Nondestructive Maturity Assessment Methods for Mango:
A Review of Literature and Identification of Future Research Needs

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1 Abstract

A review of the literature on nondestructive methods for objective assessment of maturity in mango was conducted. Most of the research conducted on this topic involved cultivars that are not currently marketed in the USA. A number of promising technologies exist for nondestructive assessment of mango maturity. Future research topics are proposed, with a focus on the mango cultivars that are currently marketed in the USA (e.g., Ataulfo, Haden, Keitt, Kent, and Tommy Atkins), to address needs for the development of nondestructive methods for objective assessment of maturity in mango.

2 Maturity and Ripeness

The condition of fruit at the time of harvest has an important effect on the consumer's level of satisfaction at consumption. While many consumers use the terms mature and ripe interchangeably to describe the state of a fruit when it is ready for consumption, Reid (2002) notes that fruit producers and postharvest produce technologists consider these terms to have distinct meanings. Reid indicates that the term mature is best described by the Webster's dictionary definition

> Mature: "having completed natural growth and development."

Reid further elaborates that the term mature describes the stage at harvest that will ensure that the fruit's quality will meet or exceed the minimum level acceptable to the consumer at the time it is consumed. In a climacteric fruit, such as mango, the fruit is not considered to be of desired eating quality at the time it initially becomes mature, but requires a ripening period (typically 8 to 10 days at 25 ^{o}C; Lakshminarayana, 1980) before it achieves the taste and texture desired at the time of consumption. In this context the term ripe is best described by the Webster's dictionary definition

> Ripe: "having attained a final or desired state."

Thus it is important to know the stage of maturity for determining when to harvest fruit since fruit harvested at an immature stage will not be able to achieve a level of quality acceptable to consumers. Sorting harvested mangoes according to their maturity stage in the packinghouse can eliminate immature-green mangoes and separate partially-mature from fully-mature green mangoes in order to improve the uniformity of ripening in lots of fruit at destination. It is also important to know the stage of ripeness for determining the optimal postharvest strategy for handling and marketing fruit.

There are five major mango cultivars marketed in the USA (‘Ataulfo’, ‘Haden’, ‘Kent’, ‘Keitt’, and ‘Tommy Atkins’). The majority of mangoes marketed in the USA are imported. Imported mangoes typically spend several days in transit between their country of production and their market in the USA. As with most fruits, the mango flesh softens as the fruit ripens and soft fruit requires more careful handling than firm fruit in order to prevent mechanical damage. To facilitate successful marketing of mangoes using conventional packaging and postharvest handling methods, mangoes destined for import into the USA are harvested at the mature-green stage while still firm. The fruit are then ripened after they arrive the USA by the wholesaler, retailer, or consumer (Kader and Mitcham, 2008). A new suspended tray package developed at UC Davis (Thompson et al., 2008) for transport of ripe fruit may allow mango harvest at a more mature or partially ripe stage if transit times are not too long.

Because the maturity level at harvest is critical to the development of good flavor quality in the fruit when fully ripe (Kader, 2008), it is important for individuals harvesting fruit to have effective methods of determining mango maturity. Unfortunately, the appearance of red color on the skin (in some cultivars) is not a reliable index of maturity. Likewise, the change in skin ground color (the greenest spot on the fruit) from dark-green to light-green or yellow is not reliable because of variations between cultivars. Differences in ground color between immature and mature green mangoes can be subtle. A number of alternative mango maturity indices have been studied.

Maturity indices for mango include:

- number of days after full bloom,
- flesh color,
- fruit shape (the “fullness” of the cheeks or shoulders),
- fruit size,
- skin color,
- soluble solids content,
- specific gravity (the ratio of the mango density to the density of water)
- starch content,
- titratable acidity, and
- total solids (dry matter) content.

Cultivar differences and differences in the growing environment can affect the performance and consistency of many of these indices, and while there is currently no consensus on the optimal maturity index for mango, Kader (2008) observed that flesh color has the most consistent performance across cultivars. Kader concluded that the development of a nondestructive flesh color sensor for mango could allow improved training of harvesting crews to better recognize an external attribute (such as fruit shape) associated with minimum maturity levels in the orchard.

3 Nondestructive Methods of Fruit Quality Evaluation

A number of methods have been developed for the nondestructive determination of fruit quality, and several reviews of these technologies are available (Abbott et al., 1997, Abbott, 1999, Butz et al., 2005, and Chen 1996). The following is a list of fruit characteristics for which nondestructive methods for assessing fruit maturity or quality have been evaluated or are commercially available for mango. This review will focus on aroma, color, composition, and firmness since research studies on these methods have been published. The remaining methods are available from commercial manufacturers listed in the Appendix.

- aroma
- color
- composition
- defects
- firmness
- shape
- size
- specific gravity (or density)

3.1 Nondestructive methods for predicting mango maturity and ripeness.

3.1.1 <u>Aroma</u>

As fruits ripen, the concentration of volatile compounds increases. The release of these volatiles is what consumers smell when eating ripe fruit, contributing to their enjoyment of the fruit. Volatiles can also be produced when the fruit is subjected to mechanical damage, thermal damage, disease, or pathogens. The aroma profile of a fruit can be measured nondestructively by placing the fruit in a sealed container, such as a glass jar or a plastic bag. The volatiles can then be analyzed in the laboratory using gas chromatography and mass spectroscopy (CG/MS). Within the last decade a handheld version of a device called an electronic nose (enose) has been developed for the identification of volatiles for quality control and odor identification in non-laboratory environments. Researchers have demonstrated the use of the enose for monitoring ripening in a number of fruits including apple (Brezmes et al., 2001), banana (Llobet et al., 1999), blueberry (Simon et al., 1996), grape (Patterson, 2007), mandarin (Gomez et al., 2007), peach (Benedetti et al., 2008), and tomato (Gomez et al., 2006). Enose technology has also been used to detect defects in fruits (such as freeze damage in orange, Tan et al., 2005; mechanical damage in apple, Li et al., 2007; and mechanical damage in blueberry, Simon et al., 1996).

While enose measurements are nondestructive, they are not currently suited for on-line applications due to the time required both to allow the volatiles to accumulate in the container, and to take the measurement (generally several minutes). A detailed overview of electronic nose technology has been written by Gardner and Bartlett (1999). Röck et al. (2008) have published a recent review of the current status of the technology.

A number of researchers have studied the volatiles emitted by specific mango cultivars (Ackerman et al., 1984; Bender et al., 2000; MacLeod and Pieris, 1984; MacLeod and Snyder, 1985; Malundo et al., 1996). Salim et al. (2005) was able to classify 'Harumanis' mangos into under-ripe, ripe, and over-ripe categories using an enose. In a preliminary study of a limited number of 'Keitt' and 'Kent' mangoes, Lebrun et al. (2008) evaluated the ability of a laboratory bench top enose (model FOX 4000, Alpha MOS, Toulouse, France) to distinguish between five different sizes (by mass) of "green" mangoes. In this study intact mangoes were held in sealed plastic containers after harvest for 3 hours to allow volatiles to accumulate in the containers. The enose was able to distinguish between the headspace volatiles of the 5 size categories of 'Keitt' mangoes and between 3 of the 5 size categories of 'Kent' mangoes. The enose could also distinguish between the headspace volatiles of ripe 'Kent' and 'Keitt' mangoes. While fruit size is a crude index of maturity and the enose used in this study was not portable, the results suggest that a handheld enose might be useful as a nondestructive tool for determining mango maturity on the tree. Additional research is needed to conduct a more complete study of mango maturity for all USA marketed cultivars and to develop a technique for instrument standardization to allow a reliable and user-friendly method of field calibration.

3.1.2 Color

Visual appearance is one of the main factors used by consumers when purchasing produce. Color is an important part of the visual appearance and is used in many grade standards as a criterion for quality. Color is the human visual perception of light reflected, transmitted, or emitted from an object in the visible portion of the electromagnetic spectrum from 380nm to 780nm. For opaque objects like fruit, most of the light energy striking a fruit only penetrates the surface a very small distance and is then reflected away from the surface. The main factor in the distribution of light energy reflected from the fruit is the presence and concentration of pigments including carotenoids, anthocyanins and other flavonoids, betalains, and chlorophylls in the skin (Gross, 1987; Mazza and Miniati, 1993). The changes in these pigments as fruit develops affect the perception of fruit color and thus the color of fruit is frequently used as an index of maturity or ripeness.

The color aspect of visual appearance of the skin can be measured nondestructively using three types of sensors: colorimeters, spectrophotometers, and color machine vision systems. Colorimeters are instruments designed to quantify color in terms of human perception. Colorimeters are broadband instruments that generally divide the information in the visible spectrum into three components similar to the red, green and blue cone cells in the human eye. Spectrophotometers are designed to provide more detailed information about the optical properties of the sample, typically dividing the information in the visible spectrum into fifteen or more components. Colorimeters and spectrophotometers are designed to give a single average reading over a spot on the sample typically ranging in size from 5 to 25 mm in diameter. For on-line use or when detailed color information is needed for spatial analysis across a two dimensional surface, a color machine vision system is typically used.

One of the first colorimeters developed was the Color Difference Meter developed by Richard Hunter in 1948 (Hunter, 1948). Hunter developed a tristimulus color space called L, a, b to mimic human color perception. The L, a, b color space is based upon the opponent color theory of human color perception developed by Hering in 1872 where perception is a function of signals from the rods and cones in the eye that are processed in an antagonistic manner with three opponent channels: black versus white (Hunter's L value), red versus green (Hunter's a value), and blue versus yellow (Hunter's b value). While many other color systems have been developed since 1948, the Hunter L, a, b system was one of the first used in foods and is commonly used in research studies as a means of measuring ripeness or defects in many commodities including mango.

3.1.2.1 Nondestructive measurements of mango skin color

Malevski et al. (1977) found that skin color measured with a colorimeter at an arbitrarily selected site on the fruit was an unreliable index of maturity in 'Haden' mango. However, the maximum red or yellow coloration in the skin of 'Haden' mango, was found to be predictive of maturity where 33% of the fruit with Hunter b values < 16 and 22% of the fruit with Hunter a values < 0 at harvest did not ripen.

Jha et al. (2005, 2006, and 2007) used a portable spectrophotometer to measure the average skin color and reflectance spectra of 'Dashehari' mango from individual measurements taken at the apex and stem ends at harvest. They harvested fruit every 2 days beginning in late May or early June until the fruit began to ripen on the tree. Then after the nondestructive optical measurements were taken, they measured the soluble solids content (SSC) and the penetrometer firmness of the fruit. Linear regression models were developed to predict the SSC at harvest using Hunter a and b values (r^2=0.83) or by using reflectance values between 440 and 480 nm (the blue portion of the visible spectrum, r^2=0.8). They were also able to develop a model to predict (r^2=0.8) the average penetrometer firmness at harvest using the reflectance in the green portion of the visible spectrum (530 to 550 nm).

Ornelas-Paz et al. (2008) nondestructively measured the skin color of 'Manila' and 'Ataulfo' mangoes during ripening using a colorimeter. The carotenoid content of the homogenized flesh was measured by HPLC-MS. They found correlations between skin CIE a* value (similar to Hunter a value) or the CIE hue angle and the carotenoid content of the flesh (r^2 =0.76 to 0.81). Because a colorimeter is designed to mimic the human perception of color and is not optimized for the determination of chemical composition, it is possible that a superior model could be developed for carotenoid prediction using a portable spectrophotometer, which provides more detailed spectral information.

A number of commercial automated on-line color machine vision sorting systems are available for non-destructive measurement of skin color on fruit packing lines (a list of manufacturers of fruit sorting equipment is provided in the Appendix). We were unable to find any published studies on mango comparing the performance of on-line color machine vision systems with handheld or bench top colorimeters or spectrophotometers.

3.1.2.2 Nondestructive prediction of mango flesh color

Subedi et al. (2007) evaluated the potential use of a prototype handheld spectrophotometer for predicting the internal flesh color of ‘Kensington Pride’ and ‘Calypso’ mangoes from a nondestructive optical measurement in the visible and near infrared regions. They were unable to develop a direct model using optical measurements in the visible region to predict the internal flesh color due to excessive noise in the visible signal when measuring mango using this model of instrument. This is in contrast to the work of Slaughter et al. (2006) on four cultivars of clingstone peaches where a direct model of internal flesh color, using nondestructive optical measurements in the visible region, could be developed (r^2=0.8). An indirect model was developed by Subedi et al. using near infrared measurements to predict the Hunter b value of the flesh (r^2=0.9). It is likely that the near infrared model is based upon indirect relationships between water, starch, and soluble solids contents and the carotenoid content of the flesh. They also observed that a near infrared model developed to predict the flesh color of one cultivar did not perform well when used to predict the flesh color of the other cultivar. When fruit from both cultivars was used to develop the near infrared model, it performed reasonably well (r^2=0.88). For ‘Kensington Pride’ the root mean square error of cross validation (RMSECV) ranged from 4.7 to 7.8. The average Hunter b values were 25 and 43 for the immature and early mature ‘Kensington Pride’ fruit, respectively.

3.1.3 <u>Internal Composition</u>

3.1.3.1 Magnetic Resonance Imaging

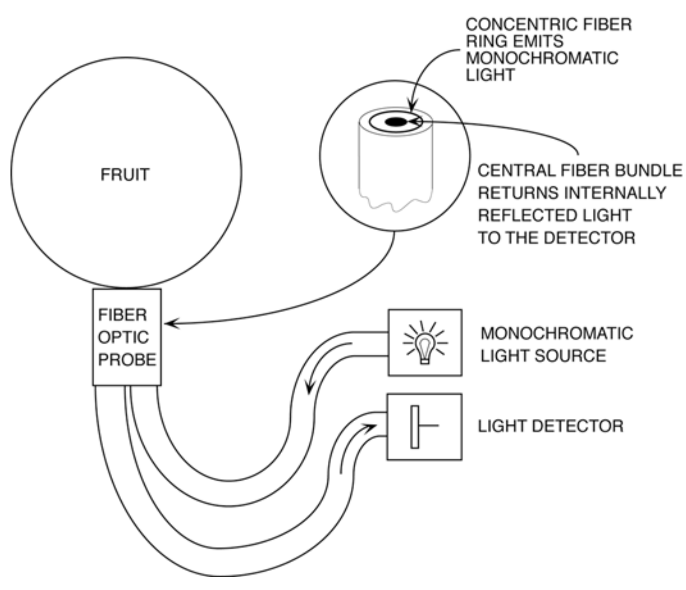
Magnetic resonance (MR) and magnetic resonance imaging (MRI) are nondestructive sensing methods that are based upon the interaction of certain nuclei, such as carbon and hydrogen, with electromagnetic radiation in the radio frequency range. Hydrogen nuclei produce one of the strongest MR signals and the presence of hydrogen in fruit components such as water, sugar and oils allow for the application of MR methods for fruit quality assessment. Areas of increased free (unbound) water or voids in the internal tissue of fruits are readily detectable by MRI and allow detection of internal defects such as bruising, chilling injury, and insect damage (e.g., Mazucco et al., 1993). For example, Joyce et al. (1993) demonstrated that MRI could be used as a nondestructive method to detect heat treatment induced injury to mesocarp tissue in ‘Kensington Pride’ mangoes because the injured areas contained air filled cavities in the tissue. MRI has been used to detect seeds in orange (Hernandez-Sanchez et al., 2006), internal browning in apple (Chayaprasert and Stroshine, 2005) and translucency in overripe pineapple (Chen et al., 1989). Chen et al. (1989) demonstrated that MRI could distinguish red tomato from green, but that discrimination of immature-green from mature-green tomatoes was poor. Chen et al. (1993) were able to use MR to measure the oil/water ratio in intact avocado as an index of fruit maturity. Clark et al. (1997) published a review of MRI application to fruits and vegetables.

Joyce et al. (2002) conducted a limited study of MRI on four intact ‘Kensington Pride’ mangoes during ripening. The image data indicated that water activity in the flesh increased in an outward-moving flux as the fruit ripened, and they observed that the MRI signal in the middle part of the flesh increased during ripening. Further work is required to investigate MRI changes in mango during maturation and ripening.

3.1.3.2 Near Infrared Spectroscopy

When light comes in contact with a biological material, the photons of light can interact with the material at the molecular level. Light is characterized by its wavelength, with visible light having wavelengths in the 400 nanometer (nm) to 700 nm region and the near infrared (NIR) region having wavelengths between 700 nm and 2500nm. The wavelength of light is inversely related to its energy level with visible light having more energy than near infrared light. Molecules have discrete energy states and light can cause a molecule to change from one energy state to another if the energy in the photon matches the energy required to elevate the molecule from one energy state to another. Thus when light comes in contact with a molecule, it can either be absorbed (because the energy level of the light matches the energy level required to excite the molecule to a higher energy state) or reflected from or transmitted through the molecule. The wavelength of the light absorbed by the molecule indicates the type of molecule (e.g. water, sugar, starch, fat, pigment, etc.) due to the unique relationship between the energy of the light and the energy states of the molecule.

Several types of optical instruments have been developed for nondestructive measurement of the internal composition of fruits. For small translucent fruits, like grape or mandarin orange, it is possible to use whole fruit light transmission techniques to make nondestructive optical measurements. However, for most fruit, like mango, the size and optical density of the fruit make whole fruit transmission measurements impractical and interactance or reflectance measurement methods are used. Interactance is a nondestructive optical technique that allows light absorbance measurements to be made through a portion of the flesh, typically at depths of about 1 cm, depending upon skin thickness. In the laboratory, interactance measurements are typically made using a fiber optic probe that is pressed against the fruit, figure 1. In thin-skinned fruits, it may be possible to use reflectance techniques to make nondestructive optical absorbance measurements of the flesh. Reflectance methods have the advantage of being non-contact. However, reflectance measurements are typically much shallower than interactance measurements, and require that the



chemical composition of the flesh just below the skin be well correlated to the chemical composition of the whole fruit.

Figure 1. Interactance probe used to make nondestructive optical absorbance measurements of fruit.

Slaughter and Abbott (2004) have conducted a review of more than one hundred research studies on the use of visible and near infrared light for nondestructive measurements of internal quality in fruits and vegetables.

3.1.3.2.1 Monitoring fruit quality during ripening

A number of researchers (e.g., Guthrie and Walsh, 1997; Schmilovitch et al., 2000; Mahayothee et al., 2004; Sivakumar et al., 2006) have studied the use of nondestructive NIR reflectance measurement methods for the determination of internal quality of mango during ripening. Several NIR calibrations for mango soluble solids content have been developed with coefficients of determination ranging from $r^2 = 0.59$ to 0.93. A few studies have attempted to use NIR methods to predict titratable acidity ($r^2 = 0.60$ to 0.75), firmness (r^2=0.62 to 0.85) or dry matter content ($r^2 = 0.66$ to 0.96). Calibrations for soluble solids and dry matter content are based upon known NIR absorbance bands for sugar, starch and water, while the calibrations for titratable acidity and firmness are typically due to indirect correlations with other constituents that have absorbance bands in the NIR region. Mango cultivars studied have included ‘Chok Anan’, ‘Kensington Pride’, ‘Nam Dakmai’ and ‘Tommy Atkins’.

A few studies have investigated the use of NIR interactance methods for nondestructive measurements of internal quality in mango during ripening using laboratory instruments. Saranwong et al. (2001) developed a NIR calibration model for dry matter content with a coefficient of determination of $r^2 = 0.94$. Delwiche et al. (2008) developed NIR calibration models for SSC and sugar content in ‘Ataulfo’ mangoes with coefficients of determination of $r^2 = 0.8$ for SSC and $r^2 = 0.7$ to 0.8 for specific sugars.

Walsh et al. (2004) developed a NIR calibration model ($r^2 = 0.79$) for dry matter in mangoes using an instrument that was commercially available for on-line use in fruit packing lines. Saranwong et al. (2003a, 2003b) used a transportable NIR instrument to predict the SSC and dry matter contents in ripening ‘Caraboa’, ‘Nam Dork Mai’ and ‘Mahajanaka’ mangoes. They found that acceptable performance was possible if the fruit were placed inside a light-tight silver bag to prevent sunlight from interfering with the measurement and if fruit with a range of flesh temperatures were included in the calibration process.

3.1.3.2.2 Monitoring fruit quality during maturation

Two recent studies have used nondestructive NIR interactance measurements on a range of mangoes harvested at immature and mature stages. In the first study, Saranwong et al. (2004, 2005) developed two NIR calibration models, one for starch content ($r^2 = 0.86$) and another for dry matter content ($r^2 = 0.92$) of ‘Mahajanaka’ mangoes when scanned at harvest. They then developed a linear model using the predicted starch and dry matter values at harvest to predict the soluble solids content of the fruit when ripe ($r^2 = 0.85$). In the second study, Subedi et al.

(2007) developed an NIR calibration model where 'Kensington Pride' and 'Calypso' mangoes were scanned at harvest, and the harvest NIR spectra were used to predict the SSC of the fruit when ripe ($r^2 = 0.90$). They observed that a NIR calibration for dry matter content developed on one mango cultivar was not suitable for use on a different cultivar. They also found that flesh color (using Hunter b value) was a better index of 'Kensington Pride' mango maturity than dry matter content.

3.1.4 Firmness

Fruit firmness is an important measurement of maturity and ripeness in many fruits. Firmness measurement has been based primarily on a destructive test like Magness-Taylor penetrometry for more than eighty years (Magness and Taylor, 1925). Several methods of nondestructive firmness measurement have been developed, and commercial on-line systems for automated firmness sorting are available (e.g., Aweta, 2008; Greefa, 2008; Sinclair, 2008). Current on-line firmness measurements are based upon either the acceleration response (Chen et al., 1985) or the acoustic signal (Cooke, 1972) issued as a result of a low energy elastic impact. García-Ramos et al. (2005) published a review paper that describes the existing nondestructive techniques for measuring fruit firmness with bench top and on-line systems.

A number of researchers have evaluated nondestructive methods of determining firmness in mango. While none of the published studies have evaluated bench top or on-line systems that are currently being manufactured, they are based upon similar principles and provide some insight to their potential performance. Jarimopas and Kitthawee (2007) compared the acceleration response of a nondestructive low energy impact for 'Nam Dokmai' and 'Chok Anan' mangoes to a standard destructive compression test on fruit harvested over a 40 day period beginning 75 days after fruit set when the fruit are still immature. The average impact firmness score (of 20 fruit batches) was well correlated (r^2=0.94) with the average firmness score from the compression test. The fruit remained firm from immature through mature-green stages and then began to soften as the fruit ripened. Al-Haq and Sugiyama (2004) compared a nondestructive sound velocity measurement of 'Irwin' mangoes to a standard destructive compression test during ripening and observed that the measurements were well correlated (r^2=0.86). Hahn (2004) used the maximum acceleration upon impact from a 10 cm drop of 'Kent' mangoes from one conveyor to another as a nondestructive method of sorting the fruit during ripening. Using this custom prototype on-line system, Hahn was able to sort mangoes into hard, soft, and very soft categories with an average accuracy of 90%. Santulli et al. (2006) used scanning laser Doppler vibrometry to measure fruit firmness during ripening of 'Rosa' mangoes. They observed that the resonant frequency of the fruit decreased (as expected) with ripening. Mizrach et al. (1997) developed a method to measure the ultrasound acoustic wave attenuation in mango as a nondestructive means of determining firmness. In a study of 'Tommy Atkins' mangoes during ripening they found that the average ultrasound signal for batches of 10 fruit were correlated (r2 = 0.94) with the average traditional destructive penetrometer firmness measurement. Changes in average firmness were also correlated with changes in acidity and SSC of the fruit during ripening.

4 Future Needs

4.1 Development of objective methods for determining mango maturity

4.1.1 Develop and evaluate an objective mango flesh color standard for maturity using a colorimeter

There is currently no standard objective method for determining maturity for the five major mango cultivars marketed in the US (‘Ataulfo’, ‘Haden’, ‘Kent’, ‘Keitt’, and ‘Tommy Atkins’). The first step in developing an objective standard for maturity determination should be the identification of a method that accurately measures maturity of the five major cultivars marketed in the USA. In the short term, the most promising method for such a standard is measuring the color of mango flesh using a colorimeter. Using a colorimeter to measure flesh color is destructive. However, this technique has several advantages. It is rapid, it uses handheld instruments (colorimeters) that are commercially available, it shows the most consistent performance across cultivars, and it is suitable for use in the orchard.

A research study should be conducted to develop and evaluate a flesh color standard, using a handheld colorimeter, for maturity determination of the five major mango cultivars marketed in the USA. Since the yellow color begins to appear in the center of the fruit and proceeds outward, it is essential that this study identify the best location and depth for flesh color measurements and that a standard be developed so that this location is used consistently in subsequent evaluations. This study should evaluate the potential of this method over multiple seasons using fruit grown in multiple locations in order to assess the influence of these factors in the performance of a flesh color standard.

4.1.2 Develop and evaluate a nondestructive method of measuring mango flesh color

To date, flesh color is one of the most consistent objective methods of determining mango maturity across multiple cultivars. Some preliminary work has been conducted demonstrating that a nondestructive method using an indirect measure of the near infrared properties of the fruit can predict flesh color. A research and development effort should be conducted specifically to produce a handheld device for nondestructive determination of mango flesh color in the orchard using a direct measure of visible light. The feasibility of a direct nondestructive measurement of flesh color in canning peaches has been demonstrated. A direct measurement of flesh color would be more likely to give consistent performance from year to year and cultivar to cultivar (instrument traits of considerable value to the mango industry) than an indirect measurement..

4.1.3 Develop and evaluate a nondestructive NIR method for determining mango maturity

Of the current nondestructive methods for fruit quality measurements, near infrared (NIR) spectroscopy has received the greatest amount of scientific study. On-line systems using NIR technology are commercially available. Two studies have demonstrated the feasibility of determining the starch and dry matter content of immature and mature mangoes using nondestructive NIR methods. These studies have shown that NIR measurements at harvest can be used to predict the soluble solids content of the fruit when ripe. While a number of prototype handheld NIR instruments for field use have been evaluated by researchers, we are not aware that any are commercially available at this time. Research on NIR methods should be conducted to:

a) Confirm that the nondestructive NIR method can distinguish immature from mature fruit for the five major mango cultivars marketed in the US.
b) Determine how cultivar, growing location, season and fruit temperature affect the NIR calibration.
c) Develop a handheld NIR instrument for orchard use.

4.1.4 Evaluate a nondestructive electronic nose method for determining mango maturity

A limited laboratory study of a bench top electronic nose (enose) demonstrated the potential for distinguishing between the headspace volatiles of different sizes of green mangoes. Additional research is needed to:

a) Conduct a more complete study on the use of a handheld enose for determining mango maturity for all US cultivars.
b) Develop the methodology and evaluate the potential for making an enose measurement of mango in the orchard.
c) Develop a method of instrument standardization to allow a reliable and user-friendly method of field calibration of a handheld enose for mango maturity measurements.

5 Conclusions

As Kader (2008) observed, only a limited number of studies have been conducted on mango cultivars that are currently marketed in the USA. While a number of promising technologies exist for objective, nondestructive assessment of mango maturity, including technologies that are suitable for orchard use, their performance on cultivars marketed in the USA requires study. The two methods available today for objective assessment of mango maturity are the colorimeter for destructive flesh color measurements, and the on-line near infrared sorter for nondestructive assessment of mango dry matter (total solids) content. Kader has proposed that flesh color could be used as a maturity standard for most cultivars. Although the colorimeter is a destructive measurement of flesh color, it could be used immediately on a few fruit in an orchard to train the harvesting crew to recognize external factors of fruit size, fruit shape, and skin ground color associated with mature mangoes in each orchard.

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8 Appendix

8.1 List of Manufacturers of on-line fruit sorting equipment

The information listed below was obtained from the manufacturers' web sites accessed on January 2009.

Aweta BV, Nootdorp, The Netherlands
http://www.aweta.nl/index.html
Nondestructive sorting technologies: blemishes, color (skin), firmness (acoustic and impact), internal sugar content (Brix, by NIR), shape, size, and weight.

Compac Sorting Equipment Limited, Auckland, New Zealand
http://www.compacsort.com/
Nondestructive sorting technologies: blemishes, color (skin), density, internal taste (NIR), shape, size, volume, and weight,

Durand-Wayland, Inc., LaGrange GA, USA
http://www.durand-wayland.com/packing/index.html
Nondestructive sorting technologies: blemishes, color (skin), density, volume, and weight.

Greefa, CA Geldermalsen The Netherlands
http://www.greefa.nl/
Nondestructive sorting technologies: blemishes, color (skin), firmness, internal sugar content (Brix, by NIR), size, and weight.

MAF Roda Group, Montauban, France
http://www.maf-roda.com/
Nondestructive sorting technologies: blemishes, color (skin), density, firmness, internal sugar content, dry mater content and oil percentage by NIR, shape, size and weight.

Sinclair Systems International, LLC., Fresno, CA, USA.
http://www.sinclair-intl.com/pages/produce_pages/pear.html
Nondestructive sorting technologies: firmness.