Applying Non-destructive Sensors to Improve Fresh Fruit Consumer Satisfaction and Increase Consumption

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Abstract

Fruits are an important component of our diet and fruit consumption is associated with reduced and/or delayed onset of major diseases including Alzheimer's, cancer, and obesity. Despite the benefits for human health, fruit consumption is not increasing and in some cases, is even decreasing. We propose to increase fresh fruit consumption by determining an ideal picking date, use of ripening programs, and developmental stage and then enforcing a minimum quality index (MQI) based on flavor quality attributes to assure an acceptable flavor experience to consumers. Because of recent advances in new, nondestructive sensor technologies, there is high interest in using nondestructive sensors (either in a handheld portable unit and/or inline) to segregate fruit according to potential consumer acceptance. The use of nondestructive sensors to segregate fruit based on parameters such as firmness and pigmentation as an index of maturation and ripening is reviewed here. Using sensory techniques (trained panels and in-store consumer tests), MQIs based on ripe soluble solids concentration (RSSC) for cherries, plums, nectarines, and peaches and based on dry matter (DM) for kiwifruit and mangos are being proposed. An accurate determination of picking date will reduce losses and assure that a large fraction of the crop is in the acceptable category. In some cases, segregation into groups with specific flavor quality attributes could warrant a premium that would justify the extra cost of using any new nondestructive sensor technology, but their performance should be tested under commercial conditions before marketing.

This article seeks to explain postharvest physiology concepts and explore potential applications for nondestructive sensors in postharvest commercial operations.

What is Physiological Maturity?

In postharvest physiology, physiological maturity can be defined as "that stage at which a commodity has reached a sufficient stage of development that after harvesting (detached) and postharvest handling, its will ripen by itself to a degree that is at least minimally acceptable to the ultimate consumer." Maturation is the stage of development leading up to the attainment of physiological or horticultural maturity; it occurs between final fruit growth and the end point of maturation indicated by the beginning of ripening and senescence (Wataba, et, al. 1984). An immature fruit may ripen off the tree, perhaps with exogenous ethylene exposure, but it will be of poor quality. A mature fruit will attain good quality when ripened off the tree. Mangos, kiwifruit, nectarines, peaches and plums are usually harvested firm-mature and undergo substantial physical and chemical changes throughout ripening which lead to a ripe fruit.

What is Horticultural Maturity?

Horticultural maturity is the stage of development when a plant or plant part (fruit) acquire the prerequisites to be used by the consumer for a particular purpose (Reid, 2002). A given commodity can be horticulturally mature at any stage of development. For examples, sprouts or seedlings are horticulturally mature at an early stage of development, while most vegetable tissues, flowers, fruits, and underground storage organs become horticulturally mature in the mid stage and seeds and nuts at a late stage of development (Kader, 1999). In olives, Spanish-style pickled green olives are harvested immature (before physiological maturity). California-style black-ripe olives are harvested at physiological maturity, when the skin color changes from green to pale or straw color. As olives become darker and red skin coloration penetrates the flesh, the fruit become undesirable for processing as California-style black-ripe olives. Olives are harvested beyond physiological maturity for processing as Greek-style olives and/or olive oil.

Why do we Need Maturity Indices?

The definition of maturity as the stage of development giving minimum market life and /or acceptable quality to the ultimate consumer implies measurable points in the commodity's development and a need for techniques to measure maturity. The maturity index for a commodity is a measurement or measurements that can be used to determine whether a particular commodity is horticulturally mature. These indices are important for trade regulation, marketing strategy and the efficient use of labor and resources.

What are the Characteristics of the Maturity Index?

For maturity measurements to be carried out by growers, handlers, and quality control personnel, they must be simple, reliable, readily performed in the field or at an inspection point, and should require relatively inexpensive equipment. The index should preferably be objective (a measurement) rather than subjective (an evaluation) and ideally the index should be nondestructive. The maturity index must consistently meet two requirements for all growers, districts, and years: it should ensure first, a minimum acceptable eating quality and second, some storage life.

How do We Determine a Maturity Index?

Determining a maturity index involves determining consistent physical and chemical changes: conducting monitoring studies throughout the commodity’s development and finding measures that correlate strongly with maturity and postharvest performance. During the rapid increase in size as the fruit nears maturity, changes in skin and flesh color, flesh softening, and flavor changes are particularly obvious. Some of the most-studied characteristics are:

1. Size and shape. Attainment of a specific size is one possible index of maturity, but it cannot be used alone since fruit size for any variety can be influenced by crop load, climatic conditions, and cultural practices. Fruit shape and/or fullness of cheeks can indicate maturity. When fruit shoulders and the suture are well developed, and filled out, stone fruits and mangos are considered mature.

2. Flesh firmness. Flesh firmness decreases during maturation and ripening on and off the tree. In general, peaches of 10 to 12 lbs firmness (8 mm tip) measured at the cheeks at picking will ripen after harvest and attain better quality than those of 14 to 18 lbs firmness. Typical firmness measurements at minimum maturity time are 9-10, 11-12 or 13-14 lbs. Available data, however, indicates that flesh firmness alone is not a satisfactory minimum maturity index, because flesh firmness among varieties and for a given variety varies with fruit size, climatic conditions, and cultural practices. In California and Chile, it is suggested that flesh firmness can be used as a maximum maturity index to determine how late fruits can be harvested while still tolerating physical abuse and ensuring satisfactory quality after transport, shipping, and marketing.

3. Soluble Solids Concentration. SSC increases with maturity and the use of SSC as a maturity index alone is limited by variation among varieties, production areas and seasons. It is important to emphasize that SSC is an indirect measure of soluble sugars. For example, when dark-colored plum varieties were introduced to the industry by the University of California in 1960, SSC was recommended as a satisfactory maturity index. It was used briefly by the Plum Committee for "Laroda", "Queen Ann" and "Nubiana". However, there were soon many complaints about individual growers not being able to meet the minimum maturity index and this maturity index was dropped.

4. Titratable acidity. Stone fruits lose acidity (TA) during maturation and ripening. This maturity feature is also affected by cultivar and seasonal variability and measuring it is more complicated than measuring SSC. The ratio of SSC: TA is more closely related to consumer quality than TA or SSC alone, but it still varies among years.

5. Color. Fruit color is determined by the various pigments present in the skin and flesh tissue. As fruit matures and ripens, color changes from green to red or yellow. Since development of red color in nectarines and peaches depends on exposure to light, the fruit's position on the tree influences its degree of red coloration. Changes in ground color (background) or flesh color are not affected by sunlight and are therefore more dependable indices of maturity. In California, extensive studies of changes in the ground color of peaches and nectarines led to the development of color chips to determine maturity. The influence of ground color as a maturity index on postharvest quality has been widely studied on clingstone peach cultivars and fresh peaches and nectarines. Researchers have demonstrated that more mature fruit have yellow skin color, flavor, flesh color (less green), softer flesh, higher soluble solids concentration, and lower TA than less mature fruit.

Some of these indicators (maturity indices) are selected using storage trials and sensory evaluation to determine which of them consistently and reliably correlate with the quality of the harvested product for all seasons, cultivars and growing locations. In the California stone fruit industry, the California Tree Fruit Agreement (CTFA), which implemented the federal marketing order, published annual minimum maturity requirements for over 200 peach and nectarine cultivars based on external ground color (that is, the disappearance of green and the formation of yellow color). For plums, overall skin color was widely used to determine maturity. CTFA used to publish annually the minimum maturity requirements for over 100 plum cultivars on the basis of surface color and firmness. Color charts were designed and were available from CTFA. In the orchard, the grower is responsible for deciding whether or not the crop has reached the proper minimum maturity for harvest. Recently in California, a series of new varieties in which high red coloration masks the ground color are limiting the use of ground color as a minimum maturity index. For these cases, nondestructive flesh color sensors could be used as a minimum maturity index tool to insure optimal fruit quality as was recommended and implemented for clingstone peaches (McGlone and Kawano., 1998).

During the last two decades, extensive information covering fruit maturity, ripening, development of maturity indices, storage trials and taste panels for peaches, plums and nectarines has been reported. Studies focusing on understanding maturity indices and the ripening process of new full red color peach and nectarine cultivars and full black color plum cultivars are required. Nondestructive determinations of SSC, dry weight, flesh color, sugar and acid content using near-infrared light (NIR), magnetic resonance (MR), and light transmittance (LT) techniques are being investigated and validated and could become available in the near future. Thus, traditional destructive fruit measurements could be replaced with nondestructive measurements.

Fruit Quality to Consumer Quality

Fruit quality is a concept encompassing sensory properties (appearance, texture, taste and aroma), nutritive value, mechanical properties, safety and defects. Together, these attributes give the fruit a degree of excellence and an economic value. Everyone in the fruit production and marketing chain, from the grower to the consumer, looks for fruit with no or few defects. However, at each step of this chain, the term ‘quality’ takes on different meanings and the economic relevance of the various quality traits is largely variable. For example, the grower is interested in high yield, in fruit with large size and high disease resistance, and in the opportunity to reduce the number of pickings. The definition of ‘quality’ for packers, shippers, distributors and wholesalers is mainly based on flesh firmness, which is considered a good indication of potential fruit storage and market life. In general, fruit ripen and deteriorate quickly at ambient temperature and cold storage is required to slow these processes, especially for some cultivars and/or long-distance market situations. For retailers, red color, size and firmness have historically represented the main components of fruit quality, as they need fruit that are attractive to the consumers, resistant to handling and have a long shelf life. From the consumer’s point of view, in general peach fruit quality has declined, mainly because of premature harvesting, chilling injury and lack of ripening prior to consumption, resulting in consumer dissatisfaction. In addition, quality is badly defined as the only parameters being considered are fruit size and skin color. Other characters such as flesh firmness, sugar content, acidity and aroma, which are perceived by the consumer as fruit quality, are completely disregarded by the grower and other individuals along the chain. In fact, the grower, equating fruit quality almost exclusively with the fruit size, does not consider that these are only the first characters perceived by the consumer and they inform only the very first choice. As soon as consumers realize that the fruit, even with good size and attractive color, is flavorless, with low sugar content, poor aroma and rapidly perishable, they redirect their interest toward other types of fruit (Crisosto and Costa, 2008). As a consequence, it is imperative for the grower and other individuals in the delivery chain to direct their attention to fruit quality from the consumer's perspective to regain consumer confidence (consumer quality). During the last decade, several sensory studies, including in-store consumer tests, have been carried out on different commodities to understand consumer preferences/acceptance and to select candidates for quality indices (Crisosto and Crisosto, 2001 and 2005; Crisosto et. al; 2003 and 2012; Delgado et al., 2013). Recently, there is an increasing appreciation that the consumer quality of fruit also includes nutritional properties (e.g. vitamins, minerals, dietary fiber) and health benefits (e.g. antioxidants) and that these are becoming important factors in consumer preferences. Experimental, epidemiological and clinical studies provide evidence that diet has an important role in preventing chronic degenerative diseases such as tumors, cardiovascular diseases and atherosclerosis (Vicente et al., 2011). The consumption of fresh fruit and vegetables exerts a protective role against the development of such pathologies.

What is Ripening?

Ripening is the set of processes that occur from the later stages of growth through the early stages of senescence and that result in characteristic aesthetic and/or eating quality, as evidenced by changes in composition, color, texture, or other sensory flavor attributes. Ripening, occurring either on or off the tree, involves changes that transform the mature fruit into one ready to eat. Changes associated with ripening include loss of green color and development of yellow, red or other color characteristics of the variety. As a fruit ripens, it softens, its acidity declines and it produces certain volatile compounds that give it its characteristic aroma. Increased respiration and ethylene production rates are among the physiological changes associated with ripening. Once the fruit ripens, senescence begins: physical and chemical changes continuing after optimum ripeness is reached including further softening, loss of desirable flavor and complete breakdown. Our sensory work on cherry, kiwifruit, tree fruit, mangos, grapes, figs, and blueberries demonstrated the benefits of ripening, on or off the tree, on consumer acceptance of fresh fruit; in most instances, consumer acceptance doubled or tripled as a consequence of ripening.

Application of Non-destructive Sensors

1. Firmness and Fruit Damage. Mechanical pitting can cause damage over a range of nondestructive and destructive firmness measurements in 'Andross', 'Carson', and 'Ross' clingstone peaches (Crisosto et al, 2007). During two years, the percentage of 'Andross', 'Carson', and 'Ross' fruit with pitting damage increased sharply as nondestructive firmness sensor Sinclair firmness index values fell below 7.0 (SFI) and when destructive penetrometer readings fell below 17 (SFI). Even though there was a low correlation between nondestructive and destructive firmness measurements, nondestructive measurements were closely related to the pitting damage. These preliminary results encourage further research to improve the relationship because an automatic nondestructive system could give processors the option to segregate out peaches susceptible to pitting prior to processing (Valero et al., 2006) Such information measured at the receiving area is useful for subjective grading and/or predicting potential pitting problems during processing.

2. Ripening Changes and Non-destructive Sensors. Peach firmness and flesh color changes are reliable ways to monitor fruit softening and can be used to predict bruising damage and transfer points during ripening (Slaughter, et. al, 2006). Ripening protocols traditionally used a destructive penetrometer fruit firmness measure to monitor ripening. Until recently, nondestructive methods to assess fruit texture properties were not commercially available. In 2006, we used the nondestructive Sinclair iQTM firmness tester to monitor ripening and predict bruising susceptibility in stone fruit. This work was carried out on four peach, three plum, and five nectarine cultivars over two seasons. The correlations between destructive and nondestructive firmness measurements were significant ($p = 0.0001$), although too low for commercial applications as they varied from $R^2 = 0.60$ to 0.71 according to fruit type. Using a different approach, the relationship between destructive and nondestructive firmness measures was characterized as a method of segregating fruit according to ripening stage. This was done using discriminant analysis and 66 to 90% agreement in ripeness stage classification was observed in validation tests. Discriminant analysis consistently segregated fruit measured by nondestructive methods into commercially important classes ("ready to eat", "ready to buy", "mature and immature"). These classes represented key physiological ripening stages with different bruising potentials and consumer acceptance. This earlier work pointed out the importance of relating nondestructive measurements directly to important commercial physiological stages rather than correlating them with current standard penetrometer values (Valero et al, 2006).

Recent work on several mango, peach, and nectarine cultivars nondestructively monitored flesh color changes that correlated very well with softening during ripening for fruit on or off the tree. We demonstrated the ability to measure flesh color nondestructively on mangos and tree fruit prior to and after harvesting. As flesh color is the best indicator of mango physiological maturity, using a near-infrared (NIR) nondestructive technology, the DA-meter (Turoni, SRL, Forli, Italy), allowed us to reduce the maturity variability in the fruit population that interferes with understanding the role of maturity on postharvest quality. Our work in progress is demonstrating the benefits of using the DA-meter as an assistant nondestructive tool to determine ideal picking date, selecting mature mango fruits at harvest and full red color tree fruit to reduce losses during postharvest life and marketing. We expect that this nondestructive sensor will be used reliably to segregate mangos according to harvest physiological maturity and clarify the role of maturity on mango quality, postharvest life limitations (chilling injury) and storage requirements. In addition to this information, we will be able to describe the dynamics of orchard maturity changes, information that can inform orchard manipulations.

3. SSC, Dry Matter (DM) and Consumer Acceptance. Ripe soluble solid content (RSSC) is generally considered an accurate predictor of consumer acceptance for many commodities. However, kiwifruit and mangos have high starch concentrations before ripening, so SSC is not an accurate and reliable quality index (Brecht and Yahia, 2009; Crisosto et al., 2012; Singh et al, 2013). Reducing sugars like fructose, glucose and sucrose are hydrolyzed by amylase from starch that accumulate during fruit development and are the major contributors to SSC after ripening. DM measures starch, soluble sugars, organic acids, pectins, minerals, etc. and is constant throughout postharvest handling. Furthermore, DM is directly related to both RSSC and the predicted eating quality of ripe mangos. Therefore, DM can be used as a MQI to regulate mango quality as it accurately predicts consumer acceptance. Based on our sensory work using different mango cultivars, we proposed a minimum quality index (MQI) based on DM for mango cultivars. As a follow-up to our sensory work and other studies using nondestructive sensors (Delwiche, et al., 2008; Schmilovitch et al., 2000; Subery et. al, 2013), we have tested on-line and handheld near-infrared (NIR) nondestructive sensors to segregate mangos based on DM. For the handheld sensors, we tested Nirvana and F-750 prototypes (Felix Instruments, Applied Food Science, WA). Our models between NIR F-750 prototype values and DM reached $R^2 = 0.50$ to 0.70, which we considered low for commercial application (Rodriguez-Bermejo, personal communication, October 2014). Currently, Felix Instruments is making technical changes to improve this relationship in their new prototypes. The segregation on-line using the Compac NIR system was more efficient, reaching $R^2 = 0.80$.

We encourage understanding of the traits and further validation of these nondestructive sensors under commercial conditions before marketing.

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