Non-Destructive Technique for Determining Mango Maturity

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Abstract
Mango (Mangifera indica L.) is an important tropical fruit that has great potential in international markets. Currently, major markets for mango include North America, Europe, and Japan. The acceptance of exported mango in destination countries depends largely on eating quality, which is affected by maturity at harvest. Mango maturity can be judged visually, based on skin color, or determined chemically based on soluble solids content, acid content, and solids:acid ratio. Maturity determination based on visual observation is unreliable and prone to errors. On the other hand, determination based on sugar or soluble solids to acid ratio is destructive. Therefore, it is important to develop a simple, reliable and non-destructive technique for mango maturity determination. In this study, a reliable and non-destructive technique has been developed and tested. This technique uses a digital camera to capture an image of the mango skin. Images obtained were analyzed using an image processing software (Adobe Photoshop) to obtain color parameters ($L$, $a$, $b$ values). Each of the color parameters was plotted against soluble solids content, total acid content, and solids:acid ratio and curve fitting was then applied to obtain polynomial equations. Results indicate that the color parameters can adequately predict the above maturity indices and, therefore, can be used to predict maturity of mango.

INTRODUCTION

Mango (Mangifera indica L.), known as the apple of the tropics, is arguably the most important tropical fruit and makes up almost 50% of all tropical fruit produced worldwide (Jedele et al., 2003). Total world production of mangoes in 2005 exceeded 25 millions MT with India the largest producer followed by China, Thailand, Mexico, Pakistan, Indonesia, Philippines, Nigeria, Brazil, and Egypt (FAO Statistics, 2005). Mango fruit is well accepted and many consider it to be the best fruit in the world because of its excellent flavor, aroma, color, and taste (Narain et al., 1998). In countries like the United States, Canada, Europe, Australia, and Japan, most supplies are imported from tropical countries. Some of the well known commercial cultivars are ‘Tommy Atkins’, ‘Haden’, ‘Irwin’, ‘Keitt’, and ‘Kent’ in the United States; ‘Kensington’ in Australia; ‘Alphonso’ and ‘Totapuri’ in India; ‘Chausa’ in Pakistan; ‘Rad’, ‘Pimsen Daeng’, and ‘Nam Dorkmai’ in Thailand; ‘Carabao’, ‘Pico’, and ‘Katchamita’ in the Philippines; and ‘Harumanis’, ‘Golek’, and ‘Manalagi’ in Indonesia.

Harvesting mangoes at the right time is essential for quality, transport, and storage stability, as well as proper ripening (Proctor, 1985). For highest quality, mangoes should be harvested at the mature but unripe stage. Mangoes intended for local consumption or for export by air should be harvested at full maturity. For export by sea, however, mangoes are harvested half-mature in order to avoid fruit damage during shipment. Attributes used to determine maturity include titratable acidity, total soluble solids, alcohol insoluble solids, starch:acid ratio, carotenoids, and phenolics (Narain et al., 1998).

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As mango fruit matures, soluble solids increase and organic acid content decreases. Slight change of the peel color can also be detected resulting from chlorophyll degradation, anthocyanin accumulation, and an increase in carotenoids (Gomez-Lim, 1997; Stafford, 1983). A physical characteristic such as fullness of fruit shoulders (or cheeks) has also been suggested as a good index of maturity (Kader, 2002). Ripening of mango is characterized by softening of tissues following solubilization of pectin (Lazan et al., 1986; Brinson et al., 1988) and further changes in the color of the peel and flesh (Gomez-Lim, 1997; Stafford, 1983).

Based on the physical and chemical changes that occur during mango fruit development, mango maturity can be judged visually based on skin color or determined chemically based on sugar-acid ratio. Maturity determination based on visual observation is unreliable and it is prone to errors. On the other hand, determination based on titratable acidity, total soluble solids, or sugar-acid ratio is destructive. Therefore, it is important to develop a reliable and non-destructive technique for mango maturity determination.

Numerous studies on non-destructive techniques for fruit maturity and quality determination have been reported. These include the studies by Gomez et al. (2005) for Satsuma mandarin, Hsieh et al. (2005) for guava, Gerald et al. (1989) for cantaloupe, Guthrie and Walsh (1997) for pineapple and mango, Kawano et al. (1992, 1995) for peaches, Jha et al. (2005), Saranwong et al. (2004) and Schmilovitch et al. (2000) for mango, Xing et al. (2005), Lu (2004) and Ventura et al. (1998) for apple, Martinsen and Schaare (1998) for kiwifruit, Nagata et al. (2004) for strawberries, and Slaughter et al. (2003) for prune. All of these studies were conducted using visible and/or near infrared spectroscopy.

In the current study, a simple and reliable non-destructive technique was developed and tested. This technique uses a digital camera to capture an image of mango skin and flesh. Images obtained were analyzed using an image processing software (Adobe Photoshop CS2 from Adobe Systems, Inc., San Jose, California) to obtain color parameters ($L$, $a$, $b$ values). The values of each of the color parameters were plotted against the values of sugar-acid ratio and polynomial curve fitting was then applied to obtain a polynomial equation that can be used to predict the value of sugar-acid ratio.

**MATERIALS AND METHODS**

‘Golek’ mangoes of varying maturity (weight ranged from 600-725 g) were harvested randomly from three trees; only one tree was harvested in one day. Ten fruit were harvested from each tree, thus the total number of mango fruit used in the experiment were 30. Fresh mangoes from each harvest were taken directly to the food engineering laboratory at Hasanuddin University for photographing (image acquisition) and soluble solids content and total acid content analysis. All measurements were conducted within four hours after harvest.

Image acquisitions were done using Sony DSC P-100 digital camera (Sony Corp., Japan) capable of producing images with 7 Megapixels resolution. Each mango was photographed from both sides to obtain images of the skin. Image of the flesh was also taken after slicing the mango longitudinally at approximately 1 cm from the stone. To standardize image acquisitions, a platform 40×40 cm made of an aluminum frame equipped with lighting system and an arm for camera attachment has been designed. The surface of the platform was lined with non-reflecting black colored fabric to minimize reflectance. Lighting was furnished by 2 light sources, each one capable of putting out 220 lumens of cool day light. The light sources were placed on the right and left sides of the platform making a 45° angle to the platform. The camera was placed 40 cm above the platform with viewing normal to the platform. In order to minimize reflected light from the surroundings, the whole setup was placed in an enclosure with internal surface lined with the same material used to cover the surface of the platform. The camera setting used in the experiment was determined based on calibration results using Munsell Color Cards. This setup was maintained throughout the experiment. Digital images obtained were
analyzed using Adobe Photoshop CS2 (Adobe Systems, Inc., San Jose, California) to obtain color parameters ($L$, $a$, $b$ values) from the images.

Soluble solids content (% sugar or °Brix) of each mango sample was measured using a hand-held refractometer with measurement range of 0-32°Brix (Model N-1α, Atago Co., Ltd., Tokyo, Japan). Acid content (citric acid content) of each sample was determined by standard titration method with 0.1 N NaOH (Lacey et al., 2000). Values of each of the color parameters ($L$, $a$, $b$) were plotted against values of soluble solid content, total acid content, and sugar-acid ratio and polynomial curve fitting was applied to obtain a polynomial equation that can be used to predict soluble solid content, total acid content and sugar-acid ratio. Goodness of fit of each polynomial equation was evaluated based on the coefficient of determination ($r^2$) and mean relative deviation modulus ($P$). The $P$-value, which represents the average percent difference between experimental and calculated values, was computed using the following equation (Andrieu et al., 1985; Chen and Morey, 1989; Madamba et al., 1996).

$$P = 100 \frac{\sum_{i=1}^{N} |SAR_{exp} - SAR_{poly}|}{N \ SAR_{exp}}$$

$N$ is the number of experimental data, $SAR_{exp}$ is the experimental value of sugar:acid ratio, and $SAR_{poly}$ is the polynomial prediction of sugar:acid ratio. A $P$-value below 10% is considered an adequate fit (Chen and Morey, 1989; Madamba et al., 1996).

RESULTS AND DISCUSSION

Mango samples used were of varying degrees of maturity as can be judged from the soluble solid content and total acid content. Soluble solid contents of samples ranged from 5 to 16.3°Brix and total acid contents ranged from 0.32 to 3.24% (Fig. 1). The solid:acid ratio ranged from 1.71 to 49.37. The $L$-value (lightness) ranged from 49 (mature fruit) to 77 (immature fruit), the $a$-value (redness) ranged from -27 (green region, immature fruit) to 9 (red region, mature fruit), and the $b$-value (yellowness) ranged from 23 (yellow region, immature fruit) to 59 (yellow region, mature fruit).

The relationship between each of the color parameters ($L$, $a$, $b$-value) and total solid content, total acid content, and solid-acid ratio can be depicted by plotting values of the color parameters against maturity indices (soluble solid content, total acid content, and solid:acid ratio). There are clear trends of relationships between the color parameters and maturity indices of mango. The $L$-value decreases while $a$ and $b$-values increase as maturity increases. From the shape of the curves, it is clear that the relationships can be best modeled using polynomials of higher degree.

Prediction of soluble solid content using fifth degree polynomials indicates that this property can be modeled adequately ($R^2>0.97$; $P<10$) using either one of the three color parameters ($L$, $a$, $b$ value) as predictor. However, the best fit was obtained when $a$-value was used as predictor (Fig. 1). In this case, $R^2=0.991$, $P=3.07$, and average and maximum difference between measured and predicted values were 0.31°Brix, and 0.94°Brix respectively. For prediction of total acid content using fifth degree polynomials, an adequate fit ($R^2>0.95$; $P<10$) was obtained using either one of the three color parameters with the best fit provided by the $b$-value as predictor ($R^2=0.967$, $P=7.56$, and average and maximum difference between measured and predicted values were 0.09 and 0.43% respectively) (Fig. 2). When soluble solids content and total acid content were combined and expressed as solids:acid ratio, the best fit (Fig. 3), was provided using the $b$-value as predictor ($R^2=0.998$, $P=5.30$, and average and maximum difference between measured and predicted values were 0.55 and 1.45 respectively). Polynomial equations for the best fit are given below.
\[
SS = 15.4190 + 0.116349a - 3.93835 \times 10^{-2} a^2 + 1.54184 \times 10^{-3} a^3 + 2.23685 \times 10^{-4} a^4 + 4.64847 \times 10^{-6} a^5
\]  
(2)

\[
TA = 65.49524 - 6.73975 b + 0.28006 b^2 - 5.78226 \times 10^{-3} b^3 + 5.90064 \times 10^{-5} b^4 - 2.37567 \times 10^{-7} b^5
\]  
(3)

\[
SAR = -398.25971 + 59.34202 b - 3.43069 b^2 + 9.55851 \times 10^{-2} b^3 - 1.26784 \times 10^{-3} b^4 + 6.46375 \times 10^{-6} b^5
\]  
(4)

SS is soluble solids content (°Brix), TA is total acid content (%), SAR is solid-acid ratio, \(a\) and \(b\) are color parameters. In addition to the polynomial analysis, an effort was also made to perform multiple regression analysis using the three color parameters simultaneously as predictors. However, the accuracy of these predictions was generally lower than those obtained from the polynomials. The best fit was obtained from regression on solid-acid ratio with \(R^2=0.991\) and average and maximum difference between measured and predicted values were 1.22 and 2.84 respectively. The form of the regression equation is given below and the plot is shown in Figure 4.

\[
SAR = -99.2596 + 0.44451 L - 0.46861 a + 2.1914 b
\]  
(5)

Use of skin color parameters for prediction of maturity indices of mango in this study provided much better prediction than those of several non-destructive techniques reported in the literature. As reported by Servakaranpalayam (2006), application of hyperspectral imaging technique for prediction of total soluble solids in mango resulted in a low coefficient of determination (\(R^2=0.61\)). By using a near infrared spectroscopic technique, Schmilovitch et al. (2000) predicted total soluble solid and acid content in mango with \(R^2\) of 0.93 and 0.61 respectively. Employing the same technique, Slaughter et al. (2003) predicted soluble solids content of prunes with \(R^2=0.96\), Kawano et al. (1995) predicted brix content of peach with \(R^2=0.92\), and Guthrie and Walsh (1997) predicted brix content of mangoes with \(R^2=0.81\). Therefore, results of this study clearly indicate that the method developed can be used to predict chemical attributes (i.e., soluble solid and total acid contents) and maturity of mango with a high degree of accuracy.

**CONCLUSIONS**

A simple, low cost, and reliable non-destructive technique for mango maturity determination has been developed and tested. This technique uses a digital camera to capture image of the mango skin which was then analyzed using an image processing software (Adobe Photoshop) to obtain color parameters (\(L, a, b\) values). These parameters were used to predict maturity indices (soluble solid and total acid contents) of mango samples by employing fourth or fifth degree polynomials.

Results of this study indicate that soluble solid content can be best predicted using \(a\)-value as the predictor (\(R^2=0.991\)) while total acid content and solids:acid ratio were both best predicted using \(b\)-value as the predictor (\(R^2=0.967\) and 0.998 respectively).

**Literature Cited**


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Figures

Fig. 1. Relationship between $a$-value and soluble solid content of mango and polynomial prediction of soluble solid content.
Fig. 2. Relationship between $b$-value and total acid content of mango and polynomial prediction of total acid content.

Fig. 3. Relationship between $b$-value and solid-acid ratio of mango and polynomial prediction of solid-acid ratio.
Fig. 4. Comparison between measured and multiple regression prediction of solid-acid ratio.