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Determination of Chokanan mango sweetness (*Mangifera indica*) using non-destructive image processing technique

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Abstract

The Chokanan mango (*Mangifera indica*) has a high commercial potential. Its sugar content increases as the colour changes during the maturation process. In this research, the relationship between the sweetness of the Chokanan mango and its mean pixel values in RGB and HSB colour space is analyzed. This information could be utilized in determining the level of sweetness of the Chokanan mango without destroying the fruit. A Keyence machine vision system was employed to capture the images of the mango in RGB and HSB colour spaces. Based on the findings, it could be concluded that hue not only has the highest correlation value (-0.916), but also has the lowest value of the standard deviation at all levels of sweetness compared to other colour components. It is possible to determine sweetness at Level 1 and Level 2 with a 100% success rate and a 87% success rate at Level 3.

Keywords: Color; hue; HSB; RGB; ripeness.
Abbreviation: CCD_charge-coupled devices; HSB_hue, saturation, brightness; HIS_hue, saturation, intensity; LCD_liquid crystal display; RGB_red, green, blue.

Introduction

Mangoes are renowned world-wide as one of the most exotic tropical fruits. In contrast to other mango varieties, the Chokanan mangoes are able to flower off-season in natural way (Chintanawong et al., 2001). This variety of mango has a high commercial potential and change colour during the maturation process. The existence and density of pigments in the fruit's skin is the main factor in determining the distribution of the fruit's radiant energy (Gross, 1987; Mazza and Miniati, 1993). Changes in these pigments during the maturing process determine the colour of the fruit's skin. Therefore, the fruit maturity index could indicate the maturity of the fruit by identifying its skin color (Slaughter, 2009).

A non-destructive technique based on machine vision technology involving colour grading has been utilized in many agricultural applications. Machine vision systems for real-time colour classification (Lee and Anbalagan, 1995; Zhang et al., 1998) have been commercialized to grade food products based on colour. Other agricultural applications include colour grading of palm oil fresh fruit bunches (Jamil et al., 2009), apples (Varghese et al., 1991; Hung et al., 1993), fresh market peaches (Nimesh et al., 1993; Miller and Delwiche, 1989a; Miller and Delwiche, 1989b; Singh et al., 1992), oranges (Sirisathitkul et al., 2006), lemons (Khojastehnazhand et al., 2010), red grapefruit juice (Lee, 2000), peppers (Shearer and Payne, 1990), cucumbers (Lin et al., 1993), tomatoes (Choi et al., 1995), potatoes (Tao et al., 1995), dates (Janobi, 1998) and beef (Sun et al., 2009). The technology has also been adopted to detect melanin spots in Atlantic salmon fillets (Mathiassen et al., 2007). Many of these systems yield promising results. In most cases, the image is first captured using red, green, and blue (RGB) colour components. It is then converted to a hue, saturation, intensity (HSI) representation because the HSI colour component is much closer to human perception, where H defines the colour, S denotes the colour density and I represents the colour brightness. It thus, could improve the accuracy of the results. Processing decisions are made primarily on the basis of hue (Dah-Jye et al., 2008). Typically, the hue of the product is compared against reference values to determine its colour grade (Miller and Delwiche, 1989a; Miller and Delwiche, 1989b). Most researches rely on this approach to determine the external quality of fruit products. However, according to Thangaraj and Irulappan (1989), colour, size and shape of fruit could also provide approximate information on the internal quality attributes. As mature Chokanan mangoes have a high sugar content (16.70^o Brix) (Li et al., 2011), it is widely assumed that the level of sweetness of Chokanan mangoes could be determined by their colour. The objective of this research is to examine the potential use of the colour machine vision in determining the level of sweetness in the Chokanan mango.

Results and Discussions

Sweetness level

Fig. 1 shows the output displayed on the screen of the Keyence machine vision system. A total of 180 mango images were used in this research. Fifty percent of the images were utilized as training dataset and the other 50% are used as the testing dataset. The value of sweetness is obtained on the same day that the image is captured by the camera. It is clustered into 3 different categories as shown in Table 1.

Table 1. Level of sweetness in different Brix ranges.

Level*	Range (Brix)
Level 1	4.0°-8.0°
Level 2	8.1°-13.0°
Level 3	13.1°-17.0°

*The level of sweetness is scaled from 1 (less sweet) to 3 (very sweet)

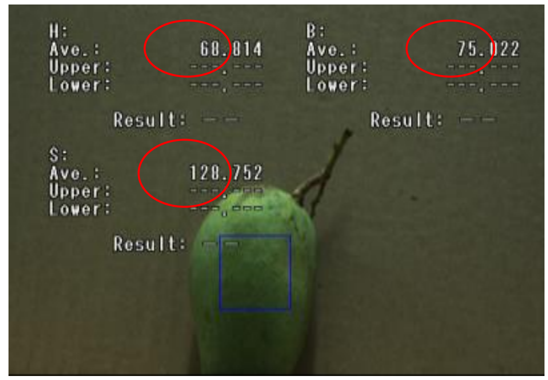

Fig 1. Output displayed on the screen of the Keyence machine vision system: H = 68.814, S = 128.752 and B = 75.022.

Colour components analysis

Table 2 shows the value of the mean, the standard deviation and the root mean square error for all levels of sweetness for the colour components. From this table, it could be concluded that in comparison to the other colour components, Hue has the lowest values for the standard deviation at all levels of sweetness, i.e., 2.73 at Level 1, 6.31 at Level 2 and 2.44 at Level 3. It also yields acceptable values for the root mean square error, i.e., 0.06 at Level 1, 0.02 at Level 2 and 0.03 at Level 3. Hue is the angular dimension of the HSB colour space. It starts at the primary colour of red at 0^0, passing through the green primary colour at 120^0 and the blue primary colour at 240^0 and then wrapping back to red at 360^0. As the ripening of the mango progresses its surface colour increasingly becomes yellow and its level of sweetness is also enhanced. Yellow is a secondary colour which is derived by mixing the primary colours of red and green. Based on the results, the value of Hue decreased from 72.37^0 (at Level 1) to 45.12^0 (at Level 2) and finally to 34.49^0 (at Level 3). This is due to the decreasing component of green colour of the mature mango. Therefore, when the mango becomes matured, the degree of its sweetness increases as its red colour component intensifies simultaneously reducing the green colour component. It is clearly shown in Table 2 that at Level 1 of sweetness, the green colour component (77.39) is greater than red (53.20). When the level of sweetness increases, the value of red component is greater than green. It is clearly seen at Level 3 of sweetness, where the value of red is 152.93 and green is 133.71. Furthermore, the value of saturation of HSB colour space shows that the purity of the hue component increases when the level of sweetness is enhanced.

Model development and validation

The results of the Pearson correlation, as shown in Table 3, show that each of the colour components indicates a significant correlation at the 0.01 level. The Hue yields a negative linear relationship, while the other colour components generate positive linear relationships. The Hue also has the highest Pearson correlation (-0.916) at the 0.01 level of significance. It is followed by saturation (0.854), red (0.832), green (0.719), brightness (0.656) and blue (0.394). Hue generates more stable results compared to the RGB colour space, which is sensitive to lighting conditions. The performance of R and G in determining the sweetness in mango and *Iyokan* oranges is almost similar (Kondo et al., 2000). It could be concluded that, the higher the red/green value (for reddish and yellowish fruit), the higher the level of sweetness.

As hue indicates the highest value of correlation with the lowest value of standard deviation, it is adopted as a model to determine the value of sweetness based on the following equation: $y = -0.19x + 20.06$ (1)

Where, y is the predicted value of sweetness and x is the average hue. The model is then tested using 90 mango images. The results of the experiment as shown in Table 4 indicates that the model could successfully predict the sweetness at Level 1 and Level 2 with 100% success, while, the percentage of success at Level 3 was calculated as 87%, which is still acceptable.

Comparison with related researches

Although colour machine vision has been widely employed for fruit grading, its application for ascertaining the level of sweetness is still limited. Currently, there is no available method that relies on colour machine vision that uses the external surface appearance to predict the sweetness of mango. Table 5 shows summary of the related researches. Item 1 on the table represents our proposed method.

Hue has been used by Sirisathitkul et al. (2006) to sort Chokun oranges based on maturity. This method could be considered as a feasible alternative method for grading Chokun oranges as it has a success rate of approximately 98%. Khojastehnazhand et al. (2010) use average hue and volume to categorise lemons into 3 grades. The method could be applied to sort the fruits into Grade 1, Grade 2 and Grade 3 with a percentage of success of 95.45%, 100% and 86.67%, respectively.

Table 2. Statistical analysis of the images for all colour components at different levels of sweetness.

Level	Colour Component	Mean (pixel value)	Standard Deviation (pixel value)	Root Mean Square Error (pixel value)
1	Red	53.20	9.21	0.08
	Green	77.39	12.35	0.02
	Blue	42.06	7.32	0.02
	Hue	72.37	2.73	0.06
	Saturation	117.90	6.93	0.07
	Brightness	100.63	35.15	0.04
2	Red	125.24	30.38	0.06
	Green	124.82	21.54	0.02
	Blue	50.87	9.19	0.08
	Hue	45.12	6.31	0.02
	Saturation	155.63	11.32	0.04
	Brightness	127.01	18.09	0.08
3	Red	152.93	27.99	0.06
	Green	133.71	24.73	0.03
	Blue	51.08	11.35	0.86
	Hue	34.49	2.44	0.03
	Saturation	170.01	12.91	0.07
	Brightness	153.31	22.79	0.06

Fig 2. Chokanan mango in different ripening stages: (a) Unripe fruit. Dull, green peel. (b) Yellowish-green peel. (c) Ripe fruit. All of the peel is yellow.

In our research, hue yields a better performance with a 100% success at Level 1 and Level 2 and 87% at Level 3, with the average success rate of 95.67%.

Steinmetz et al. (1999) investigated sensor fusion to predict the sugar content in apples by combining image analysis and near-infrared spectrophotometric sensors. The repeatability of the classification technique was improved when the two sensors were combined, giving a value of 78% for the 72 test samples. A study by Kondo et al. (2000) investigated the correlation between the appearance and the sugar content of *Iyokan* oranges by using image processing. The correlation coefficient between measured sugar content values and predicted sugar content values was 0.79 when the colour component ratio (red/green), weight, height/width ratio (height/width) and degree of roughness were used as parameters, while it was 0.84 when red/green, weight, Feret's diameter ratio and a texture feature were applied. They used neural networks to represent the nonlinear or ambiguous relationships of the parameters. Our proposed method is simpler than the method used by Steinmetz et al. (1999) and Kondo et al. (2000). In our method, a model is developed based on a linear regression analysis that only uses the average hue to predict the sweetness of mango. It is simple, fast and does not involve any step-by-step procedure to optimize the criterion used to develop the model.

Although all of these methods generate encouraging rates of success; however, it should be acknowledged that there exists some degree of error in them. This is due to the unique characteristics of biological products which have many different and variable properties (Kondo and Ting, 1998). Therefore, colour, size and shape might vary from one product to another and it is very difficult to distinguish the colour and taste of the fruits.

Table 3. Results of the Pearson Correlation.

Color Component	Pearson Correlation
Red	0.832**
Green	0.719**
Blue	0.394**
Hue	-0.916**
Saturation	0.854**
Brightness	0.656**

**Correlation is significant at the 0.01 level (2-tailed).

Table 4. Results of measured sweetness and predicted sweetness.

Level of Measured Sweetness	Level of Predicted Sweetness			Total Number of Mangos
	1	2	3	
1	30 (100%)	0 (0%)	0 (0%)	30
2	0 (0%)	30 (100%)	0 (0%)	30
3	0 (0%)	4 (13%)	26 (87%)	30

Table 5. Related researches on fruit quality determination using image processing technique

No	Properties	Method	Success rate
1	Chokanan mango sweetness determination.	Hue.	Level 1: 100% Level 2: 100% Level 3: 87% Average: 95.67%
2	Sorting Chokon oranges maturity. (Sirisathitkul et al. 2006)	Hue.	98%
3	Sorting lemon. (Khojastehnazhand et al. 2010)	Hue.	Grade 1: 95.45% Grade 2: 100% Grade 3: 86.67% Average: 94.04%
4	Apple sugar content prediction. (Steinmetz et al. 1999)	Sensor fusion.	78%
5	*Iyokan* oranges sugar content prediction. (Kondo et al. 2000)	Red/green, weight, height/width and degree of roughness.	Correlation= 0.79
6	*Iyokan* oranges sugar content prediction. (Kondo et al. 2000)	Red/green, weight, Feret's diameter ratio, and a texture feature.	Correlation= 0.84

Materials and Methods

Plant material

Chokanan mango (*Mangifera indica*) of the MA 224 cultivar is one of the sweetest mangoes in the world. It has an oval shape, wide at the top and narrow at the end. The fruit's colour surface turns from green into yellow during the maturation process. A matured fruit has a sweet taste. In this study, the mango samples at three different maturation stages i.e. unripe, yellowish-green peel and ripe, obtained from the Federal Agricultural Marketing Authority (FAMA) Malaysia were used.

Image acquisition

The Keyence machine vision system was used to acquire mango images. It consists of a charge-coupled devices (CCD) camera, a liquid crystal display (LCD), a microcontroller and a joystick. The experiment was conducted in a room with proper lighting condition. The position of the camera was adjusted in order to obtain sharp and clear images. The camera was set up horizontally and facing towards the mango, with a constant distance of 40cm. Fig. 2 shows an example of the Chokanan mango in different stages of maturity.

Obtaining the sweetness value using an AR2008 Abbe refractometer

An AR2008 Abbe refractometer was used to determine the sweetness of the mango. The refractive index or Brix value and temperature were shown on a LCD display. The experiment was conducted on the same day that the mango image was captured. In order to measure the sweetness of the mango, the mango was cut into slices and placed on the contact plate of the digital refractometer. The knob was then tightened to ensure that the sample was held on the plate. The samples were tested at room temperature (24.6^{o}C).

Sweetness level determination

Statistical approach was used to analyse the information on chokanan sweetness. This includes mean, standard deviation and root mean square error of the chokanan image taken from different colour components in size 200cm x 200cm window. To evaluate how strong pairs of variables are related, the linear correlation between colour components and sweetness level were determined using a Pearson correlation. The value of 1 in Pearson correlation shows a perfect positive correlation between two variables, while -1 shows a perfect negative correlation and 0 shows no correlation. Colour model with the best value of correlation would be used to develop a sweetness prediction model based on the regression analysis.

Conclusion

Red, green, blue, hue, saturation and brightness are significantly related to the sweetness of mango. In our research, hue had a negative linear relationship with sweetness, while the other colour components had positive linear relationships. The Hue also had the highest value of the Pearson correlation, -0.916 at a 0.01 level of significance. The Chokanan mango sweetness determination model was developed based on the hue using linear regression analysis. The proposed model yielded promising results with the average success rate of 95.67%. Therefore, from this research, it could be concluded that colour machine vision, specifically hue, could be used to determine the level of sweetness of Chokanan mangoes.

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