Abstract
As mango is a climacteric fruit, the maturity stage at harvest is paramount in determining the final product quality after post-harvest ripening. The method of manually “tapping” mangoes, a traditional practice of farmers, utilizes the acoustical properties the fruits to decide harvest time. Mango fruit acoustics change over time as the mango seed develops and the surrounding cavity that initially exists within the endocarp fills. Usually, this method is used in parallel with visual evaluation of the mesocarp color around the endocarp to ensure that the decision of harvest time is based on two different criteria. Supporting the development of an objective, non-invasive acoustic maturity analysis, a study on the dynamics of the cavity closure mentioned above was conducted monitoring maturation and post-harvest ripening of mango fruits (cv. Chok Anan) grown in a research orchard at Mae Jo University, Thailand. Fruits analyzed at 2-3 day intervals during maturation and ripening were cross sectioned along the sagittal plane. The areas of the seed and endocarp were measured by use of a millimeter raster. As a result, the closure of the cavity was documented and correlated with other parameters of mango development that are conventionally used in destructive characterization of harvest maturity and ripeness. Knowledge about the ripening behavior, including the dynamics of the cavity closure, may promote the definition of thresholds for picking maturity in development and calibration of acoustic maturity sensors based on resonance.

1 Introduction
Mango is an increasingly popular fruit grown in tropical and subtropical regions. World production of mango reached $26.5 \times 10^6$ Mt in 2004 (FAOSTAT DATA, 2005). Like many drupe fruits and similar to bananas and pomes, mangoes exhibit climacteric ripening behavior. This is characterized by decreasing fruit respiration during development leading to a preclimacteric minimum followed by a rise in respiration levels (the climacteric) until full ripeness and a subsequent respiratory decline during fruit senescence (Biale and Young, 1980). The climacteric rise is associated with a sharp increase in ethylene production which induces ripening. Ethylene levels at harvest influence the magnitude of the climacteric curve, and therefore, the final product quality (Lalel et al., 2003). Fruits harvested too early do not undergo the desired ripening changes and a late harvest will lead to off-flavor and reduced shelf life.

Many methods exist for determining the harvest time of mango that require a set of maturity-related physiological or quality attributes. Producers and traders commonly use destructive methods that are inexpensive for determination of harvest time. Such methods are based on pit hardening and the mesocarp color change around endocarp (Crane and Campbell, 1994).
Furthermore, thresholds of acidity and contents of soluble solids, carbohydrates and phenolics are used (Lakshminarayana, 1980). However, differences exist between mango varieties. In some cases, access to technological resources, such as a laboratory, and considerable expertise are needed. Most producers are ill-equipped to accurately determine the best time for harvest and remain using unsophisticated methods based on experience with no real standardization.

Various nondestructive parameters have been suggested for determining mango maturity. Harvest time is often contingent on the time from fruit set, change in peel color (break), and/or initiation of fruit drop (Nakasone and Paul, 1998). Fruit size and shape, specific gravity, heat units and appearance of the lenticels are also used to specify harvest maturity (Lakshminarayana, 1980). Once again, these properties are unreliable for really assuring an exact stage of maturity due to subjectivity and dissimilarity among varieties. Some technologically advanced methods provide interesting possibilities. Chen (1999) reviewed various approaches founded on force-deformation, impact, sonic vibration and ultrasonic measurements, electrical properties, near-infrared (NIR) analysis, X-ray and gamma ray analysis, nuclear magnetic resonance and image analysis for the evaluation of quality attributes of plant foodstuffs. In mango, ultrasonic measurements have been used to monitor post-harvest softening and to determine the contents of sugar and acids as the major fruit quality attributes (Mizrach et al., 1997). Similarly, NIR spectroscopy offers a reliable tool to specify post-harvest ripeness of mangoes (Mahayothee et al., 2004) or their fruit quality (Schmilovitch et al., 2000). NIR quantification of starch and dry matter contents has been suggested to determine picking maturity of mangoes (Saranwong et al., 2003). Although NIR measurements have been integrated in large-scale automated sorting of various fruits (Schmilovitch et al., 1999), such technologies are still not widely available for use in the mango orchard. Moreover, they require the comprehensive calibration based on precise knowledge of the maturation kinetics and of suitable thresholds for picking maturity.

One traditionally practiced method called “tapping” uses developmental changes in the resonance produced when the mango is knocked to determine the best time for harvest. This is possible because as the mango fruit matures there is a change in density, a phenomenon already utilized in the processing industry by using buoyancy to identify immature fruits. Trained persons can decipher the resonance the best corresponds with the optimal harvest time. The change in resonance could be due, at least in part, to the filling of a cavity which exists within the endocarp which disappears as the seed develops (Figure 1). So far, dynamics of endocarp cavity closure in mango remain largely undocumented. It is hypothesized that a device could be designed for quick, inexpensive and non-destructive determination of the optimal harvest time, if this physiological development was more closely examined.

A promising technology in respect to detecting the endocarp cavity closure is Acoustic Resonance Spectrometry (ARS). In recent years, ARS has received attention as a quantitative tool for characterizing matter and detecting inherent fractures that significantly influence mechanical and hydraulic properties in both engineering and geological materials. Fractures form internal boundaries that are visible via acoustic resonance which occurs as a result of constructive and destructive interferences of propagating waves. Therefore the geometrical and mechanical properties of a fracture are characterized by the acoustic resonance. ARS technology has been employed to detect cracks in eggshells (De Ketelaere et al., 2000), deterioration of wood (Dunlop, 1983) as well as differentiation of wood species (Mills et al., 1993) and it has even been used to predict dissolution rates in pharmaceuticals (Buice et al., 1994). With respect to material characterization, an application of ARS called Electromagnetic Acoustic Resonance (EMAR) has documented importance in nondestructive industrial applications (Hirao and Ogi, 1997). It is plausible that this technology could also detect cavity properties inside the mango without disturbing the fruit. First the dynamics of the cavity closure must be documented – the purpose of this study.
2 Materials and Methods
Mango fruits (cv. Chok Anan) were obtained from an experimental mango orchard of Mae Jo University located near Chiang Mai, Thailand (18.53° N, 100.03° E, 350 m a.s.l.). Crop harvest date was determined by the traditional combination of the “tapping” method and visual inspection of the lenticels. To monitor on-tree maturation, fruit samples of a representative lot of trees were picked and analyzed every 2-3 days beginning 11 days prior to until 5 days after the conventionally determined harvest time. On the evaluation dates, samples were transported to the laboratory at Chiang Mai University and longitudinal cuts were made through the sagittal plane of the fruits (Figure 1A), halving the endocarp and seed. Cross sections were lightly shaved when necessary to ensure that the full breadth of the cavity was shown. Fruit halves were then placed face down on a transparent 1 mm² raster (Figure 1B/C) and digitally scanned at high resolution (600 pixels). Seed and endocarp areas were measured for three fruits per evaluation. Seed area was converted to a percentage of the entire endocarp area for each fruit. Additional scans for measuring the cavity volume involved longitudinal (sagittal and frontal) and transverse (at 1 cm intervals) sections.

![Figure 1: Longitudinal cut through the sagittal plane of a mango fruit (A.) and cross sectional scans with raster 11 days before (B.) and 5 days after optimum harvest (C.)](image)

To characterize preharvest maturity and postharvest fruit ripeness, mesocarp firmness was determined via bulk measurements using an Instron Universal Texture Analyzer 3365 (Instron, Canton, MA, USA) equipped with a Kramer shear cell and a maximum load capacity of 5 kN. Roughly 40 g of mesocarp cubes of approx. 1 cm³ forming a uniform layer in the shear cell were subjected to compression and shear forces at a crosshead speed of 10 cm min⁻¹. Firmness was expressed as maximum specific load in N 100 g⁻¹. The sugar-acid ratio (TSS/TA) of the mesocarp was calculated from the contents of total soluble solids (TSS) and titratable acids (TA) as previously described (VÁSQUEZ-CAICEDO et al., 2005). For monitoring of maturation, the fruits of each analysis day were divided into two lots that were either subjected to maturity analysis or to the cavity measuring. At the harvest time specified for the mango trees of this orchard (17 May 2005), the fruits of trees not involved in on-tree maturation monitoring were harvested and subjected to post-harvest ripening for 7 days at 27±2°C and 70±5 % relative humidity.

3 Results and Discussion
During on-tree maturation, neither firmness nor the sugar-acid ratio changed (Figure 2A/B). As described for other mango cultivars (LESHEM et al., 1986), a respiratory rise was stimulated by detachment from the parent tree, thus inducing post-harvest ripening. This was shown by the fruit softening and parallel increase in the sugar-acid ratio, characteristic of acid degradation and initial sugar accumulation. Hence, the post-harvest ripening index (RPI) that specifies fruit ripeness based on these changes (VÁSQUEZ-CAICEDO et al., 2005) cannot be used in detection of picking maturity.
Figure 2: Mesocarp firmness (A.) and sugar-acid ratio (B.) of mango (cv. Chok Anan) during on-tree maturation (Preharvest) and postharvest ripening at 27°C (Postharvest)

The cavities on the initial and on the final day of analysis, respectively, are displayed in Figure 1B/C. Cavity analysis could not be performed until the end of the post-harvest ripening period (25 May) as the mesocarp became too soft. Seed area steadily increased over the on-tree monitoring period (16 days) by 8% (Figure 3). A linear function was fitted to the closure of the cavity ($R^2 = 0.98$). From this equation, the seed area for the harvest time based on conventional determination of picking maturity can be estimated at 71% of endocarp area. Thus endocarp hardening was not complete at harvest. Picking maturity may be characterized by specific threshold for the cavity size that might be used in calibration of nondestructive instruments.

Figure 3: Percentage of the cavity filled by the seed during development

Regression equation ($R^2 = 0.98$):

$$y = 0.49x + 71.1,$$

where

$y =$ the seed area (% of endocarp) and

$x =$ the time from harvest determined by conventional analysis (days)

4 Conclusions

It was assumed that the cavity volume, unable to be measured in this study, is correlated with the area of the cross section of the seed. Length, width and height of endocarp and seed may serve in a mathematical approach to calculate cavity volume. Determination of cavity volume will allow for prediction of the resonance produced by knocking the mango. From these first results, it can be recommended to design and test instruments for measuring the resonance induced by a mechanical knocking of the mango and for the detection of the size of the seed and cavity based on ARS technology, especially by EMAR. Furthermore, the threshold of the cavity area found above must be confirmed by a wide range of mango lots from different crop years with varying fruit sizes. The influences of fruit size, cultivar and climate (humidity) on the reproducibility of the acoustic signal require further investigations especially prior to comprehensive calibration either with cavity size, maturity indices, respiration rates or ethylene levels.
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6 References


