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Quantification of Starch Content in Apples Using Image Analysis and Its Relationships to Physicochemical Properties

Y. J. Cho, W. Jun, C. T. Kim, C. J. Kim, D. M. Kim, B. H. Hwang, J. K. Kim

Abstract: The starch content of apples, which is related to the maturity and ripeness, was quantified by using a computer vision system. The stained area was measured by image analysis when an apple slice was stained with KI/I_2 solution. The ratio of the stained area of the apple slice to its whole area, so called the starch index, was defined as an indicator of the starch content. When *Tsugaru* apples were manually sorted into immature, turning and mature groups, their starch indices were 0.374, 0.312 and 0.129, respectively. The starch index had relationships to various physicochemical properties of *Tsugaru* apples. At the statistically significant level of 0.1%, it was correlated with the pH value, bio-yield force, rupture force and color of intact and skin-removed apples. At the 1% significant level, it had the correlation with the density and moisture content.

Keywords: Starch content, Apple, Image analysis, Physicochemical properties

Introduction

Information on fruit maturity and ripeness can be utilized to decide the best time of harvest and establish the plan of storage and marketing. Immature fruits may be underpriced whereas overmature ones are not appropriate for long-term storage since the maturity is closely related to the taste and many physico-chemical properties (Seymour et al., 1993).

Some physicochemical properties of apples may change with their maturity and ripeness level (Zerbini et al., 1999). Knee et al. (1989) investigated various indicators of maturity and ripeness for harvest of apples intended for long-term storage. They reported that starch content and firmness of apples at the harvest time indicated a different maturity order. Drake and Kupferman (2000) studied the relationships of maturity and storage quality of apples to their starch content.

Chemical titration methods of the starch content determination are hardly used for fruit quality evaluation because it is difficult and time-consuming. Traditionally, starch in a plant tissue has been stained with an iodine solution in the aspect of qualitative evaluation.

In this study, a starch index determined by a simple and rapid procedure using image analysis was proposed to quantify the starch content of apples and the index value were correlated to the maturity level by human perception. Also, the relationships between the starch index and various physicochemical properties were investigated.

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The authors are **Y. J. Cho, W. Jun, C. T. Kim, C. J. Kim** and **D. M. Kim**, Korea Food Research Institute, Korea, and **B. H. Hwang** and **J. K. Kim**, Dept. of Horticultural Science, Chung-Ang University. **Corresponding author:** Y. J. Cho, Senior Researcher, Korea Food Research Institute, San 46-1, Baekhyun-dong, Bundang-ku, Songnam-si 463-746, Korea; e-mail: yjcho@kfri.re.kr

Materials and Methods

1. Materials

Tsugaru apples were harvested and obtained from a local orchard on August 31, 1999. The harvested apples were manually sorted into immature, turning and mature groups. Seventy-five apples were randomly selected from each maturity group for the testing.

2. Starch Content Quantification

Starch contents of apples were quantified by using image analysis. The image processing was performed with a computer vision system consisted of a 2/3 one-chip color CCD camera (Model TMC-74, PULNiX) and a color frame grabber (Model Oculus-TCX, Coreco). First, sliced apples were thermally processed at 60℃ for 20 minutes to improve their stainability and stained with the KI/I_2 solution yielding different degrees of stain with maturity (Fig. 1).

A color image having red, green, and blue frames was captured from the stained apple slice. The RGB color system of the image was converted to the color system with hue, intensity, and saturation components.

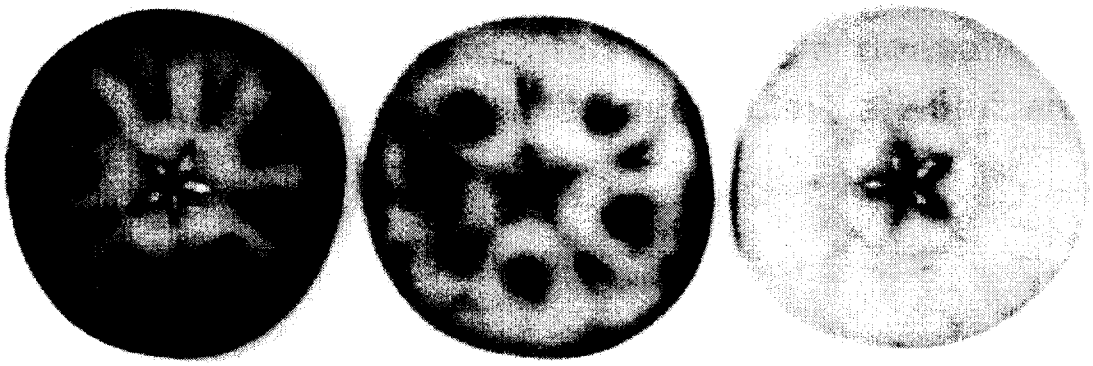

Fig. 1 Differences in the degree of stain according to the maturity (from left: immature, turning, and mature apples).

Because the color stained with the KI/I_2 solution was mainly blue, the frame of hue was segmented by the threshold value of pure blue. Then, the segmented and whole areas were measured and the ratio of the stained area to the whole area, defined as a starch index, was calculated.

3. Measurement of Physicochemical Properties

Moisture content, soluble solids content and pH of apple flesh, density of an intact apple, and mechanical properties and color of intact and skin-removed apples were measured.

Moisture content was measured by an oven method (70℃ and 20 hours). Soluble solids contents and pH values were measured by a refractometer and pH meter, respectively. Density was measured by a platform scale method. Bio-yield and rupture points were determined by using a compression tester having a flat plunger of 5 mm diameter. In compression test, loading speed was 5 mm/min. Values in Hunter color system were measured with a spectrophotometer and color distribution was analyzed by using a computer vision system.

Results and Discussion

1. Starch Index

Fig. 2 shows an apple slice stained with the KI/I_2 solution and a binary image indicating its starch distribution. The starch index is the ratio of the segmented area in the binary image to the whole area in the original image.

Table 1 shows the starch indices of *Tsugaru* apples are different with their maturity. Manually sorted apples into the immature, turning, and mature groups had the average starch indices of 0.374, 0.312 and 0.129, respectively.

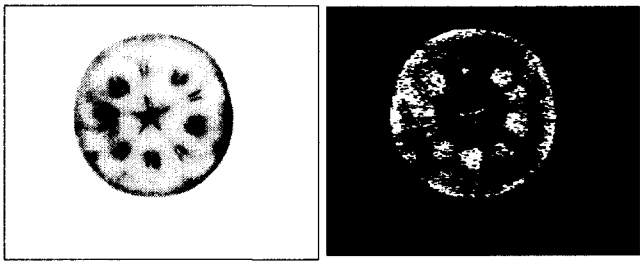

Fig. 2 An apple slice stained with the KI/I_2 solution (left) and a binary image indicating its starch distribution (right).

Table 1. The starch indices of *Tsugaru* apples with maturity

Maturity level	Starch index [a),b)]	
	Mean	Standard deviation
Immature	0.374	0.205
Turning	0.312	0.204
Mature	0.129	0.137

[a)] Ratio of the stained area of an apple slice to its whole area

[b)] An average of 25 apples in each maturity group

The starch index developed in this study would be, therefore, expected to be an indicator for quantifying apple starch, even though it does not mean the real value of starch content.

2. Relationships with Physicochemical Properties

Various physicochemical properties of apples such as starch content, firmness, color, moisture content have

interrelationships to the maturity or the ripeness (Mohsenin, 1986; Van Woensel et al., 1987; Knee et al., 1989; Cho and Hwang, 1998). In this study, the starch indices of *Tsugaru* apples were related to various physicochemical properties.

Table 2 shows the correlation coefficients of the starch indices with various physicochemical properties. At the 0.1% significant level, the starch index had high correlations with the pH value, bio-yield force, secant slope, rupture force, and Hunter's color value a of apple flesh. Also, the bio-yield force, rupture force, Hunter's color value a of the intact apples had high correlations with the starch index at this statistical level.

At the 1% significant level, the density, moisture content, and secant slope within bio-yield of apple flesh had correlations with the starch index. Meanwhile, the rupture deformation and Hunter's color value b of the intact apples, and the bio-yield deformation and rupture deformation of the apple flesh had the correlation with the starch index at the 5% significant level.

The highest correlation coefficient was −0.666 between the starch index and the pH value of the apple flesh, followed by 0.642 between the starch index and the bio-yield force of the intact apples. The latter agrees with the study of Knee et al. (1989) that the starch content and firmness were the major indicators

Table 2. The correlation coefficients of the starch indices of *Tsugaru* apples with various physicochemical properties

Property			Correlation coefficient[a)]	Significant probability
Height			-0.057	0.6292
Width			-0.014	0.9018
Height/width ratio			-0.036	0.7562
Density of an intact apple			0.373**	0.0011
Moisture content of apple flesh			-0.367**	0.0013
Soluble solids content of apple flesh			0.063	0.5895
pH of apple flesh			-0.666***	0.0001
Intact apple	Bio-yield deformation		0.227	0.0511
	Bio-yield force		0.642***	0.0001
	Secant slope within bio-yield		0.361**	0.0016
	Rupture deformation		0.260*	0.0252
	Rupture force		0.611***	0.0001
	Hunter's color value	L	0.135	0.2491
		a	-0.447***	0.0001
		b	0.285*	0.0136
Skin-removed apple	Bio-yield deformation		0.237*	0.0414
	Bio-yield force		0.498***	0.0001
	Secant slope within bio-yield		0.391***	0.0006
	Rupture deformation		0.284*	0.0139
	Rupture force		0.589***	0.0001
	Hunter's color value	L	-0.096	0.4157
		a	-0.431***	0.0001
		b	-0.039	0.7379
Hue of color of intact apple	Mean		-0.097	0.4074
	Standard deviation		-0.458***	0.0001

*, ** and *** indicate 5%, 1% and 0.1% significant levels, respectively.

a) The correlation coefficients were calculated with 75 apples.

of apple maturity.

Conclusions

The starch content of apples has been known as an indicator of their maturity. Its chemical quantification procedure is difficult as well as time-consuming. For the starch content to be an effective indicator in the field of apple production, a rapid and simple technique for its measurement is needed.

In this study, an image analysis technique was developed to evaluate the starch content of apples. Since only the starch in apple flesh is dyed with KI/I_2 solution, an apple slice was first stained with the solution and its color image was analyzed to calculate the ratio of stained area to the whole area which was defined as the starch index of apples.

When the technique developed in this study was applied to *Tsugaru* apples sorted into immature, turning, and mature groups by a farmer, their starch indices were turned out to be 0.374, 0.312, and 0.129, respectively.

The starch index also had some correlations with various physicochemical properties of apples. At the statistically significant level of 0.1%, the starch index showed good correlations with the pH value, bio-yield force, rupture force and color of intact and skin-removed apples. At the 1% significant level, there existed meaningful correlations between the starch index and the density and moisture content of apples.

The image analysis procedure developed in this study would be expected to be a promising technique for evaluating apple maturity and ripeness.

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