSC and firmness at the full development stage is lowest.

Prediction of fruit quality using the color features of fruit surface

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 a range of 0.836 to 0.914 (RMSEC: 0.23 to 1.50 °Brix). 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 Rv^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 prediction result of table 2 indicates 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.

Prediction of fruit quality using the texture features of fruit surface

Table 3 indicates 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 Rc^2 values for calibration of all the fruit quality parameters were higher than 0.85. For prediction of SSC and firmness, the Rv^2 values of 0.96 (RMSEV: 0.60 °Brix) and 0.79 (RMSEV: 2.99 N) were obtained, respectively. The performance of the models using the fruit texture features was higher than that 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 of the test results of tables 2 and 3, the texture features of fruit surface may be more useful for

Table 1. Weight, diameter, SSC, and firmness of the fruit samples at three different fruit development stages (mean±standard deviation)

Fruit feature	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

Table 2. Performance of PLS models using 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

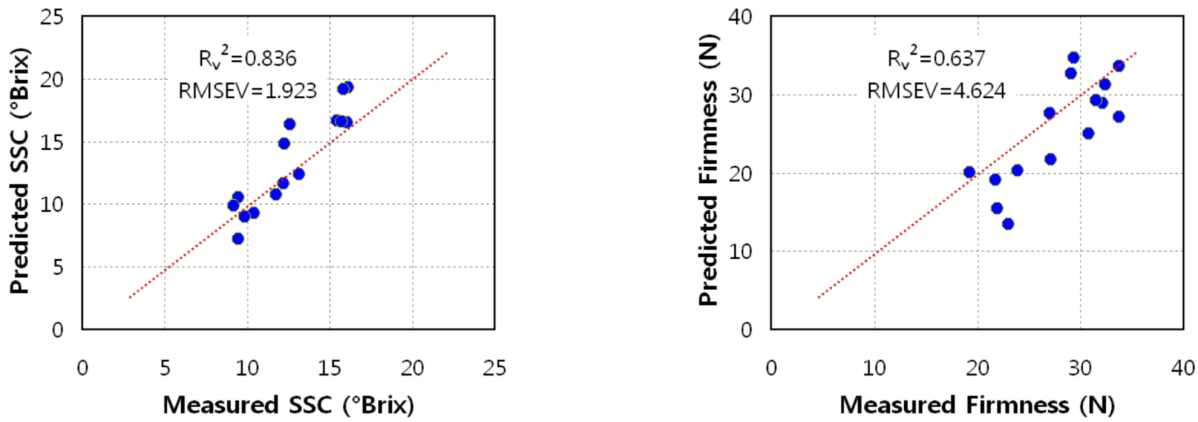

Figure 2. Measured versus predicted SSC and firmness using the color features of fruit surface.

Table 3. Performance of PLS models using 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

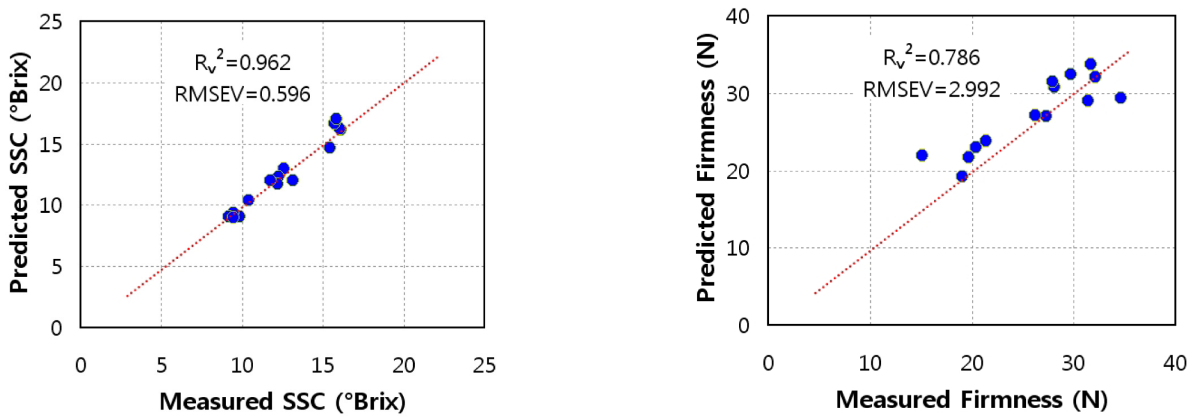

Figure 3. Measured versus predicted SSC and firmness using the texture features of fruit surface.

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 to strengthen the usefulness of the color and texture features for estimation of fruit quality.

Conclusions

The true color images obtained at fruit equator were analyzed with 18 color features and 9 texture features. The 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 Rv^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 to strengthen the usefulness of the color and texture features for estimation of fruit quality.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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