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STUDY OF APPLE FRUIT QUALITY BASED ON THE ANALYSIS OF LASER SCATTERING IMAGE

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A b s t r a c t. A 670 nm, 3 mW solid-state laser diode module was used as light source to monitor the changes of apple quality (c.v. Jonagold) under room storage conditions. Laser beam scattering images were captured and the number of total pixels in the image was taken as an indicator of fruit quality. The total number of pixels (image size) increased during storage. The fruit firmness measured by the non-destructive acoustic impulse response technique showed a negative correlation (R = -0.85 to -0.87) with the result of laser image analysis. The correlation between the total number of pixels and mechanical properties of apple flesh measured by means of a universal testing machine are discussed.

K e y w o r d s: apple, laser scattering image, firmness measurement

INTRODUCTION

Recently there has been an increasing interest in using computer-assisted image processing as non-contact and non-destructive way for quality control. Considerable research has been done on applying machine vision system to inspect the quality of agricultural products. Some researchers have applied machine vision system for sorting apples and bruise detection [7,10,11]. The intensity of the transmitted light through apples has been measured to detect watercore during storage [17]. It was found that the intensity of light transmitted through the fruit decreased with time for all classes of watercored fruit. NIR image was used to characterise the effects of time, bruise-type and severity on the NIR reflectance from bruise and unbruised apples (c.v. Delicious and Golden Delicious) [18].

Different light sources have been used. So far, only a few researchers applied laser beam as light source to study food quality. It has been reported that only about 4% of the incident radiation is reflected off the surface as regular reflectance [4] and the remaining radiation transmits through the surface, encounters randomly oriented internal interfaces and scatters in all directions. A helium neon (He-Ne) laser beam was used to determine pork quality by studying scatter coefficient [2] and a correlation was found between scatter coefficient and quality of pork meat. Sun *et al.* [14] investigated the distribution of light transmitted through a piece of white potato flesh by using two light sources: 1) a 632.8 nm, 5 mW, He-Ne laser; 2) a monochromatic light at 625 nm wavelength conveyed through a 6.2 nm diameter light guide. Duprat *et al.* [6] studied ripeness of Golden apples based on laser light source machine vision. They found a non-linear negative relation between the image size and the firmness during shelf life. Tu *et al.* [16] studied the possibility of using a low power laser beam as light source to investigate the texture of apples and tomatoes. Laser diodes with different power (3 and 12.5 mW) have been tested and the results showed good correlation (R^2=0.79) between the two sources in the firmness measurements of the apples [5]. Other researcher [8] studied the possibility of using a laser-puffer detector to measure fruit firmness.

The objective of this research was to evaluate the use of laser scattering image technique to measure the ripeness of apple during shelf storage. The changes of fruit firmness were measured with acoustic impulse technique and destructive compression test. The relation between the change of firmness and change of scattering image was studied.

MATERIALS AND METHODS

Apples

The experiments were conducted for two successive years on the two-coloured (background and blush side) variety Jonagold (*Malus domestica* Borkh. cultivar Jonagold). In 1996, 40 Jonagold apples with similar background colour and size were purchased from a local market. These apples were equally divided into 8 groups with 5 apples each. In 1997, a total of 72 apples (c.v. Jonagold) with diameter of 80-85 mm were purchased from a local market. The apples were divided into 8 groups with 9 apples each. In the experiments, the apples were numbered, stored and monitored under room temperature at 20 °C, 65% relative humidity for 14 days. Stiffness factors of all the apples were determined in the beginning of the experiment. At 2 days interval, the firmness of apples was first tested with non-destructive methods (acoustic response technique and image acquisition) followed by destructive compression test. The development of ripeness was followed and different techniques were analysed based on the measurement results.

Image acquisition

Optical measurements were performed in a dark room. The experimental set-up is shown in Fig. 1. The sample holder can be turned around so that the image of the sample can be taken from different points. The light source was a 670 nm (red light), 3 mW output solid-state laser diode module with 4.5x2.5 mm of beam size and <0.5 mRad beam divergence (Vector Technology Ltd., Gwent, UK). The angle between the incident light and the camera was 15°. The images were captured by a solid-state colour video camera (JVC KY-F55B, 3-CCD; JVC Victor Company of Japan, Limited). The camera had three parallel AC-coupled analogue outputs, red, green and blue (RGB) corresponding to the three National Television System Committee (NTSC) colour primaries. The camera was equipped with a Pentax® TV zoom lens (8-48 mm 1:1.0; Optical instruments division, Asahi Precision Co., Ltd., Japan). The signal from the camera was digitised and captured using a Comet™ card (Matrox Electronic System Ltd., Quebec, Canada)

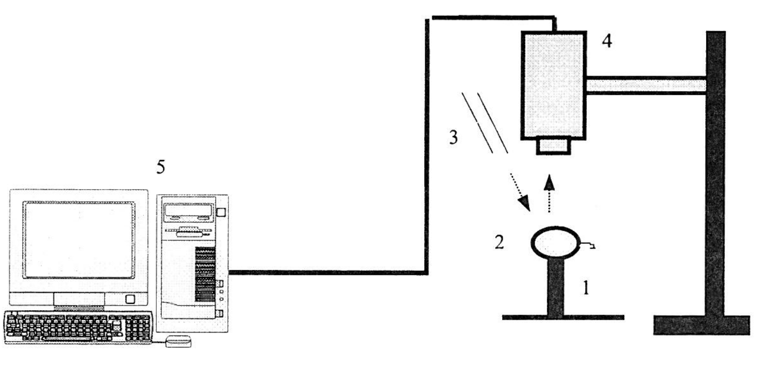

Fig. 1. Image acquisition system: 1 - sample holder, 2 - sample (Jonagold apple), 3 - laser light source, 4 - camera, 5 - computer with frame grabber.

installed on a PC-AT586 (Pentium-S) 150 MHz with 16 Mb RAM. The digitised images were analysed by software developed in the C language and meanwhile displayed on a 17-in colour monitor. The digitised images were also saved on a cassette for later reviewing.

The working distance from the camera lens to the sample was set at 50 cm [9]. The position of the laser light source was adjusted so that the image was displayed in the centre of the monitor. Since the laser beam can only illuminate a part of the sample, each apple was captured 4 times at different points around the equator with the sample holder turned over 90° each time. The camera was calibrated before the test with a standard colour chart.

Image segmentation and analysis

The *R, G, B* values are correlated and corresponding to light intensity. The chromaticities (chromaticity co-ordinates) are denoted with a small letter: *r* (red), *g* (green) and *b* (blue). The normalised colour co-ordinates can be defined in *RGB* colour space as:

$$r = \frac{R}{R+G+B} \quad (1)$$

$$g = \frac{G}{R+G+B} \quad (2)$$

and

$$b = \frac{B}{R+G+B}. \quad (3)$$

Each pixel on fruit has a Red(R), Green(G) and Blue(B) value between 0 and 255 resulting in 256^3 distinct colours. It is obvious that $r+g+b=1$. As laser beam source was red light and the digitised colour image contains primary red colour. The mean $r \geq 0.7$ (r=1-b-g) was found for all the apples and the image threshold was carried out based on red data. Based on some pretests, the global threshold ($R \geq 27$) was used to segment the apple from the background of the image and capture the smooth image pictures. The threshold $R \geq 150$ was chosen to identify the high level intensity reflectance (Fig. 2). The different thresholds were chosen in order to observe the changes of inner, outer parts and total image following the fruit ripening. The number of pixels in the image was calculated as an indicator of the fruit texture.

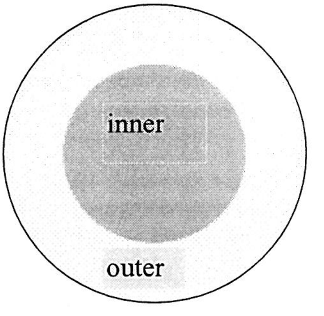

Fig. 2. Threshold of the scattering image. Inner: $150 \leq R \leq 255$, outer: $27 \leq R \leq 150$ total pixels: pixels in the $27 \leq R \leq 255$ region.

Fruit firmness measurement

Apple firmness was measured with the non-destructive acoustic impulse response technique [3]. The stiffness factor was calculated as $f^2m^{2/3}$ (f: peak frequency, Hz; m: mass of the apple, kg). The mean value of a three -point measurement of the sample was taken as the result. This stiffness factor is linearly correlated with the Young's modulus of the fruit and used as fruit firmness index.

The compression tests were carried out with a Universal Testing Machine System (UTS Testsysteme GmbH, Germany). The apple flesh was cut with a cylindrical cutter (inner diameter = 17 mm). The apple core was carefully avoided and the outer parts of the flesh cylinders were used. Sample cylinders with a height of 5 mm and diameter of 17 mm were compressed between two parallel plates at a compression rate of 50 mm min^{-1}. The maximum deformation was 80% of the initial sample height. The compression test was carried out following the non-destructive image acquisition and acoustic response tests.

RESULTS AND DISCUSSION

Analysis of the laser beam scattering images

The correlation between the number of outer part pixels and the number of inner part pixels of the laser scattering image is shown in Table 1. It can be seen from Table 1 that the total number of pixels is highly correlated with the pixel numbers in the outer part of the image. The numbers of inner and outer part pixels are not changing at an equal rate proportional to the whole image size. This is due to that the inner part of the image is mostly corresponding to the laser beam intensity. Previous study [16] has proved that laser beam position on the apple (background or blush side) had a significant effect on the number of pixels captured. It is better to use the scattering image on the background side to classify apple ripeness. In this study, we analysed the laser beam scattering image of each apple based on the mean of the total pixel numbers at the 4 points around the equator to reduce the effect of background or blush side.

Another affecting factor is the shape of the fruit. The curvature of the projection point may affect the scattering image. However, the effect of shape was not discussed in the experiment since: (i) the laser beam was 5 mm in diameter which is small in comparison to the curvature of the fruit surface (ii) the comparison of the image was based on similar projection points around the equator for each fruit following the storage and (iii) fruits were pre-chosen with similar shape and size. This factor should be further studied for more general situations.

The number of total pixels of the image was corresponding to the image size and it was taken as apple texture indicator. The number of total pixels was analysed by means of the SAS [12] program. Duncan's multiple range test was applied to analysis the variance of the means which is shown in Table 2. It is obvious that the number of total pixels increased following the storage time which corresponding to the ripening of apples. There exist significant difference between every 4 days interval indicating that the laser scattering image may be able to distinguish apple ripeness under room conditions. Similar results were found in the second year (1997).

Table 2. Analysis of variance of the number of total pixels of Jonagold apples

Day	Mean total pixels	Duncan grouping	
	1996		
0	1318.6	E[1]	
2	1361.5	E	
4	1388.6	E	D
6	1487.9	C	D
8	1514.7	C	
10	1867.3	B	
12	1892.9	A	B
14	1990.2	A	
	1997		
0	936.2	E[1]	
2	1013.5	D	
4	1037.3	D	
6	1148.2	C	D
8	1436.1	B	
10	1552.8	B	A
12	1563.8	A	
14	1593.4	A	

[1]Means with the same letter are not significantly different (Duncan's multiple range test at P=0.05 level).

Table 1. Correlation matrix of the number of pixels in laser scattering image of Jonagold apple (1996, 1997)

	# of total pixels	# of outer pixels	# of inner pixels
1996			
# of total pixels	1.00	0.94	0.85
# of outer pixels		1.00	0.84
# of inner pixels			1.00
1997			
# of total pixels	1.00	0.90	0.81
# of outer pixels		1.00	0.80
# of inner pixels			1.00

The increase of the number of total pixels reflects especially the changes of surface and near surface structure. As the apples become ripe, they lose water and the surface becomes wrinkle reflecting more light. Another reason for the increase of the number of total pixels in the apple scattering image is the loss of chlorophyll during maturation. The apple with more chlorophyll shows stronger absorption in the red light region and therefore the reflectance is lower [6,13,15]. When apples mature, the background colour turns to yellow due to loss of chlorophyll so that the reflectance increases and more pixel numbers are observed in the scattering image. Further more, the internal air spaces between cells increased and the flesh density decreased during the ripening of apple fruit [19], which affect the light scattering and influence the image size. These are possible factors affecting the scattering image.

It should be pointed out that the number of total pixels of captured image can be varied between different measurement set up and samples but the trend of the increase of image size following the ripening of apples has been observed for 2 years (Fig. 3). Linear regression with time showed R^2= 0.90 and R^2= 0.86 (Fig. 3) for the year 1996 and 1997, respectively.

The increase of the number of pixels showed that the laser scattering image analysis can be applied to classify apples according to maturity stage after appropriate training of the measurement system with certain standard (number of total pixels) of apples in different stage of ripeness.

Acoustic and compressing measurement results

The texture properties obtained by acoustic and compression tests are shown in Fig. 4. The non-destructive acoustic impulse measured stiffness factor decreased during the storage. Compression rupture forces also showed the trend of decreasing correspond to the softening of apples. Apple continuously lost its weight which result a shrinkage in the surface and affect the light scattering. The percent of weight loss increased almost linearly during apple storage.

The correlation between measured parameters of apples can be seen in Table 3. There exist strong correlation between number of total pixels, stiffness factor and percent of weight loss. The correlation between the total number of pixels and the stiffness factor was quite good (R = -0.85 and -0.87). However, the correlation between the total number of pixels and rupture force was not high (R = -0.31 and -0.61). Abbott and Liljedahl [1] reported relationships of sonic resonant frequency to compression and Magness -Taylor firmness tests of apples during refrigerated storage. They found the resonant frequencies and stiffness factors were most highly correlated with compression slope, then work, and then maximum force.

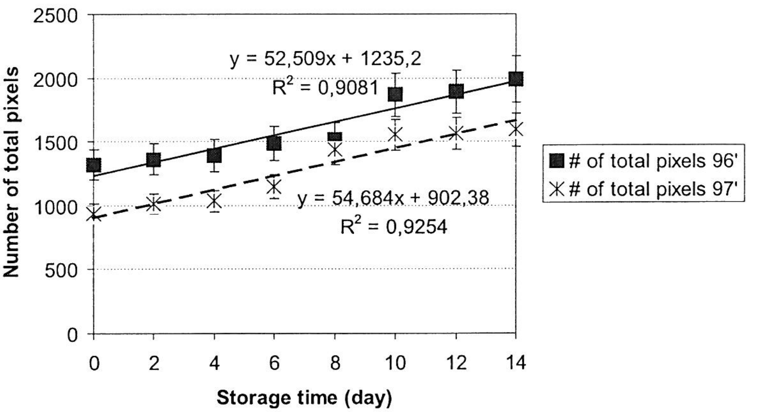

Fig. 3. Changes of the number of total pixels during the storage (The bars indicate standard errors).

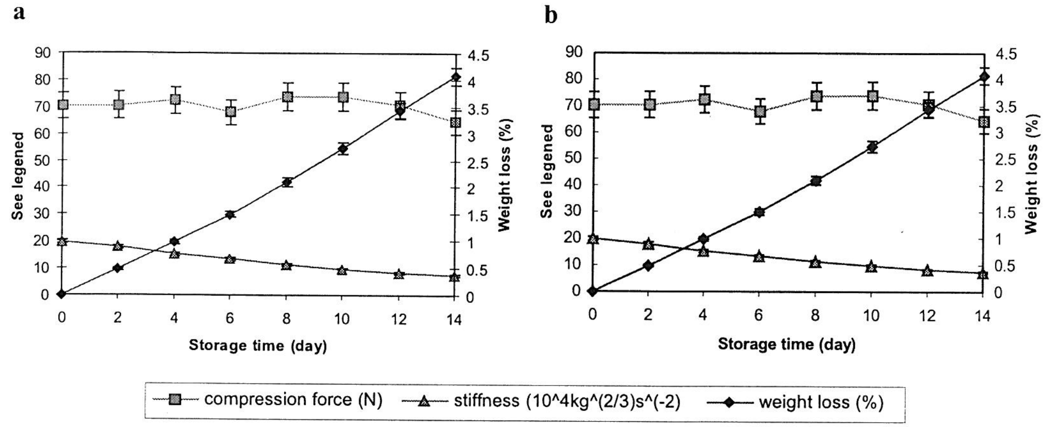

Fig. 4. Compressive rupture force, stiffness factor and weight loss changes of Jonagold apple during storage in 1996 (a), and 1997 (b). (The bars indicate standard errors).

Table 3. Correlation matrix of measured parameters of Jonagold apples

Parameter	Force	E-mod	Work	Total pixels	Stiffness	Weight loss
				1996		
Force	1.0	0.85	0.87	-0.31	0.41	-0.30
E-mod		1.00	0.79	-0.35	0.32	-0.28
Work			1.00	-0.63	0.56	-0.66
Total pixels				1.00	-0.85	0.87
Stiffness					1.00	-0.95
Weight loss						1.00
				1997		
Force	1.0	0.77	0.82	-0.61	0.71	-0.20
E-mod		1.00	0.78	-0.42	0.52	-0.33
Work			1.00	-0.65	0.68	-0.50
Total pixels				1.00	-0.87	0.75
Stiffness					1.00	-0.69
Weight loss						1.00

Force: Compressive rupture force (N)
E-mod: Compressive Young's modulus (MPa)
Work: Energy needed to rupture the apple sample (mJ)
Total pixels: Number of total pixels
Stiffness: Acoustic stiffness factor ($Hz^2kg^{2/3}$)
Weight loss: Percent of weight loss ((initial weight of an apple - weight after storage) / initial weight of an apple x 100%).

Similar correlation was observed for the two years experiments. This indicates that it is replicable and has potential applications.

CONCLUSIONS

The number of total pixels of laser beam scattering image was increased during the storage. Image analysis showed that the number of total pixels was significantly different at 4 days interval under our experimental conditions, and laser scattering image analysis may be able to monitor fruit ripening.

The apple firmness decreased during storage which was measured by acoustic and compression tests. The percent of weight loss of fruits increased resulting in a loss of skin smoothness which affected the laser scattering image. The stiffness factor as measured by the acoustic impulse response technique was negatively correlated with the scattering image size. For Jonagold apple, correlation coefficients R of -0.85 and -0.87 were obtained in the experiments. Both non-destructive testing methods provide valuable information about fruit quality. There is a potential to use laser light source to classify fruit quality after the measurement system is trained and the criteria have been established. More research work still needs to be done to establish criteria for different fruits before using the suggested measurement system.

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