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IN-FIELD MEASUREMENT OF FRUIT RESPIRATION FOR DETERMINING CLIMACTERIC ACTIVITY AND HARVEST MATURITY OF MANGO

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ABSTRACT Mango is a widely cultivated crop and is a climacteric fruit characterized by changes in respiration during development. Mangos are commercially harvested directly after the pre-climacteric minimum at a mature yet unripe state after which optimal post-harvest ripening occurs. Since methods for evaluating harvest maturity are typically subjective, destructive or expensive methods, much potential exists for rapid, accurate and economical technology. A sound approach for determining maturity stage of mango is the measurement of CO_2 production, as it is directly related to climacteric activity. Non-dispersive infrared (NDIR) is a simple spectroscopic technology used in gas detection, which is economical and highly accurate. NDIR sensors provide the possibility for developing tools for mango producers to measure fruit respiration, gauge mango development and optimally schedule harvest activities. The objective of this study was to investigate commercially available NDIR sensors for monitoring fruit respiration in mango orchards. An in-field system incorporating NDIR sensors for measurement of fruit respiration was developed. Experiments were carried out in Chiang Mai, Thailand and included two local varieties. A group of fruits was monitored on-tree during development and another was periodically sampled for analysis. Standard fruit respiration experiments were performed using a gas chromatograph for comparative studies with field measurements. Climacteric curves of fruits were successfully detected in the field. Measurements were found to stabilize quickly and could easily be made in a few minutes. Moderate rise of temperature and change of atmospheric composition in the measurement system was not found to impact respiration. Fruit size was found to affect absolute respiration rates. The pre-climacteric minimum occurred consistently below 13 ml CO_2 kg^{-1} hr^{-1}. Respiration values from the field were found to correspond with laboratory measurements (R^2 = 0.96). In conclusion, tests with non-destructive CO_2 sensors showed excellent potential, but practical modification of the system must be considered for use by farmers.

Keywords: Mango, climacteric, maturity, non-destructive, NDIR sensor, respiration

INTRODUCTION Mango is an increasingly popular fruit grown in tropical and subtropical regions. World production reached 33 million tonnes in 2007 (FAOSTAT, 2008). Mango exhibits climacteric behaviour, characterized by decreasing fruit respiration during development leading to a minimum, followed by a rise in respiration levels (the climacteric) until full ripeness (Biale and Young, 1980). The climacteric rise is associated with a sharp increase in ethylene production which induces ripening. Climacteric fruits are commonly harvested directly after the pre-climacteric minimum, meaning mature but not ripe for consumption, after which the fruit then undergoes post-harvest ripening during the climacteric rise (Grierson, 2002). The closer fruit is picked to the occurrence of the climacteric rise, the shorter the time is from harvest until ethylene production begins (Katz et al., 2005). Moreover, the time of harvest influences the magnitude of the climacteric curve, and therefore, the final product quality (Bower et al., 2002; Zude-Sasse et al., 2000). For example, fruits harvested too early do not realize the full potential the desired ripening changes and a late harvest will lead to reduced shelf life and off-flavour (Lalel et al., 2003; Medlicott et al., 1988). Therefore, an optimum harvest times exist which is contingent on ultimate exploitation of the fruit e.g. destination market, end use (Fig. 1). For export fruits, final quality is conceded to storability whereas the opposite is true with fruits used for local purposes.

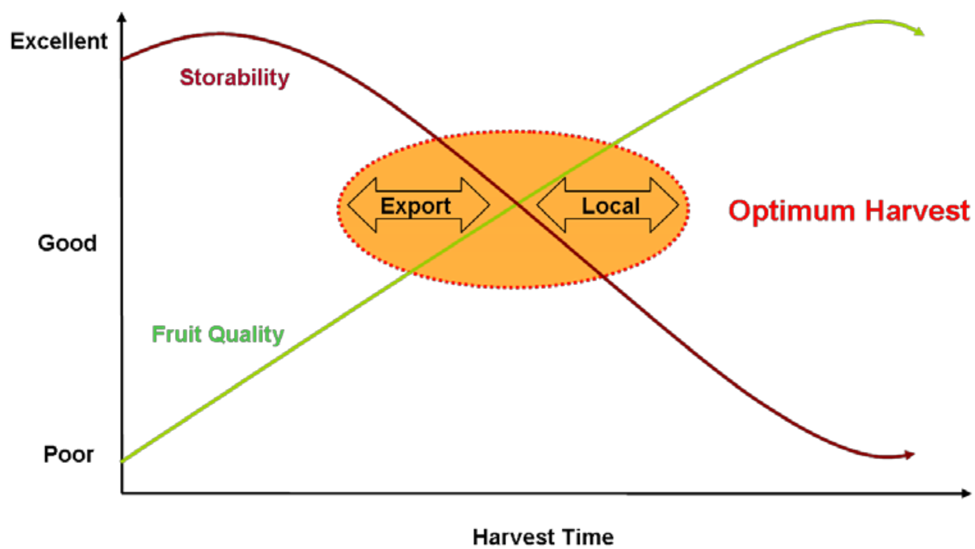

Figure 1. Depiction of optimal harvest time of mango based on ultimate use, where final quality is conceded to storability for export markets and visa-versa for local purposes.

Several methods are known for determining the optimum harvest time of mango that require a set of maturity-related physiological or quality attributes. Producers and traders commonly use destructive methods for determination of harvest time. Such methods focus on pit hardening and colour change of the flesh around endocarp (Samson, 1986). Furthermore, thresholds of acidity and contents of soluble solids can be used (Lakshminarayana, 1980). However, differences exist between mango varieties and variability within trees and orchards can be high (Herold et al., 2005). In some cases, access to technological resources, such as a laboratory, and considerable expertise are needed. Various non-destructive parameters are also available for gauging mango maturity. Harvest time is often defined by the time after fruit set, changes in peel colour, or initiation of fruit drop (Nakasone and Paull, 1998). Fruit size and shape, specific gravity, heat units and changes in lenticel colour are also used (Schaffer et al., 1994). Again, these methods are dependent on variable parameters and, therefore, are unreliable for assuring an exact stage of maturity. Most producers are under-equipped to accurately determine the best time for harvest and remain using unreliable methods based on experience with no real standardization.

Since harvest maturity is typically evaluated by destructive methods which are often expensive, time consuming and requiring special skills, a large potential exists for rapid, accurate, non-destructive sensor technology for performing this function. Such sensors are useful because they allow measurement of every fruit, since they are non-destructive, and can be repeated while leaving the fruit on the tree until it is mature. When accurately calibrated, no special expertise is required to perform measurements, which typically only take a few seconds to make. Emerging technologies provide promising possibilities. One interesting approach for determining maturity of mango is the measurement of CO_2 production, since this is directly related to climacteric activity. So far, only a few methods for measuring CO_2 non-destructively in the field have been proposed and tested (Ehleringer and Cook, 1980; Long et al., 1996). However, these have previously required sophisticated and high-cost sensors and were used in other applications. With recent technology advancements, high-accuracy CO_2 sensors which are more economical have come onto the market. Such sensors provide the possibility for developing tools for producers to measure fruit respiration in the field. Nonetheless, such sensors need to be researched and adapted for this application.

In Thailand, farmers have to base harvest decisions on the end-use of the fruit, e.g. fruits destined for processing or export may be harvested earlier than those for the fresh market. Nonetheless, determining optimum harvest time for respective fruits is a problem farmers face since no objective non-destructive methods exists to do this. Presumably, simple principles and technologies could be adapted to measure changes in mango fruits non-destructively. Above all, it has been stated that technical innovations, particularly with respect to maturity determination, are required to boost income generating potential of mango production (de Bie, 2004). The development of sensor-based decision support for accurate, reproducible determination of harvest time, especially with respect to various varieties, production locations and ultimate uses, is promising.

MATERIALS AND METHODS An approach using non-destructive technology for determining the harvest maturity of mango was explored using respiratory behaviour as measured by CO_2 production as a physiological indicator. Non-dispersive infrared (NDIR) CO_2 gas analyzers were modified to quantify respiratory activity of mango non-destructively in the field. NDIR sensors are simple spectroscopic devices often used in gas detection. The main components are an infrared source, a sample chamber or light tube, a wavelength filter, and the infrared detector. The gas is diffused into the sample chamber, and gas concentration is measured electro-optically by its absorption of a specific wavelength in the infrared (IR) range. The IR light is directed through the sample chamber towards the detector. The detector has an optical filter that eliminates all light except the wavelength that the selected gas molecules can absorb. Ideally, other gas molecules do not absorb light at this wavelength, and do not affect the amount of light reaching the detector.

In-field research was carried out in local commercial orchards in Chiang Mai province with emphasis on the mango varieties ‘Nam Dok Mai’ which is the most important export variety and ‘Chok Anan’ a variety produced mostly for local markets and processing. The Nam Dok Mai (cultivar ‘See Tong’) orchard was located near Phrao (N19º26’10.6”, E99º12’41.9”, 485m) and the Chok Anan orchard was near Mae Jo (N18º55’19.9”, E99º2’39.9”, 379m). In these orchards, commercial harvest is defined around 100 days after full bloom (DAFB), thus experiments were conducted for two weeks prior to and one week after this time to represent early and delayed harvests, respectively. Four trees were randomly selected at each site, from which two fruits were monitored.

The fruits were subjected to respiration measurements using NDIR sensors (TES-1370A, Taipei, Taiwan) in a 2000 ml closed system setup (Fig. 2). Measurements were done between 7:00 and 9:00 in the morning to avoid influences from temperature variation and the system was covered in a black cloth to minimize solar influence. NDIR sensors were equipped with automatic data loggers with set recording interval of 10 sec and measured CO_2 concentration, temperature and relative humidity. Fruit mass was measured using a field balance (±10 g). In each orchard, a second lot was defined from which one fruit from each tree was harvested on respective days for laboratory analysis. Samples were transported under controlled conditions to the Post Harvest Technology Institute at Chiang Mai University. For comparative studies with the field measurements, standard fruit respiration experiments were performed in the laboratory according to Ravindra and Goswami (2008). Head space experiments were conducted at 25º C using one fruit per 1500 ml container weighed by laboratory balance (±0.01 g). The gas chromatograph (GC-9A Shimadzu, Japan) was fitted with a Hayesep Q column (6’ length, 1/8’ diameter) and He was used as carrier (40 ml min^{-1}). An additional experiment was performed for measurement accuracy, where 16 Chok Anan fruits were measured CO_2 with the sensor system in the field and afterward were harvested, transported to the laboratory and subjected to GC analysis as described above.

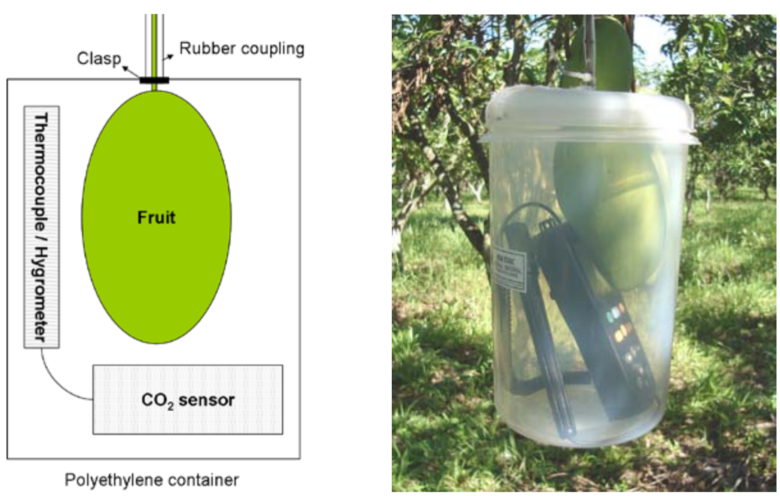

Figure 2. Experimental set up of the on-tree respiration measurements.

RESULTS AND DISCUSSION The field measurement system was able to capture respired CO_2 gas from mango fruits. Examples of CO_2 concentrations in the closed system are given in Fig. 3. Over the three-week monitoring period, climacteric curves of fruits were successfully identified. Initial temperatures were similar in all measurements (Table 1), but temperature was found to increase on average by 0.20-0.25°C min^{-1} during measurements in the closed system. Overall determination lasted up to 10 min and thus, it is believed any effect on fruit temperature (Fonseca et al., 2002) was minimized. Even on the hottest days, a maximum increase of only 5°C was experienced. Empirically, temperature was not found to affect in-field values, as increases in CO_2 remained constant during measurements. In addition, elevated CO_2 levels in the closed system during experiments (Table 1) did not reach elevated concentrations long enough to affect respiration (Bender et al., 2000), which was confirmed since no decrease was found over time. Differences were found between monitored fruits regarding a large time variation in the occurrence of the pre-climacteric minimum for both mango varieties (Fig. 4). The characteristic minimum of respiratory activity was often several days away from commercial harvest in either direction. This could be due to a number of factors including variation in fruit set, position in the canopy, or fruit/leaf ratio per branch (Léchaudel and Joas, 2006; Simmons et al., 1998). However, the pre-climacteric minimum consistently occurred below 13 ml CO_2 kg^{-1} hr^{-1}.

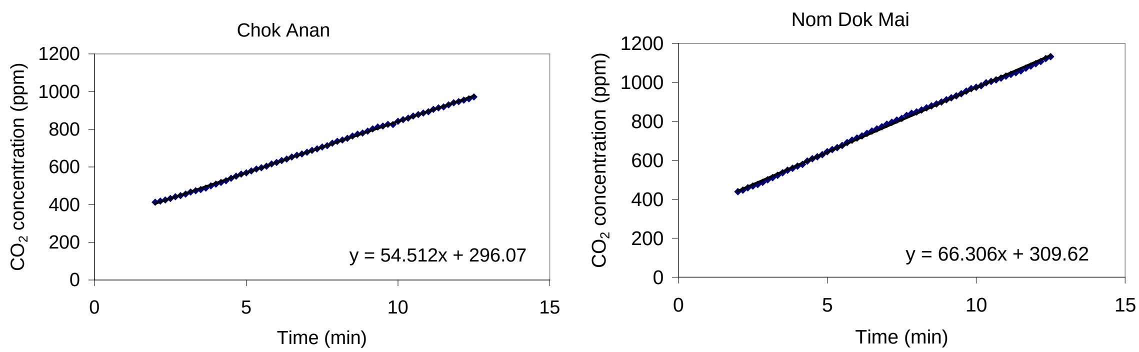

Figure 3. CO_2 production of representative mango fruits 'Chok Anan' and 'Nam Dok Mai' on as detected by NDIR sensors during on-tree monitoring.

Table 1. Specification of measurement conditions in the closed CO_2 monitoring system

	Mean		Maximum after 10 min	
	Initial temperature (°C)	Temperature rise (°C min^{-1})	Temperature rise (°C)	CO_2 concentration (%)
Chok Anan	24.73 ± 0.92	0.20 ± 0.16	4.35	0.33
Nam Dok Mai	24.87 ± 1.54	0.25 ± 0.17	4.94	0.42

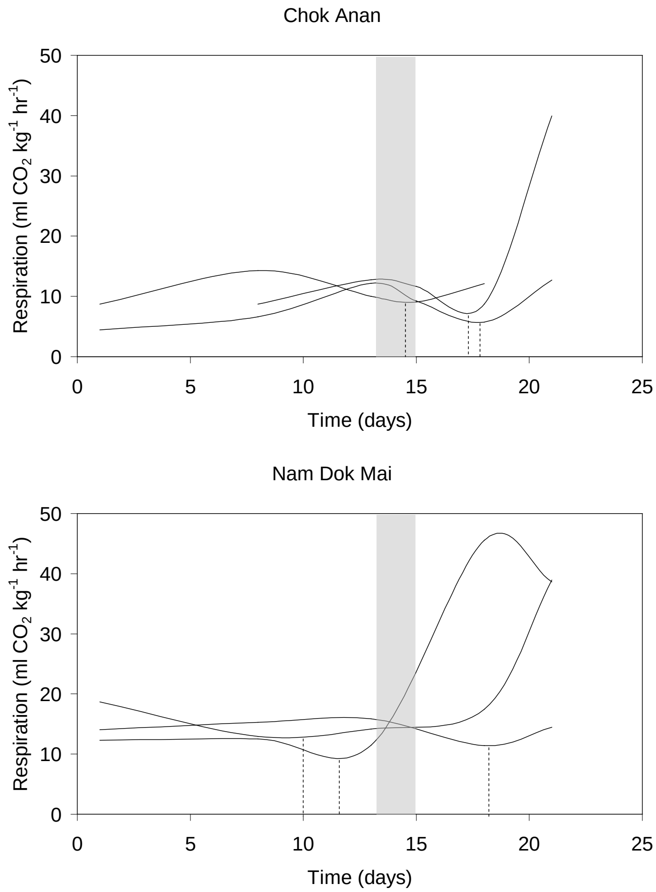

Figure 4. Respiration curves of representative fruits during last three weeks of on-tree monitoring with pre-climacteric minimum indicated by dotted lines. Gray areas represent commercial harvest period.

The destructive GC measurements of fruit respiration over the development period also showed the characteristic climacteric pattern (Fig. 5). However, large variations from the mean values were seen. This further verified the staggering of climacteric curves of fruits of similar variety and orchard. Even on the commercial harvest date, a deviation of 30% from the mean value was found. High deviation five days after commercial harvest also implied that some fruits were still showing lower respiratory activity. The ability of an uncomplicated sensor system to detect climacteric activity is thus very promising in regards to harvest decision support for producers.

Regarding to the accuracy of the NDIR sensors, comparison of measurements on the same fruits between the portable sensors and standard CG lab experiments showed high correspondence (R^2=0.96) between values (Fig. 6). This indicated that the field sensor system is reliable for determining actual respiration activity of mango fruits. However, to determine if additional calibration is required, this data should be repeated with a larger sample size.

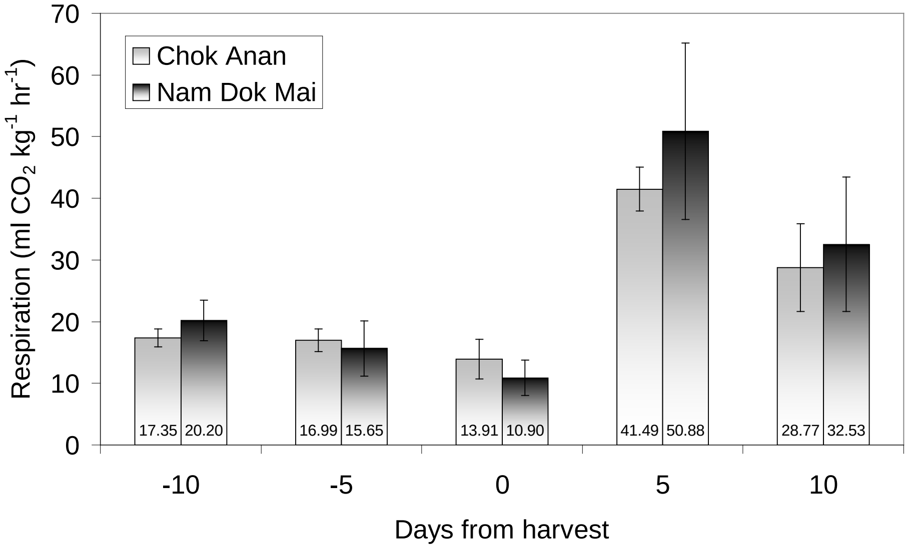

Figure 5. Respiration rate of mango harvested at different days before and after commercial harvest date as measured by standard destructive GC method.

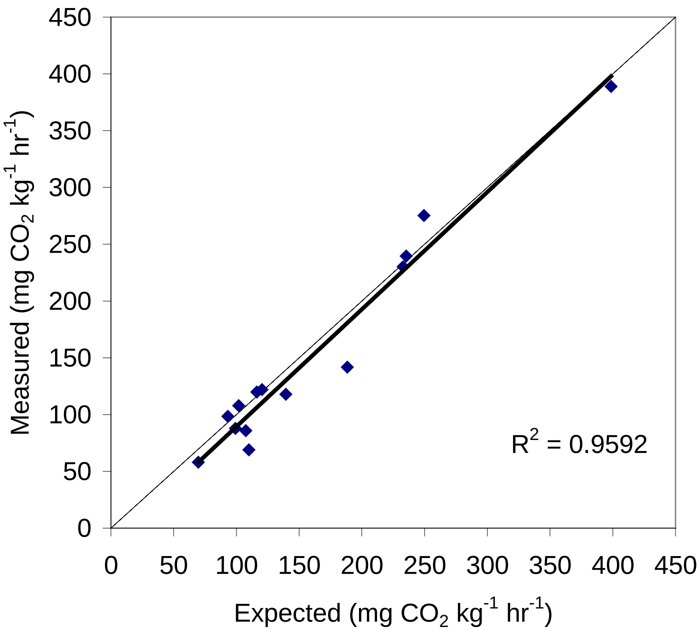

Figure 6. On-tree measurement of respiration rate of mango fruits ‘Chok Anan’ vs. destructive measurement by standard GC analysis (16 fruits).

CONCLUSIONS Initial testing showed CO_2 production of mango fruit could be successfully measured in the field using NDIR sensors in a closed system. Climacteric stages varied considerably during the monitoring period, indicating the need for in-field detection of maturity. Field measurements corresponded well with values from standard laboratory analysis. These results need to be confirmed in a broader field study with larger sample sizes and more replications. Also, any final sensor-based measuring system for farmers should be altered to make the sensor more practical for in-field measurements. Furthermore, the influences of fruit photosynthesis and pathological infestation have so far not been determined. Therefore, tests with non-destructive CO_2 sensors have thus far been preliminary and further investigations are required.

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REFERENCES

Bender RJ, Brecht JK, Sargent SA, and Huber DJ. 2000. Mango tolerance to reduced oxygen levels in controlled atmosphere storage. J. Am. Soc. Hort. Sci. 125(6):707-713.

Biale JB, and Young RE. 1980. Respiration and ripening in fruits - retrospect and prospect. In: Friend J, and Rhodes MJC, editors. Recent Advances in the Biochemistry of Fruits and Vegetables. London: Academic Press. p 1-39.

Bower J, Holford P, Latche A, and Pech JC. 2002. Culture conditions and detachment of the fruit influence the effect of ethylene on the climacteric respiration of melon. Postharvest Biol. Technol. 26(2):135-146.

de Bie CAJM. 2004. The yield gap of mango in Phrao, Thailand, as investigated through comparitive performance evaluation. Sci. Hort. 102:37-52.

Ehleringer J, and Cook CS. 1980. Measurements of photosynthesis in the field: utility of the CO_2 depletion technique. Plant Cell Env. 3(6):479-482.

FAOSTAT. 2008. ProdSTAT. Food and Agriculture Organization of the United Nations.

Fonseca SC, Oliveira FAR, and Brecht JK. 2002. Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review. J. Food Eng. 52(2):99-119.

Grierson W. 2002. Fruit development, maturation and ripening. In: Pessarakli M, editor. Handbook of Plant and Crop Physiology. New York: Marcel Dekker. p 143-159.

Herold B, Truppel I, Zude M, and Geyer M. 2005. Spectral measurements on 'Elstar' apples during fruit development on the tree. Biosystems Eng. 91(2):173-182.

Katz E, Riov J, Weiss D, and Goldschmidt EE. 2005. The climacteric-like behaviour of young, mature and wounded citrus leaves. J. Exp. Bot. 56(415):1359-1367.

Lakshminarayana S. 1980. Mango. In: Nagy S, and Shaw PE, editors. Tropical and Subtropical Fruits: Composition, Properties and Uses. Westport: Avi. p 184-257.

Lalel HJD, Singh Z, and Tan SC. 2003. Maturity stage at harvest affects fruit ripening, quality and biosynthesis of aroma volatile compounds in 'Kensington Pride' mango. J. Hortic. Sci. Biotechnol. 78(2):225-233.

Léchaudel M, and Joas J. 2006. Quality and maturation of mango fruits of cv. Cogshall in relation to harvest date and carbon supply. Aust. J. Agric. Res. 57(4):419-426.

Long SP, Farage PK, and Garcia RL. 1996. Measurement of leaf and canopy photosynthetic CO2 exchange in the field. J. Exp. Bot. 47(11):1629-1642.

Medlicott AP, Reynolds SB, New SW, and Thompson AK. 1988. Harvest maturity effects on mango fruit ripening. Trop. Agric. 65(2):153-157.

Nakasone HY, and Paull RE. 1998. Mango. Tropical Fruits. New York: Cab Intl. p 208-238.

Ravindra MR, and Goswami TK. 2008. Modelling the respiration rate of green mature mango under aerobic conditions. Biosystems Eng. 99(2):239-248.

Samson JA. 1986. Mango. Tropical Fruits. 2nd ed. New York: Longman. p 62-71, 216-234.

Schaffer B, Whiley AW, and Crane JH. 1994. Mango. In: Schaffer B, and Anderson PC, editors. Handbook of Environmental Physiology of Fruit Crops, Vol. II. Boca Raton: CRC Press. p 165-197.

Simmons SL, Hofman PJ, Whiley AW, and Hetherington SE. 1998. Effects of leaf: fruit ratios on fruit growth, mineral composition and quality of mango (*Mangifera indica* L. cv. Kensington Pride). J. Hortic. Sci. Biotechnol. 73(3):367-374.

Zude-Sasse M, Herold B, and Geyer M. 2000. Comparative study on maturity prediction in 'Elstar' and 'Jonagold' apples. Gartenbauwiss. 65(6):260-265.