Postharvest Biology and Technology 62 (2011) 267–274

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Methods to analyze physico-chemical changes during mango ripening: A multivariate approach

Malkeet S. Padda[a,*,1], Cassandro V.T. do Amarante[b], Raphael M. Garcia[c], David C. Slaughter[d], Elizabeth J. Mitcham[a]

[a] Department of Plant Sciences, University of California, Davis, CA 95616, USA
[b] Department of Agronomy, Santa Catarina State University, Santa Catarina, Brazil
[c] IFAPA Centro Alameda del Obispo, Cordoba, Spain
[d] Department of Biological and Agricultural Engineering, University of California, Davis, USA

ARTICLE INFO

Article history:
Received 8 March 2010
Accepted 5 June 2011

Keywords:
Mangifera indica L.
Firmness
Color
Total soluble solids content
Dry matter
Canonical discriminant analysis

ABSTRACT

Canonical discriminant analysis (CDA) was used to identify the best method to discriminate between maturity and ripening stages, assessed in terms of dry matter content, firmness, color (peel and flesh), total soluble solids content attributes, before and during 'Keitt' mango ripening at 20 °C. Dry matter content was determined by hot-air oven and microwave oven methods. Fruit firmness was determined non-destructively by hand squeezing, with a durometer, using acoustic resonance and low-mass elastic impact methods (AWETA), as well as destructively by the penetrometer. Peel and flesh color were expressed as L^*, a^*, b^*, h^0 and C^* values. Total soluble solids content was analyzed from filtered juice from whole fruit tissue and from unfiltered juice squeezed out by hand. Canonical discriminant analysis indicated that the durometer and the penetrometer were better methods to assess firmness than hand firmness, acoustic resonance or impact methods. The best color attributes to follow changes during early stage of 'Keitt' mango ripening were a^* and b^* values of the flesh, whereas b^* value of the peel was considered better during later stages of ripening. Results of total soluble solids content in filtered juice from whole fruit tissue were less variable compared to unfiltered juice squeezed out by hand. Dry matter content was better assessed by drying the sample in a microwave oven than in a hot-air oven. A combined CDA including the best methods to assess each ripening attribute, as well as titratable acidity, showed that the best tools to assess changes in fruit during ripening were the penetrometer, followed by flesh a^* value and total soluble solids content (from filtered juice from whole fruit).

1. Introduction

Mango (*Mangifera indicia* L.) is a tropical fruit generally harvested at the mature green stage when shipped to distant markets to minimize over-ripening and losses in quality during postharvest handling and transportation. The stage of ripeness and eating quality of mango fruit is judged by a variety of attributes evaluated by various methods at specific steps in the supply chain. The main physico-chemical attributes related to ripening quality of mango fruit include firmness, flesh color (sometimes peel color), total soluble solids content, titratable acidity, and aroma volatiles (Lalel et al., 2003; Li et al., 2009; Yashoda et al., 2006). Accurate determination of fruit ripening stage is important for fresh cut products, and to provide a consistent supply of good quality fruit for retail marketing (Saranwong et al., 2004). Recent studies have focused on developing non-destructive techniques to evaluate the internal quality and stage of ripeness of mangoes (Delwiche et al., 2008; Jha et al., 2005).

Firmness has been considered a reliable indicator of mango maturity at harvest and ripeness during commercial mango handling, and an important tool for growers, importers, retailers and consumers. Fruit firmness changes from very hard at harvest to very soft at the fully ripe stage. Penetrometers (hand held and automated) have been the most common destructive method used to measure the firmness of mango fruit (Al-Haq and Sugiyama, 2004a; Mitcham and McDonald, 1992). The penetrometer measures the force (Newtons) required to plunge a metal probe of known diameter to a certain depth in the fruit flesh. Polderdijk et al. (2000) reported that penetrometer firmness gave less reliable results than hand firmness (degree of force required by palm of hand or fingers to compress fruit cheeks by 1–2 mm), especially during the later stages of fruit ripening. There has been interest

* Corresponding author. Tel.: +1 831 253 8153.
E-mail addresses: mspadda1@gmail.com, mspadda@hotmail.com (M.S. Padda).
[1] Current address: Driscoll Strawberry Associates, Inc., 345 Westridge Dr. Watsonville, CA 95077, USA. Tel.: +1 831 763 3310.

0925-5214/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.postharvbio.2011.06.002

to develop a non-destructive firmness method for mango fruit. A firmness test, where fruit was compressed on the most convex part (the cheek), using a texture analyzer was not able to discriminate small changes in firmness as occur during mango maturation (Sirisomboon et al., 2008). Recently, a handheld impact firmness tester was designed to measure fruit firmness while the fruit remain attached to the tree (Slaughter et al., 2009). Previous studies have shown that a non-destructive acoustic transmission technique and ultrasonic wave attenuation can be used to measure flesh firmness in mango (Al-Haq and Sugiyama, 2004b; Mizrach et al., 1999; Valente and Ferrandis, 2003). The use of a sound velocity technique has been suggested to measure the stage of ripeness of mango, although it does not assess the same characteristics as a penetrometer (Subedi and Walsh, 2009). Based on a principle similar to the acoustic method, the sound velocity method uses a 'hand gun' with a plunger that moves along the barrel and lightly taps the fruit surface to produce vibrations, which are detected by 2 unidirectional microphones.

Most of the previous studies focused on analyzing firmness changes using only one technique at a time and a very little information is available comparing different methods to determine firmness changes during mango ripening. Even though acoustic and ultrasonic wave attenuation methods are fast and nondestructive, commercial use of these techniques has been very limited because of the high installation cost of automated systems and variability in results depending on fruit type. A reliable non-destructive method to determine ripening stage during packing and distribution will help to improve the quality of mangoes delivered to retailers and consumers.

The amount of soluble sugars and acidity are important components of the flavor of ripe mangoes, along with aroma volatiles. Mature green 'Keitt' mangoes accumulate approximately 7% starch which is converted to soluble sugars during fruit ripening (Simao et al., 2008). Recent studies have indicated that non-destructive near-infrared (NIR) technology can be used to segregate mangoes based on total soluble solids content (Delwiche et al., 2008; Saranwong et al., 2003). However, refractometers are commonly used to quantify total soluble solids content under commercial conditions. Commercial mango growers generally squeeze juice from a half mango (cheek) onto the reflecting mirror of a refractometer, while quality laboratories squeeze a wedge of tissue or the entire half mango and filter the juice through cheesecloth before reading with a refractometer. The difference between the 2 methods is unknown. Total soluble solids content has been strongly correlated with sweetness, and sucrose was the predominant sugar responsible for sweetness in ripe 'Keitt' mangoes (Silva et al., 2008). Both citric and malic acids contribute to titratable acidity which decreases during ripening of 'Keitt' mangoes (Medlicott and Thompson, 1985).

Fruit flesh color is an important indicator of maturity and ripeness. All mango cultivars develop orange and yellow pigments in the flesh with maturity and ripening, but changes in skin color are not always correlated with maturity, ripeness or internal eating quality. During ripening, peel color may change from green to yellow or deep orange, depending on the cultivar, or may remain green. 'Tommy Atkins' mango peel developed more red and yellow pigments than 'Keitt' mango (Mitcham and McDonald, 1992).

The final eating quality of mango fruit depends largely on harvest maturity. Discrimination of mature and immature mango fruit at harvest is extremely important because an immature mango fruit never attains its full eating quality potential. The initial development of internal flesh color is a good indicator of fruit maturity. Dry matter content has also been shown to be a good indicator of harvest maturity of mango (Saranwong et al., 2004) and is correlated to the final total soluble solids content achieved in the ripe fruit. However, the hot-air oven method used to quantify dry matter is very slow (~2 d) and inefficient and has not been adopted by the mango industry. Recent research has shown the potential use of a NIR technique to assess dry matter as a harvest maturity index for mango (Subedi et al., 2007). However, this technology is new and requires further improvements to make it reliable and affordable for mango growers. Previously, a simple microwave technology was developed to determine dry matter content in avocado (Lee et al., 1983), corn (Beewar et al., 1977), kiwifruit (Ragozza and Colelli, 1990), and olives (Micelbart and James, 2003). As reported in other crops, use of microwave technology to determine dry matter content can be a quick and simple method to judge harvest maturity in mango fruit, although a non-destructive technique would be advantageous for fruit sorting after harvest.

ANOVA is commonly used to analyze the significance of differences between groups (such as ripening stages or treatments) for each parameter measured. However, ANOVA does not show how treatments or groups compare when all attributes are considered together, or how those attributes may be inter-related. This is relevant, for example, when the main objective is to identify the best methods and/or ripening attribute(s) to track changes in fruit ripening. Multivariate analysis techniques, such as canonical discriminant analysis (CDA), can be used to identify the best method to assess each physico-chemical attribute during fruit ripening, as well as the main attribute(s) to discriminate postharvest ripening changes. Canonical discriminant analysis provides standardized canonical coefficients (SCC), which are used to rank attributes in order of their contribution to the separation of groups and to characterize the canonical discriminant functions (CDFs), and canonical correlation (r) between CDFs and the original attributes. While SCC provide information about the attributes contributing jointly (multivariate contribution), r shows the importance of each attribute independent of the others (univariate contribution) to the separation of groups (such as ripening stages) (Cruz-Castillo et al., 1994). The use of parallel discriminant ratio coefficient (DRC), a product of SCC and r, has been suggested to assess the relative importance of attributes in a CDF, with attributes having large and positive DRC's having more power in discriminating groups (Thomas, 1992; Thomas and Zumbo, 1996).

The objective of this study was to use CDA to determine the most reliable methods to analyze the major physico-chemical changes during ripening of 'Keitt' mangoes, as well as to investigate the best physico-chemical indices to monitor changes in mango ripening. In addition, the use of the microwave oven was compared to hot air oven drying as a quick and reliable method for quantifying mango dry matter content, an indicator of fruit maturity and eating quality potential.

2. Materials and methods

Mature green 'Keitt' mango fruit were procured from a commercial packinghouse in Corona, CA. Fruit were harvested one day before packing, and transported on the same day, in an air conditioned vehicle, to the Postharvest Pilot Plant at the University of California, Davis. Fruit with poor quality, misshapened, sunburned or immature based on cheek fullness and shoulder shape were discarded. After sorting, boxed fruit were allowed to ripen at 20 °C and 85–90% relative humidity. Twenty fruit were analyzed on day zero (immediately after sorting) and every other day until fully ripe (14 d). All quality measurements and methods to measure quality (firmness, color, total soluble solids, dry matter, and titratable acidity) were made on the same fruit for the same period of evaluation, starting with the non-destructive measures. Each evaluation period during ripening was considered as a treatment, and each treatment had 20 single fruit replications.