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Principles, methodologies and technologies of fresh fruit quality assurance

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REVIEW PAPER

Abstract

Trending the principles of quality assurance through years is necessary to ensure that the consumers' rights in assessing quality products can always be sustained. This paper is designed to contribute by collecting the principles that have been defined for fruits quality perceptively and scientifically and methodologies and technologies that have been used to determine and quantify the defined principles. Objectively, consumers are purchasing fruit produce based on the quality attributes that have been guaranteed to them. However, the standard set by authorities commonly is based on external attributes of the fruits and not their intrinsic properties. To produce fresh fruits that are widely accepted by consumers, for over 10 years, fruits' growers with the intensive research from various agricultural research department and universities have put forward methods for measuring fruit intrinsic qualities, especially soluble solids content, acidity and firmness, parameters which define flavour and sensory satisfaction.

Keywords: acidity, firmness, fruit, quality assurance, soluble solids content

1. Introduction: issues on quality parameters

Fruits and vegetables have a high importance in world food production and for human nutrition consumption and health benefits (Dris and Jain, 2004; Joffe and Robertson, 2001). The World Health Organization (WHO) recommends a daily intake of more than 400 g of fruits and vegetables per person due to their importance in reducing many diseases (Joffe and Robertson, 2001). Serious diseases such as cardiovascular, diabetes and certain types of cancer can be prevented by consuming a sufficient amount of fruits and vegetables. For example, research conducted in Denmark shows that the intake of appropriate fruits and vegetables will lower the risk of lung cancer for some groups of people (Sorensen *et al.*, 2007).

Fruits are acidic and sugary and are grouped into several major divisions, mainly depending on their botanical structure, chemical composition and climatic requirements. Berries are fruits which are usually small and rather fragile. Grapes are also physically fragile and grow in clusters. Melons, in contrast, are large and have a tough outer rind. Drupes, also known as stone fruit, include apricots, cherries, peaches and plums contain single pits. Pomes are a type of fruit that contain many pips and are represented by apples, quinces and pears. Citrus fruits are high in citric acid like oranges, grapefruits and lemons. Tropical and subtropical fruits include bananas, dates, figs, pineapples and mangoes which require warm climates, but exclude the separate group of citrus fruits (Dauthy, 1995).

During the commercialization of fresh fruits, the quality of the product can deteriorate at certain stages when they are reaching the final market. One of these critical stages is at the point when fruit comes out of the producer facilities and reaches the wholesaler storage chambers. This transition, however, may sometimes include quality-controlled procedures. The fresh produce that arrives at the market may experience very different conditions to those observed at field. This may be due to bad handling during packaging or transporting which will cause impact or bruises on the fruits. The level of fruit ripeness may also change more or less during this period of time (Valero and Ruiz-Altisent, 2000). Woodcock *et al.* (2008) stated that quality changes in food products between production and consumption are due to:

- contamination by dust, dirt, chemicals or weeds;
- mechanical injury during harvesting or processing;
- physico-chemical changes from weather conditions;

- contamination or spoilage by microorganisms, insects or rodents;
- biochemical changes due to enzymatic activity.

Therefore, a quality assessment system is required to ensure that the fruit purchased by consumers possess good quality (Valero and Ruiz-Altisent, 2000).

The issues related to the quality assurance of fruit produce are in agreement with current consumers' needs which are based on trusted grades and quality standards and rejecting products with adulteration. Consumers are also choosing to buy healthy and non-contaminated products. Therefore, the fruit and vegetable industries require more research on the technology required for determining quality. For the fruits industries, determination of internal qualities are important indicators for harvesting, transportation, storage and other handling properties before the product can be distributed into the market. For these reasons, the necessary measurements need to be taken to meet these demands (Lin and Ying, 2009). There are many efforts being made to establish the standard quality parameters for fresh produce and the instrumentation to meet these expectations. For instance, the Physical Properties Laboratory (LPF) directed by Prof. Margarita Ruiz-Altisent has been working on fruit quality assessment on a theoretical and practical basis concerning the quality specifications as well as instrumental measurement of quality in fruits (Dris and Jain, 2004). In the field of nutrient research and the regulatory commercial requirement, indices for internal quality parameters such as soluble solids contents, total acids and firmness are becoming the focus (Reid *et al.*, 2006). Thus, this paper will review the issues on fruit quality specifically related to soluble solids contents, sugar content, acidity, total acids and firmness and technologies that have been applied in measuring them.

2. Fruit quality assurance

The word 'quality' originates from the Latin language which means 'property' or 'characteristic'. In the food industry, the word 'quality' originally was used as a synonym for 'freshness' and 'unspoilt'. The International Organization for Standardization (ISO) defines quality as 'the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs' and quality assurance as 'all those planned and systematic actions necessary to provide adequate confidence that a product, process or service will satisfy quality requirements' (ISO 9000:2005; ISO, 2005). Quality has also been specifically defined as conformance to requirement, the degree of conformance to a standard, fitness for use and as user satisfaction (Crosby, 1979; Juran and Gryna, 1988; Wayne, 1983). Consequently, quality can also be described by the customer requirements and not only by the product property itself (Shewfelt, 2000). The term 'quality' has become one of the most emphasized factors in the field of food and food production in the last two decades. This is due to the importance of quality and quality management systems which are tools for food safe production and economy (Buckenhueskes, 2007). Consumer perception of product quality has changed significantly in the last few years. Competition from the surplus production of horticultural crops has led to changes in the consumers' purchasing behaviour as they demand only the highest quality of products. In addition, this change is also affected by the rising awareness of environmental, nutritional and health concerns among society (Huyskens-Keil and Schreiner, 2004).

Products from the fruit and vegetable industries can be classified into two major groups: they are fresh market or processed, such as canning, freezing, juicing and dried/dehydrating. Sometimes, fruit and vegetables harvested for fresh use do not meet the required quality standards. These fresh fruits are then sold for processing (Lucier *et al.*, 2006). At the present time, quality properties, classification and evaluation of fresh fruits and vegetables are conducted to comply with the criteria of the official quality grades and standards set by the United Nations Economic Commission for Europe (UN ECE) or the United States Department of Agriculture standards which are based on the Codex Alimentarius of the Food and Agriculture Organization of the United Nations (FAO) and WHO (Barreiro *et al.*, 2004; Huyskens-Keil and Schreiner, 2004). These quality standards are used for national and international trade as a measure of the economically important fresh horticultural products. However, the current official product quality standard is based upon subjective assessment which prioritises the visual and external product attributes mainly to satisfy the technological concerns of trade. Consequently, the product properties which reflect the growing consumer requirements relating to environmental, health and sensory benefits, such as chemical composition, are not considered (Huyskens-Keil and Schreiner, 2004). In Malaysia, the standard set by the Federal Agricultural Marketing Authority also emphasizes the external attribute of the fruits, such as size, colour, shape and percentage of visible defects on the fruits (Famaxchange, 2009).

In growing the globalization of the fresh produce market, UN ECE has drawn up standards for fresh fruits and vegetables, E.91.II.E.42, which every product in the market must comply with. The properties of the product that can be standardized are based on the magnitude that can be measured, such as size, shape, presence and size of external damage. Some other properties that can be included are based on the subjective assessment such as colour and its distribution and also on the occurrence of misshapen products. These regulations do not include properties that can not be measured through defined objective procedures. As a result, it is common that fresh produce reaching the markets may not satisfy consumers' quality expectations. For instance, there are many cases where attractive fruits, such as peaches and pears are completely inedible or tasteless. In another example, there has been a practice of 'de-greening' oranges at the beginning of the season through a treatment process that changes the peel into a beautiful orange colour from originally green. Present standards established the minimum colour for mandarins. With this de-greening technique, the fruits are suitable for the market, but the sugar content may be non-existent (Barreiro *et al.*, 2004). This issue was within international concern as early as 1963 when the Codex Alimentarius Commission was created by FAO and WHO with one of their aims being 'to protect the health of consumers and to promote fair trade practices' by protecting the consumers against 'fraudulent practices' (Walsh, 2006). Therefore, growers and distributors are now developing company specifications which, ahead of the legal quality, are summarizing the relevant intrinsic properties that consumer will accept such as sugar contents, acid contents, firmness, aromas (juice content has been established as a comparatively standard measurement) and vitamins (Barreiro *et al.*, 2004).

There are various components of quality that are being used to evaluate fruits and vegetables. Quality can be categorized into an external and internal component as shown in Table 1. Six quality factors which are normally defined for fruits and vegetables are appearance, flavour, texture, nutritive value, defect factors and safety. In supply chains, the quality in fresh fruits and vegetables are classified as market quality, utilization quality, sensory quality, nutritional quality, ecological quality, external and internal quality and shipping quality. Most of these various terminologies are being applied in different ways to classify and describe the quality parameters of a product. However, these usually mean different things to different customer groups. Figure 1 summarizes different quality attributes from different group of customers (Huyskens-Keil and Schreiner, 2004). In summary, the quality specifications of the fruits can be divided into three different categories which are legal quality, consumer quality and company quality (Barreiro *et al.*, 2004).

Barreiro *et al.* (2004) have summarized the most relevant quality attributes for several fruits gathered from a survey in an European project (FAIR CT 95 0302 'Mealiness in fruits') with participation from 818 consumers, 77 producers and 26 warehousemen and from other parallel sources of information. Almost in all cases, the most significant quality attribute was identified from internal property such as firmness or taste. This is however based on the fact that other important quality attributes such as size, shape and cleanness are already met (Barreiro *et al.*, 2004). The summary of the findings from the survey in the European project by Barreiro *et al.* (2004) are shown in Table 2. According to Shewfelt (1999), consumers judge quality based on the appearance at the time of initial purchase and consider good quality of fresh fruits and vegetables to be those that have a good appearance, firm and offer high flavour and nutrition (Shewfelt, 1999). Research has been conducted to identify common consumer complaints about peach purchases. 30% of the complaints were of the little flavour of the fruits, 21% that they were too hard, 5% too soft and 13% on mealiness (Crisosto, 2008).

The European project also discovered that there is emerging prospect for developing instrumentation to measure the properties of fresh product that can be used to define consumers' preferences more precisely. Hence, the market is starting to acknowledge that the properties which the consumers relates to their perception of quality when eating fresh fruits are indeed intrinsic properties of the product itself. This has increased the possibility for analyzing the intrinsic properties of fruits and relevant instrumentation (Barreiro *et al.*, 2004).

Table 1. External and internal quality factors for fruits and vegetables (Noh and Choi, 2006; United Nations, 2007).

External qualities	size	weight, volume, dimension
	shape	diameter, depth ratio
	colour	uniformity, intensity (measurement can be made by visual guides and colorimeters)
	defect	bruise, stab, spot (measurement can be made by mechanical methods, e.g. ultrasound)
Internal qualities	flavour	sweetness, sourness, bitterness, saltiness, astringency, aromas (mostly qualitative and subjective evaluation through smelling or can be measured by technical method such as gas chromatography) and taste compounds (which can be technically quantified through chromatography)
	texture	firmness, crispness, juiciness, tenderness, crunchiness, chewiness, fibrousness (which are measured by applying force to the produce) and textural characteristics (which are evaluated as 'mouth feel')
	nutrition	fat, carbohydrate, proteins, vitamins, minerals functional property and other substances that influence human well-being
	defect	internal cavity, water core, frost damage, rotten
	safety	can be determined through the examination on fruits items based on their pathogenic microbial load, content of chemical contaminants or presence of physical foreign matter in the fresh produce

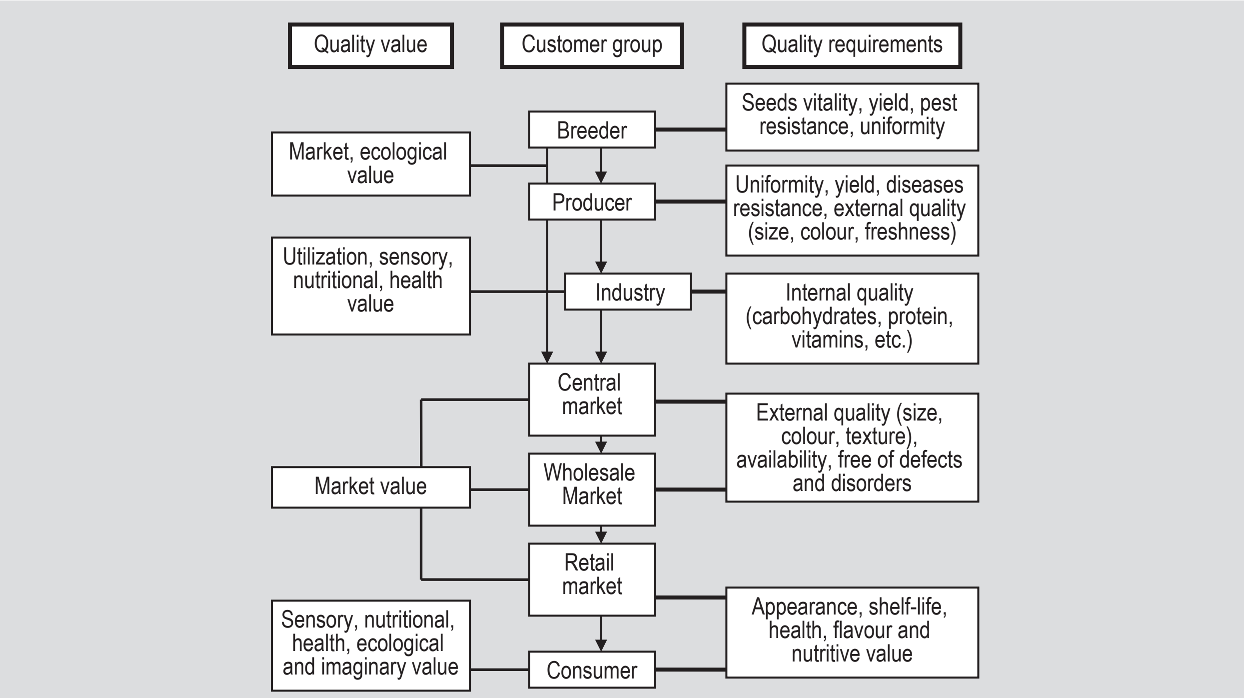

Figure 1. Quality values defined by factors in the supply chain (customer groups) and their requirements (Huyskens-Keil and Schreiner, 2004).

Table 2. Summary of most relevant quality attributes for several fruits gathered (Barreiro *et al.*, 2004).

Fruits	Most desirable quality attribute	Second	Third
Apple	firmness/texture	bruises	sugar and acidity
Apricot	firmness	sugar	colour
Citrus	rots-moulds	blemishes or bruises	sugar and acidity
Melon	sugar	colour	-
Peach	firmness	sugar and acidity	bruises
Pear	firmness	sugar and acidity	bruises
Tomato	colour	firmness	sugar and acidity

3. Fruits maturity and ripeness

Maturity at harvest is the most important factor that determines fruit quality for the consumer and the shelf-life of the fruits (Lamp, 1997). Maturity is the character of the fruits on the tree when it grows to its intended size and shape. Ripeness is the subsequent process which happens to fruits within a week or so after they mature (Wischik, 2008) and it results in developing changes in composite colour, texture or other sensory attributes (Kader, 1999). The fruits ripen by producing the following indicators (Wischik, 2008):

- Aroma: a bitter and astringent phenol (which initially was to discourage animals before the seed was ready) will fade away and nice aromas will be produced (which will then be used to encourage animals) (Wischik, 2008).
- Sweetness: fruit sweetness is in the form of sucrose or fructose (Wischik, 2008). The ripening of the fruits is associated with changes in the composition of carbohydrates. In some fruits such as apple, pear and banana, starch accumulates during ripening but later disappears while sucrose increases in amount. For fruits without reserve starch, such as plum, peach and citrus, ripening is characterized by a decrease in acid content and an increase in sugars. In the ripening avocado, the sugar content decreases and fat content increases (Esau, 1972). Sugars and acidity are two key elements which determine the flavour of fruit. Fruit contains natural acids, such as citric acid in citrus fruits, malic acid in stone fruits, tartaric acid in grapes (Dauthy, 1995; Garner *et al.*, 2008) and ascorbic acid (source of vitamin C) in citrus fruits, tomatoes, cabbage and green

peppers. These acids will give the fruits tartness which will help in slowing down bacterial spoilage. The sugar/acid ratio is very frequently used as an indicator to give a technological characterization of fruits and of some vegetables (Dauthy, 1995). Fruit ripens from the inside out and during this maturation process there is a gradient in properties such as sugar content. Even mature fruit has natural variations in properties such as sugar and acid content from one side to another. One example of the high variation of sugar content within an apple is a blush Golden Delicious. Although the localized and near-surface region of the blush can be 3% to 5% higher in °Brix, the overall contribution to the whole apple °Brix average is usually relatively small (Ozanich, 2001). From the context of a citrus fruits, it is known that sugar and acid content vary as a function of storage time and temperature. Miller and Zude (2002) reported more pronounced changes at higher temperatures and a more significant change in sucrose than glucose and fructose. Citric acid declined over 4 to 9 weeks storage time.

- Juiciness and softness: an immature fleshy fruit wall initially has a firm texture, but it becomes softer as the fruit starts to ripen. Chemical changes in the cell contents and in the structure of the walls are responsible for the softening (Esau, 1972). The enzyme polygalacturonase attacks pectin in the cell walls making cells slide around (softness) and they may even become dissociated from each other (Esau, 1972; Wischik, 2008) and spill their contents (juiciness). Acids are used up during this process, thus, making the fruit less sour (Wischik, 2008).
- Colour: the pigments and colour of fruit and vegetables are in most parts associated with the cellular plastic enclosure, such as the chloroplasts and other chromoplasts, and to a minor degree they are dissolved in fat droplets or water within the cell protoplast and vacuoles (Dauthy, 1995). Immature fruits have numbers of chloroplasts in the outermost cells which are green in colour. The development of carotenoid pigments which are fat-soluble and the disappearance of chlorophyll produces a change to a yellow, orange or red colour, as observed in tomato (Dauthy, 1995; Esau, 1972). Ripening fruit may generate anthocyanins which will give the tissue a red, purple or blue colour (Esau, 1972). One of the properties of the anthocyanins is to transform colours with pH. Hence, many of the anthocyanins which are either purple or blue in alkaline media become red upon the addition of acid. Many plant pigments are natural pH indicators since organic acids influence the colour of foods (Dauthy, 1995). These pigments maybe spread to the entire fruit wall as in some cherries. However, they may also be limited to peripheral parts of the fruit wall as in the plum or Concord grape. The outer epidermis of fruit usually accumulates tannins (Esau, 1972).

Apart from the above listed properties of ripen fruits, vegetal cells contain an important amount of water which plays a significant role in the evolution, reproduction cycle and in physiological processes. Fruit water content affects the storage period and the consumption of tissue reserve substances. Useful storage life for fruits is from one to seven days while for leafy vegetables, it is within one or two days (Desrosier and Desrosier, 1977). The typical water content of fruits is between 80 and 90% while vegetables contain generally 90-96% water (Dauthy, 1995).

Immature fruits have a higher tendency to shrivel and are of lower quality then when ripe. Overripe fruits, on the other hand, are likely to become soft and mealy soon after harvest. Fruits picked at the proper time are more likely to have a longer storage-life than those picked either too early or too late in the season. Fruits, with a few exceptions such as pears, avocados and bananas, will arrive at their best eating quality when allowed to ripen on the tree or plant (Lamp, 1997). Some fruits are picked while they are mature but unripe (Dauthy, 1995; Lamp, 1997). This is very important especially for soft fruits like cherries and peaches which will become very soft when fully ripe and can easily get damaged by the act of picking itself. Furthermore, this is also important since many types of fruits continue to ripen off the tree and some may become overripe before they could be utilized if picked at peak ripeness (Dauthy, 1995). Besides, this will help the fruits withstand the postharvest handling when transported over long distances. Most fruits are picked at a time between their best eating quality for the consumer and that which can provide the required flexibility for marketing purposes.

Fruits can be divided into two groups. The first type are the fruits that stop ripening once removed from the plant and second are the fruits that can be harvested mature and continue to ripen off the plant (Lamp, 1997). The examples of fruits which belong to each group are:

- Group 1: berries (such as blackberry, raspberry, strawberry), cherry, citrus fruits (grapefruit, lemon, line, orange, mandarin and tangerine), grape, lychee, pineapple, pomegranate, tamarillo.
- Group 2: apple, pear, quince, persimmon, apricot, nectarine, peach, plum, kiwifruit, avocado, banana, mango, papaya, cherimoya, sapote, quava, passion fruit.

As fruits ripen, they will produce ethylene (C_2H_4) which is the 'ripening hormone' that coordinates the ripening process (Wischik, 2008). Fruits in the first group generate very small amounts of ethylene and do not further react when exposed to ethylene. These types of fruits should be picked when fully ripe to guarantee good flavour. On the other hand, fruits in group 2 produce higher quantities of ethylene as they ripen. Further exposure to ethylene will result in faster and more uniform ripening (Lamp, 1997). Table 3 lists the optimum stages of maturity for several common fruits. The suitable maturity stage will rely on the chosen market and different cultivars may have different harvest maturities.

Table 3. Harvest maturity indicators for several common fruits (Gast, 1994; Kader, 1999).

Fruits	Indicators
Apple	Industry standards for soluble solids are at least 12%
	Ground colour change to a yellowish cast
	Iodine-starch test 60% of the area blue-black in colour
	Firmness should be less than 88.95 N and more than 53.35 N
Apricot	Colour of external surface area is ¾ or larger yellowish green or less than ½ yellow
Blueberries	Fruit should be blue in colour without any green
	Soluble solids of 10 to 15%
	pH 3.43 to 3.73
Cherries	Sweet cherry should have the characteristic skin colour for the variety, which can range from yellow to black red
	Sour cherries should be bright red
	Soluble solids should be at least 14 to 16% depending on cultivar
Grapes	Wine and juice markets require grapes with specific soluble solids and acid content
	Fresh market grapes will depend on the flavour and aroma. Grapes will often colour up before they are ripe, so soluble solids and the colour change of the stems from green to brown may be a better indicator
	Soluble solids of 14 to 17.5% depending on cultivar and production area or soluble solids to acidity ratio of 20 or higher
Grapefruit	Soluble solids to acidity ratio of 5.5 to 6.0 in desert area and 2/3 of fruit surface is yellow in colour
Kiwifruit	Soluble solids of 6.5%
Lemon	30% of juice by volume
Nectarine and peach	Surface ground colour change from green to yellow and the shape is in fullness of shoulders and suture
Pears	Soluble solids are not usually used but should be at least 13% for marketability
	Pear firmness should be 102.28 N, but can be less if the soluble solids are less than 13%
	Ground colour changes from a green to yellowish green
	Iodine-starch test 60% or less of the area blue-black in colour
Plums	Each variety has its own characteristic colour change, familiarity with standards for planted varieties is important
	Soluble solids should be at least 17% and pressure testing may be useful
Pomegranate	Red juice colour and below 1.85% of acid content in juice
Strawberry	More than 2/3 of fruit surface is showing pink or red colour
Tangerine	Soluble solids to acidity ratio of 6.5 and yellow, orange or red colour on 75% of the fruit surface

4. Fruits quality measurement system

In the fruits industry, quality measurement is an area that technology and market sections share mutual share concerns (Lin and Ying, 2009). Until now, many efforts have been made to produce instruments that are able to quantify fruit quality. A variety of instruments has been introduced but more designs are being made for instruments that are non-destructive, portable, low cost, fast and easy operation with high precision and reproducibility (Barreiro, 2004). Agro-Technologie (Forges Les Eaux, France) for instance, has manufactured a variety of instruments to measure the quality of fruits and vegetables and also to interpret the behaviour of plants for better control of growth and irrigation techniques (Agro-Technologie, 2008). In addition to the current existence of commercial and most accepted technology and techniques for measuring fruit quality, researchers continually develop new ideas on a par with the current technologies. For instance, Barreiro *et al.* (2004) have listed the common instruments and the unit of measurements for varieties of fruits parameters as shown in Table 4. Most of the parameters measured by these instruments are referring to the measurement of fruit intrinsic quality. Typical parameters that are often associated with the intrinsic quality and maturity of fruits are soluble solids content, acidity and firmness. Therefore, further elaboration will focus more on these parameters and instruments that are associated with it.

Measurement of soluble solids content

The soluble solids content of juice is commonly measured by refractometers through the refraction of light passing through a solution and is expressed in °Brix. The refractometer approach is usually being applied in the assessment of fruit ripeness but has also been used to measure vegetable quality (Huang *et al.*, 2007). A refractometer is an optical device that utilises the concept that light passing through a liquid will be refracted or bent at a certain angle. Denser liquids will refract more light. Therefore, dissolved solids will produce a refractive index proportional to the amount of solids (Harrill, 1998). Figure 2 shows a standard curve that represents the

Table 4. Summary of different instruments used for the measurement of fruit qualitative parameters (Barreiro *et al.*, 2004).

Quality attribute	Manufacturer	Unit
Colour	Minolta (Tokyo, Japan)	XYZ, L*a*b*
Juiciness	Agro-Technologie (Forges Les Eaux, France)	Chylofel
Manual Magness-Taylor firmness	Wagner Instrument (Greenwich, CT, USA)	Maximum penetration force (N)
Automated Magness-Taylor firmness	Stable Micro Systems (Surrey, UK)	Maximum penetration force (N)
		Deformability modulus (N/mm)
Acidity	Schott Gerate (Mainz, Germany)	Titration acidity (g/l)
Sweetness	Atago (Tokyo, Japan)	Soluble solids (°Brix)
Starch (potential sugar)	Agro-Technologie	Iodine index
Firmness	Agro-Technologie	Durofel
Respiration	Abiss (Varennes Jarcy, France)	CO_2 (%) and O_2 (%)
Physiological Stage	Agilent Technologies (Santa Clara, CA, USA)	Ethylene emission (nl/g h)

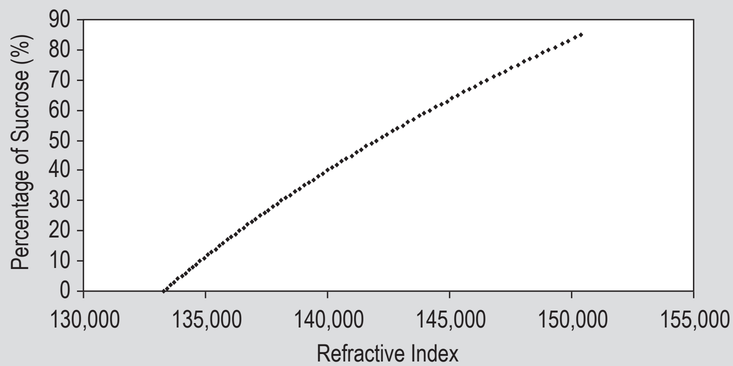

Figure 2. Relationship between the refractive index and the concentration of sucrose in percentage (Chemistry Lab Techniques, 2004).

relationship between the refractive index and the percentage of sucrose (°Brix) in a solution of water with a temperature of 20 °C using light with an emitting wavelength of 589 nm (Chemistry Lab Techniques, 2004).

°Brix is the measurement of the percentage of soluble solids content in a given weight of a plant juice. The °Brix is often associated with the percentage of sucrose. However, °Brix is actually the summation of the grams of sucrose, glucose, fructose, vitamins, minerals, amino acids, proteins, hormones and other soluble solids over one hundred gram of the particular sample (Harrill, 1998). But in the measurement of fruit juice which has a composition almost entirely of sugar, the °Brix should be almost equivalent to the actual sugar concentration. Therefore, generally, the measurement from the refractometer is not referred to as 'sugar concentration' or simply 'concentration', but as °Brix (Atago, 2009). Table 5 shows the summary of total sugars and water content in common fruits.

°Brix varies straightforwardly with fruit quality. For example, a poor, sour tasting grape from worn-out land will measure 8 °Brix or less. In contrast, a full flavoured, delicious grape, grown on rich and fertile soil is able to produce 24 °Brix or higher. Therefore, sugar is only one part of the component in the measurement of °Brix (Harrill, 1998). Many efforts have been made to classify the quality of fruits according to the °Brix level. Table 6 shows the quality definition according to the level of °Brix for various fruits. This table is also called the basic Reams' chart and is widely distributed by Pike Agri-Lab Supplies, Inc. (Jay, ME, USA) (Harrill, 1998). The °Brix percentage of a juice may be different depending on the fruit or vegetable and where the sample is extracted from. In order to obtain a higher accuracy in the measurement of the fruit or vegetable °Brix, the juice should be extracted from different parts and these parts should be mixed well (Atago, 2009).

The refractometer from Atago (2009) includes several versions in handheld and digital form. For a digital handheld refractometer, the resolution of measurement is as low as 0.1 °Brix while the full scale measurement is at 53 °Brix, 85 °Brix and 93 °Brix, depending on the model (Atago, 2009). Refractometers are very precise, reliable and being

Table 5. Summary of total sugars and water content in common fruits (Cordain, undated; The Fruits Pages, undated).

Fresh fruit	Total sugars (%)	Water (%)
Apples	13.3	84
Apricots	9.3	87
Avocado	0.9	81
Banana	15.6	76
Blackberries	8.1	85
Blueberries	7.3	80
Cherries (sweet)	14.6	86
Cherries (sour)	8.1	86
Grapefruit	6.2	90
Grapes	18.1	83
Guava	6.0	81
Kiwi fruit	10.5	84
Lemon	2.5	96
Lime	0.4	91
Mango	14.8	84
Orange	9.2	87
Papaya	5.9	91
Peach	8.7	89
Pear	10.5	86
Pineapple	11.9	84
Plum	7.5	84
Pomegranate	10.1	82
Starfruit	7.1	91
Strawberries	5.8	91
Tomato	2.8	97
Watermelon	9.0	93

Table 6. Quality definition according to the level of °Brix for various fruits (Harrill, 1998).

Fruits	Poor	Average	Good	Excellent
Apple	6	10	14	18
Banana	8	10	12	14
Carrot	4	6	12	18
Coconut	8	10	12	14
Grapes[1]	8	12	16	20
Lemon	4	6	8	12
Lime	4	6	10	12
Mango	4	6	10	14
Orange	6	10	16	20
Papaya	6	10	14	18
Pear	6	10	12	14
Pineapple	12	14	20	22
Raisin	60	70	75	80
Strawberry	6	10	14	16
Tomato	4	6	8	12
Watermelon[2]	8	12	14	16

[1] The top part of the bunch is 1.5 times sweeter than near the bottom of the bunch.
[2] The sugar content is generally higher near the centre of the melon. The value will decrease towards the outer edge and near the stem.

used as reference standards in most laboratories. However, the disadvantage of refractometers is that they have low specificity since similar values of soluble solids (°Brix) may refer to different values of chemical composition. Besides, a current refractometer is also destructive since the instrument needs a few drops of juice on it for the measurement (Barreiro *et al.*, 2004).

Measurement of acidity

Sugar content and acidity both add to the taste of fruits. Organic acids such as tartaric, malic and citric are common constituent of fruits. During the ripening process, the acid content decreases and the pH increases. Fundamentally, there are two distinct methods for expressing acidity in fresh fruits: titratable acidity and hydrogen ion concentration (also known as pH). However, there is no direct relationship between titratable acidity and pH due to variations in buffer capacity even though the higher level of acids in fruit are often linked to lower pH values and vice versa (Amerine and Joslyn, 1950). The titratable acidity expresses total acidity in a sample but does not measure the strengths of the acid, while pH indicates acid strength. Acidity is defined as the consumption of a base necessary to shift the pH value to 7.0, which is the end point of titration using sodium hydroxide. A value of pH 7.0 is the point of neutralization and commonly using indicated phenolphthalein, a colour indicator to determine the end-point of reaction. An example of the instrumentation that measures fruits acidity and pH is of Hanna Instruments (Woonsocket, RI, USA) which is able to measure the titration of fruits acid in g/100 ml for citric acid (range 0.20-8.00%). tartaric acid (range 0.23-9.30%) and malic acid (range 0.21-8.30%) with a measuring resolution of 0.01%. This instrument can also measure the pH of fruit juices with a range of measurement between -2 to 16, with a resolution of 0.01. Extech Instruments (Nashua, NH, USA) has commercialized their pH meter with a flat probe that is suitable for use in measuring the pH of fruits surfaces. The Extech model EX900 has a resolution of measurement as low as pH 0.01, with a complete range of measurement from 0.00 to 14.00 (Extech Instruments, 2008). Table 7 shows the common level of titratable acidity and the pH of several fruits. There are also fruits with a weak level of acidity, such as carrot (pH 5.88-6.40), papaya (pH 5.20-6.00) and watermelon (pH 5.18-5.60).

Table 7. Level of titratable acidity and pH for various fruits (Hanna Instruments, 2009; U.S. Food and Drug Administration, 2007).

Fruit	Titratable acidity (g/100 ml)	pH	Predominant acid
Apple	0.36-0.80	3.33-3.90	malic acid
Cranberry	1.6-3.6	2.30-2.52	citric acid
Grapefruit	1.2-2.0	3.00-3.75	citric acid
Lemon	4.0-6.2	2.00-2.60	citric acid
Mango	0.34-0.84	3.40-4.80 (ripe); 5.80-6.00 (green)	citric acid
Orange	0.8-1.4	3.00-4.34	citric acid
Peach	0.24-0.94	3.30-4.05	citric acid
Pear	0.36-0.80	3.5-4.6	malic acid
Pineapple	0.7-1.6	3.20-4.00	citric acid
Strawberry	0.6-1.1	3.00-3.90	citric acid
Table grape	0.4-0.9	2.80-3.84	tartaric acid
Tomato	0.34-1.00	4.30-4.90	citric acid

Table 8. Specifications for different model of penetrometer from Wagner Instrument (Wagner Instruments, 2008).

Model	Capacity/ graduation	Tips	Applications
FT 02	9.8 × 0.10 N	FT 18	berries and small fruits
FT 10	49.0 × 0.49 N	FT 516	peaches and soft fruits
FT 20	98.1 × 0.98 N	FT 516	peaches and nectarines
FT 30	137.3 × 0.98 N	FT 516/FT 716	pears and apples
FT 40	196.1 × 1.96 N	FT 14	avocados and hard fruits

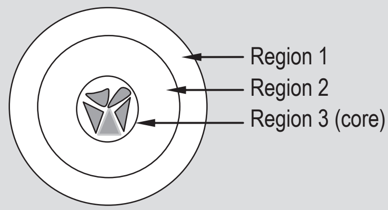

Figure 3. Three regions of apple as defined by Mohr and Associates, Inc. (Washington, DC, USA).

Measurement of fruits firmness

There are very wide selections of instruments to measure fruits firmness. The Magness-Taylor penetrometer is the oldest and most accepted measurement tool for fruits firmness (Barreiro *et al.*, 2004). Fruit cultivators world-wide are using the penetrometer to assist them to determine maturity and harvest times for plums, navel oranges, nectarines, kiwifruit, peaches, as well as stone and pome fruit. During the measurement, the plunger of the penetrometer is pressed against the fruit and the gauge will show the measurement of the rupture pressure. Different varieties of fruits have different rupture points. The penetrometer can be used as a handheld instrument or can be mounted on a drill press for additional accuracy (Wagner Instruments, 2008). Table 8 lists all penetrometer models provided by Wagner Instrument (Model FT, Greenwich, CT, USA) with different specifications for different applications.

Figure 3 shows the cross section of an apple with three separate regions. Region 1 extends inward from the outer surface to a depth of 0.8 cm. This is the standard Magness-Taylor firmness measurement depth that is used by most mechanical and electronic firmness measurement tools that are currently available. Region 2 is from the boundary of region 1 to a depth proportional to the radius of the fruit (1.5 cm for apples) while region 3 is the core region.

There are a few precautions that need to be taken when using a penetrometer. The following are some factors and problems which may influence the measurement of fruits firmness and some suggestions focusing on the apple fruits (Bramlage, 1983):

- If the measurement is conducted in the orchard, there is a possibility that fruit from outside of the tree will measure firmer than those towards the inner side.
- Generally, larger fruit tends to be softer. Sometimes a 0.6 cm difference in diameter can make a difference in the pressure test of 4 to 9 N. It is suggested that the fruits measured should not vary more than 0.6 cm in diameter. Obviously some kind of sizing device is therefore necessary for choosing a sample. Furthermore, the chosen fruits should have a size that represents the majority of the crop and should be specified before measurement.
- The temperature of the fruit usually has an influence on pressure tests and sometimes the influence can be significant; fruit firmness tends to be slightly less when it is warm if compared to when it is cold.
- Increasing the nitrogen level of fruits, such as apples, may reduce firmness more than it affects post-harvest condition of the fruits if they were at the threshold of nitrogen deficiency before treatment. Thus, there may be misjudgement of the condition of the fruits by comparing lots of widely varying nitrogen levels.
- The more water the fruit core the firmer it may show in pressure testing, even though increasing water content indicates increasing fruit maturity. Pressure tests may indicate very little about condition of water cored fruits such as in apple.
- Water loss: if fruits are losing water rapidly, they may be softening due to loss of turgor (i.e. wilting).

- Current penetrometers still have problems in terms of their reproducibility which relates to the range of validity (Barreiro *et al.*, 2004). In one test conducted in Geneva and New York, it was found that the measurement results on the same lots of apples obtained by professional users of a Magness-Taylor, differed by as much as 13.33 to 17.75 N (Bramlage, 1983).

5. Non-destructive technology in quality assurance

Assessing the internal quality parameters of fruits usually involves destructive procedures with much labour and time consumption. Therefore, a much simpler, faster and highly accurate measurement method is required (Temma *et al.*, 2002) which employs non-destructive sensing techniques to assure the quality and wholesomeness of fruit. This would increase consumer satisfaction and acceptance and enhance industry competitiveness and profitability. Various non-destructive sensing techniques have been studied and implemented for predicting the internal quality of fresh fruits (Valero and Ruiz-Altisent, 2000).

The development and application of fast and non-destructive methods for food quality measurement has increased through recent decades (Camps and Christen, 2009). In the agricultural industry, quality assessment of fruit has been conducted using both destructive and non-destructive method. Conventional measurement techniques applied to quantitatively determining quality parameters in fruits are through destructive methods such as soluble solids, acidity, pH and firmness measurement by penetrometer, as has been discussed in Section 4. Chemical methods have been applied in determining fruit quality parameters which requires destructive approaches. The setback of this methodology is that the measurement is done selectively by estimating the quality of a batch from sample. Despite economic losses due to destructive testing of the fruit sample, there is also concern as to how the sample is representative of the whole batch (Zerbini, 2006). The introduction of a non-destructive means of measurement is highly desirable since it eliminates the need to destroy samples before the measurement can be made. Many instruments have been introduced to deliver this technique and they are summarized in Table 9.

Non-destructive mechanical methods have been applied for measurement of fruit texture, mainly firmness. In addition to the commonly used penetrometer, there are also wide variety of non-destructive methods available such as acoustic resonance, impactometry, durofel and ultrasound. Impact he test parameters are measured by accelerometers with the resonance frequency being detected with a microphone. The resonance frequency basically changes in accordance with the ripening state of the fruits (Barreiro *et al.*, 2004). However, the impact tests results are highly influenced by the variations of fruit location, impact angle, deviations of fruit from spherical shape and water content (Zerbini, 2006). Furthermore, each of these instruments produces different measurements which are weakly correlated to the destructive penetrometer. This is because these instruments measure deformability, stiffness and elastic properties which are more related to turgor pressure and water loss, unlike the destructive penetrometer which resembles more the 'biting' firmness which is related to mechanical strength of cell wall and middle lamella. The correlation between the destructive (Magness-Taylor, Wagner Instrument) penetrometer and other non-destructive firmness instruments can be further improved by using penetrometer force/deformation ratio rather than only the force. However, this analysis can only be registered and performed through automated 'universal' or 'texture' tests and not with manual instruments (Barreiro *et al.*, 2004; Hertog *et al.*, 2004). Furthermore, energy absorption and sonic and ultrasonic vibration can provide information on fruits' internal damage, such as

Table 9. Non-destructive measurement of quality factors for horticulture produce (Noh and Choi, 2006).

Methodology	Technique being used	Components
Optic	Image analysis	Size, shape, colour, external defects
	Reflectance, absorption and reflectance spectroscopy	Internal components, colour, defects
	Laser spectroscopy	Firmness, visco-elasticity, defects, shape
X-ray	X-ray image and CT	Internal cavity and structure, ripeness
Mechanics	Vibrated excitation	Firmness, visco-elasticity, ripeness
	Sonic	Firmness, visco-elasticity, internal cavity, density, sugar content
	Ultrasonic	Internal cavity and structure, firmness, tenderness
Electromagnetic	Impedance	Moisture content, density, sugar content, density, internal cavity
	MR/MRI	Sugar content, oil, moisture content, internal defect and structure

CT = computed tomography; MR/MRI = magnetic resonance/magnetic resonance imaging.

bruises and weevil canals (Gao *et al.*, 2010; Mizrach, 2008). The summary of ultrasonic technology applications for evaluating fruit quality has been comprehensively presented by Mizrach (2008) who covered the concepts, technologies, developments, modifications and applications linked to the employment of ultrasonic techniques for fruit and vegetable quality evaluation during pre- and postharvest processes.

Other techniques that have been applied for the non-destructive measurement of fruits quality are magnetic resonance imaging (MRI), X-ray and nuclear magnetic resonance (NMR). MRI can be used to determine the quality, histology, histochemistry and structural characteristics of fruits (Yacob *et al.*, 2005). This technique has been tested and is able to produce images of internal structures of intact fruit at high resolution. However, this technique requires a high equipment cost and low speed of measurement (Clark and Burmeister, 1999; Clark *et al.*, 1997; Wang and Wang, 1989). X-rays have been applied in detecting diseases and defects in agricultural products. For instance, Yacob *et al.* (2005) conducted an experiment using MRI and X-ray to identify possible area on Malaysian Harum Manis mango that has been infested by weevils. NMR is applied to detect the concentration of hydrogen nuclei and is sensitive to variations in the binding state. The mobility of water, oil and sugar hydrogen nuclei varies according to the content in the maturation process of fruits such as mechanical injury, tissue degeneration, over maturity, decay, insect damage and frost injury of fruits (Gao *et al.*, 2010).

Of all the techniques presented in Table 9, optic methods are highly regarded as being very close to practical use. These techniques have been widely used in sorting and grading technology (Noh and Choi, 2006). The development of optical technology is gaining wide importance among researchers especially in the development of bioinstrumentation. Optical technology is gaining popularity due to its non-invasive measurement procedures and ability to be implemented as an online monitoring system. So far, many academic researches have been carried out to determine the intrinsic properties of various fruits. The experiments conducted are mostly through the application of spectrometers which produce a range of wavelength as the outputs. The spectra are processed using multiple statistical analyses to deliver the final results. The practical intention of this mode of research is to find out the chemical and biological compositions are related to quality attributes. In optical analysis (spectroscopy) the predefined quality attributes are correlated with the wavelength that fits best, commonly in terms of intensity. A few optical peripherals can be attached to the optical system such as lenses, filter, grating, prism and slit in order to acquire a suitable light illumination system onto the sample and correctly focus the resultant light onto the detector. These additions enhance the reliability and accuracy of measurements (Sadar, 1998).

Spectroscopic measurement techniques have been applied by many researchers in the measurement of fruit properties. The spectroscopic instrument used must be able to be integrated with the existing facilities and able to function in varying processing environments. Several spectroscopic techniques are growing in use around the world based on different scientific principles (Ghosh and Jayas, 2009). There are techniques of measurement that are usually being implemented in the measurement of commonly defined fruits' intrinsic properties, such as sugar content (soluble solids content), acid content and firmness. The interaction between radiation and matter has been proven useful in many research labs (Valero and Ruiz-Altisent, 2000). Nicolai *et al.* (2007), have produced a very detail discussion related to NIR (near infrared) spectroscopy as a non-destructive means for measuring fruit and vegetable quality. In their research summary, they compiled a collection of experiments with the fruits that have been tested, instruments used, acquisition methods (reflectance, interactance and transmittance), spectral range of wavelengths that have been employed and the resolution of measurement. To enhance the flexibility of measurement, fibre optics have been applied as a measuring probe and an interface between optical sensory system (commonly a spectrometer) and light source with the sample. The application of fibre optics in spectroscopic analysis provides the capability of 'taking the spectrometer to the sample' instead of the conventional method of taking the sample to the spectrometer (Melling and Thomson, 2002). Supplementary Table S1 summarises the spectroscopy experiments that have been conducted for the measurement of various fruit intrinsic qualities. The summary includes the techniques of measurement, instruments, statistical analyses and their respective results.

Another optical technology that has been applied in fruit quality analysis is the machine vision technique which had earlier applications in identifying plant species. With the swift development of image processing technology and computer software and hardware, machine vision systems offer a promising future for fruit quality auto-detection and grading (Gao *et al.*, 2010). Charge coupled devices (CCD) cameras are the fundamental equipment in the construction of optical imaging systems. The CCD cameras able to produce two dimensional images which can be further processed and provide an effective and economical solution for detecting the transition from one object to another based on colour (Gage, 2008). For instance, Yibin *et al.* (2004) have applied a machine vision technology to inspect the maturity of citrus fruits by surface colour analysis and using the ratio of total soluble solid to titratable acid as maturity indexes.

6. Summary

Awareness on the importance of quality assurance within fruits production has increased customers demand by using their purchasing power to select fresh produce that is high in intrinsic properties and values. This is due to the current standard set of fruits quality which is based on the external aspect of the fruits such as colour and its distribution, shape, size and weight which often does not represent the satisfaction during consumption. This transformation has led the fruit industries to raise their effort to market product that fulfil the new consumers' demand. In consequence, the quality aspect of fruits has been redefined and focussed on the intrinsic properties, thus, the needs for reliable mechanism to evaluate these quality parameters are becoming of utmost concern. According to Barreiro *et al.* (2004), a variety of instruments has been introduced into the agricultural industry. But more designs are being made for instruments that are non-destructive, portable, low cost, fast and easy operation besides having high precision and reproducibility. The requirement for these complex grading instrumentations may differ according to applications which can be grouped as for growers, on-site laboratories and research laboratories. The cost of operation is related to these factors (Barreiro *et al.*, 2004). Therefore, Nicolai *et al.*, (2007) stated that the current measurement system which still relying on external appearance, can be changed into intrinsic quality grading lines only if consumers are willing to pay premium prices to gain these benefits. On the whole, the transformation of quality assurance definitions from external into internal parameters in fruit should be accompanied by a reliable mechanism to evaluate what has been set as standard. This should be done by considering the possible increment in total production cost. Therefore, continuous development of innovative technology in fruit quality determination is important so that quality assurance can be defined empirically and quantitatively. Optical techniques, particularly spectroscopy have been seen as highly potential and reliable tools for evaluating fruit quality.

Figure 4 summarises the research trends for fruit quality applications by specifically referring to optical techniques. The focus of research currently is on the application of a broad range of spectrometer and chemometrics techniques for quantitative analysis. The aim of the future research endeavours can be focussed on the development of specialized optical fibre sensors that utilize wavelengths and ranges of sensitivity best suited to the quality parameters of fruit, perhaps through the application of monochromatic LEDs and photo detectors. This effort can drastically reduce the cost of operation and allow the systems to be easily accessible by all level of fruit growers.

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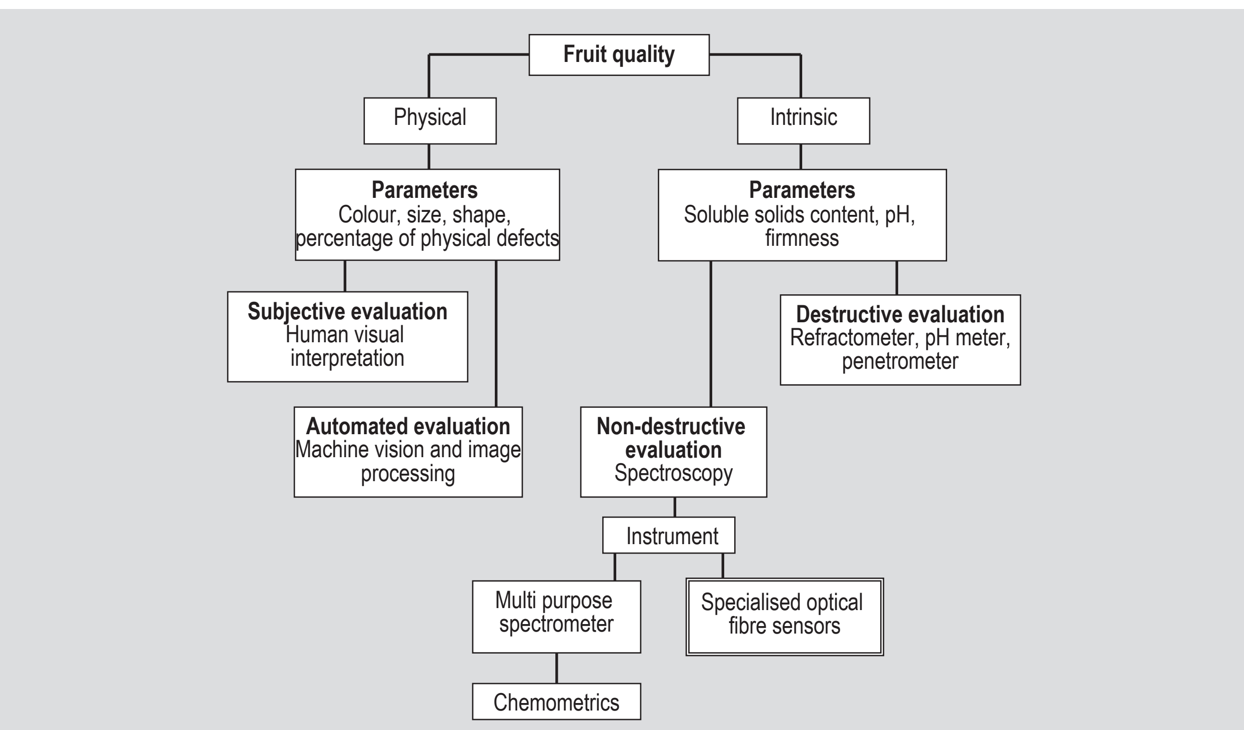

Figure 4. Transformation of quality definition and optical evaluation methodology.

Supplementary material

Supplementary material can be found online at http://dx.doi.org/10.3920/QAS2012.0175.

Table S1. Results from fruits intrinsic quality measurement through spectroscopy conducted by various researchers.

References

Abebe, A.T., 2006. Total sugar and maturity evaluation of intact watermelon using near infrared spectroscopy. Journal of Near Infrared Spectroscopy 14: 67-70.

Amerine, M.A. and Joslyn, M.A., 1950. Table wines: the technology of their production. University of California Press, Ewing, NJ, USA.

Atago CO., LTD. Easy guide to refractometers. Available at: http://www.atago.net/english/g_gaiyou.html.

Barreiro, P., Ruiz-Altisent, M., Valero, C. and Garcia-Ramos, J., 2004. Fruit postharvest technology: instrumental measurement or ripeness and quality. In: Dris, R and Jain, S.M. (eds.) Quality handling and evaluation, volume 3. Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 321-340.

Bramlage, W.J., 1983. Measuring fruit firmness with a penetrometer. Post Harvest Pomology Newsletter 1: 5-9.

Buckenhueskes, H.J., 2007. Industrial quality control. Flavours and fragrances: chemistry, bioprocessing and sustainability. Springer, Berlin-Heidelberg, Germany, pp. 303-312.

Camps, C. and Christen, D., 2009. Non-destructive assessment of apricot fruit quality by portable visible-near infrared spectroscopy. LWT - Food Science and Technology 42: 1125-1131.

Cao, F., Wu, D. and He, Y., 2010. Soluble solids content and pH prediction and varieties discrimination of grapes based on visible-near infrared spectroscopy. Computers and Electronics in Agriculture 71: S15-S18.

Carlini, P., Massantini, R. and Mencarelli, F., 2000. Measurement of soluble solids in cherry and apricot by PLS regression and wavelength selection. Journal of Agriculture and Food Chemistry 48: 5236-5242.

Chemistry Lab Techniques (2004). Refractometry. Available at: http://www2.ups.edu/faculty/hanson/labtechniques/refractometry/intro.htm.

Clark, C.J. and Burmeister, D.M., 1999. Magnetic resonance imaging of browning development in 'Braeburn' apple during controlled-atmosphere storage under high CO_2. HortScience 34: 915-919.

Clark, C.J., Hockings, P.D., Joyce, D.C. and Mazucco, R.A., 1997. Application of magnetic resonance imaging to pre- and post-harvest studies of fruits and vegetables. Postharvest Biology and Technology 11: 1-21.

Clark, C.J., McGlone, V.A., De Silva, H.N., Manning, M.A., Burdon, J. and Mowat, A.D., 2004. Prediction of storage disorders of kiwifruit (*Actinidia chinensis*) based on visible-NIR spectral characteristics at harvest. Postharvest Biology and Technology 32: 147-158.

Cordain, L., undated. Table of fruits and sugars. Available at: http://thepaleodiet.com/fruits-and-sugars.

Crisosto, C.H., 2008. Establishing a quality control system. Central Valley Postharvest Newsletter 17: 2.

Crosby, P.B., 1979. Quality is free. McGraw-Hill, New York, NY, USA.

Dauthy, M.E., 1995. Fruit specific preservation technologies. In: Dauthy, M.E. (ed.) Fruit and vegetable processing. FAO Agricultural Services Bulletin, No. 119, Food and Agricultural Organization of the United Nations, Rome, Italy.

Desrosier, N.W. and Desrosier, J.N., 1977. Technology of food preservation (4th Ed.). AVI Publishing Co., Westport, CT, USA.

Dris, D. and Jain, S.M., 2004. Production practices and quality assessment of food crops. Volume 1: preharvest practice. Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 261-285.

Esau, K., 1972. Fleshy fruit wall. In: Plant anatomy. Wiley Eastern Private Limited, New Delhi, India, pp. 595-603.

Extech Instruments, 2008. ExStik 4-in-1 water quality meter kits. Product datasheet.

Fan, G., Zha, J., Dub, R. and Gao, L., 2009. Determination of soluble solids and firmness of apples by Vis/NIR transmittance. Journal of Food Engineering 93: 416-420.

Famaxchange, 2009. Spesifikasi grad dan piawaian. Available at: http://www.famaxchange.org/web/guest/standard_grade_specification.

Fernandez-Novales, J., Lopez, M.I., Sanchez, M.T., Garcia-Mesa, J.A. and Gonzalez-Caballero, V., 2009. Assessment of quality parameters in grapes during ripening using a miniature fiber-optic near-infrared spectrometer. International Journal of Food Sciences and Nutrition 60: 265-277.

Gage, A., 2008. Color analyzer: have a rainbow of applications. Photonics Spectra, pp. 87-89.

Gao, H., Zhu, F. and Cai, J., 2010. A review of non-destructive detection for fruit quality. computer and computing technologies in agriculture III. IFIP Advances in Information and Communication Technology 317: 133-140.

Garner, D., Crisosto, C.H., Wiley, P. and Crisosto, G.M., 2008. Measurement of pH and titratable acidity. Central Valley Postharvest Newsletter 17: 2.

Gast, K.L.B., 1994. Harvest maturity: indicators for fruits and vegetables. Postharvest Management of Commercial Horticultural Crops, Kansas State University, Manhattan, KS, USA.

Ghosh, P.K. and Jayas, D.S., 2009. Use of spectroscopic data for automation in food processing Industry. Sensing and Instrumentation for Food Quality and Safety 3: 3-11.

Gomez, A.H., He, Y. and Pereira, A.G., 2006. Non-destructive measurement of acidity, soluble solids and firmness of Satsuma mandarin using Vis/NIR spectroscopy techniques. Journal of Food Engineering 77: 313-319.

Gonzalez-Caballero, V., Sanchez, M.T., Lopez, M.I. and Perez-Marín, D., 2010. First steps towards the development of a non-destructive technique for the quality control of wine grapes during on-vine ripening and on arrival at the winery. Journal of Food Engineering 101: 158-165.

Hanna Instruments, 2009. HI84432 titratable acids mini titrator and pH meter manual. Available at: http://www.hannainst.com/usa/prods2.cfm?id=007001&ProdCode=HI+84432.

Harrill, R., 1998. Using refractometer to test the quality of fruits and vegetables. Pine Knoll Publications, Redlands, CA, USA.

Hertog, M.L.A.T.M., Ben-Arie, R., Roth, E. and Nicolaï, B.M., 2004. Humidity and temperature effects on invasive and non-invasive firmness measures. Postharvest Biology and Technology 33: 79-91.

Huang, L., Wang, C. and Bomford, M., 2007. Effects of plant source, age, and foliar molasses application on brix readings of kale extracts. American Society for Horticultural Science Annual Conference, 16-20 July, Scottsdale, AZ, USA.

Hui-shan, L., Hui-rong, X., Yi-bin, Y., Xia-ping, F., Hai-yan, Y. and Hai-qing, T., 2006. Application Fourier transform near infrared spectrometer in rapid estimation of soluble solids content of intact citrus fruits. Journal of Zhejiang University Science B 7: 794-799.

Huyskens-Keil, S. and Schreiner, M., 2004. Quality dynamics and quality assurance of fresh fruits and vegetables in pre and postharvest. In: Dris, R and Jain, S.M. (eds.) Production practices and quality assessment of food crops. Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 401-449.

International Organization for Standardization (ISO), 2005. ISO9000:2005. Quality management systems - Fundamentals and vocabulary. ISO, Geneva, Switzerland.

Jha, S.N., Kingsly, A.R.P. and Chopra, S., 2006. Non-destructive determination of firmness and yellowness of mango during growth and storage using visual spectroscopy. Biosystems Engineering 94: 397-402.

Joffe, M. and Robertson, A., 2001. The potential contribution of increased vegetable and fruit consumption to health gain in the European Union. Public Health Nutrition 4: 893-901.

Juran, J.M. and Gryna, F.M., 1988. Quality Planning and Analysis. Tata McGraw-Hill, New Delhi, India, pp. 126-128.

Kader, A.A., 1999. Fruit maturity, ripening and quality relationship, international symposium effect of pre- & postharvest factors in fruit storage. ISHS Acta Horticulturae 485: 203-208.

Lamp, L., 1997. Fruit maturity and ripening. Available at: http://cetulare.ucdavis.edu/news/ripefrut.htm#top.

Li, X. and He, Y., 2006. Non-destructive measurement of acidity of Chinese bayberry using Vis/NIRS techniques. European Food and Research Technology 223: 731-736.

Lin, H. and Ying, Y., 2009. Theory and application of near infrared spectroscopy in assessment of fruit quality: a review. Sensing and Instrumentation for Food Quality and Safety 3: 130-141.

Lu, R., 2007. Nondestructive measurement of firmness and soluble solids content for apple fruit using hyper spectral scattering images. Sensing and Instrumentation for Food Quality and Safety 1: 19-27.

Lucier, G., Pollack, S., Ali, M. and Perez, A., 2006. Fruit and vegetable backgrounder. Electronic outlook report from the Economic Research Service VGS-313-01.

Mahayothee, B., Leitenberger, M., Neidhart, S., Mühlbauer, W. and Carle, R., 2002. Non-destructive determination of fruit maturity of Thai mango cultivars by near infrared spectroscopy. International Symposium Sustaining Food Security and Managing Natural Resources in Southeast Asia, Challenges for the 21st Century, 8-11 January 2002, Chiang Mai, Thailand. Available at: https://www.uni-hohenheim.de/fileadmin/einrichtungen/sfb564/events/uplands2002/Full-Pap-S3B-3_Mahayothee.pdf.

Melling, P.J. and Thomson, M., 2002. Fiber-optic probes for mid-infrared spectrometry. Handbook of vibrational spectroscopy. John Wiley & Sons Ltd, Chichester, UK, pp. 1-9.

Miller, W.M. and Zude, M., 2002. Non-destructive brix sensing of Florida grapefruit and honey tangerine. Proceedings of the Florida State Horticultural Society 115: 56-60.

Mizrach, A., 2008. Ultrasonic technology for quality evaluation of fresh fruit and vegetables in pre- and postharvest processes. Postharvest Biology and Technology 48: 315-330.

Mohr and Associates, Inc. Apple quality testing in five market centers using the MDT-1 agricultural penetrometer. Available at: http://www.mohr-engineering.com/documents/apstdy823nsbtedt4b-2.pdf.

Nicolai, B.M., Beullens, K., Bobelyn, E., Peirs, A., Saeys, W., Theron, K.I. and Lammertyn, J., 2007. Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy: a review. Postharvest Biology and Technology 46: 99-118.

Noh, S.H. and Choi, K.H., 2006. Non-destructive quality evaluation technology for fruits and vegetables. International Seminar on Enhancing Export Competitiveness of Asian Fruits, 18-19 May 2006, Bangkok, Thailand.

Ozanich, R., 2001. Near-Infrared spectroscopy progress report. Washington Tree Fruit Postharvest Conference, 13-14 March 2001, Wenatchee, WA, USA.

Reid, L.M., O'Donnell, C.P. and Downey, G., 2006. Recent technological advances for the determination of food authenticity. Trend in Food Science and Technology 17: 344-353.

Sadar, M.J., 1998. Turbidity science. Technical Information Series, Booklet 11. Hach Company, Loveland, CO, USA.

Schmilovitch, Z., Mizrach, A., Hoffman, A., Egozi, H., Fuchs, Y., 2000. Determination of mango physiological indices by near-infrared spectrometry. Postharvest Biology and Technology 19: 245-252.

Servakaranpalayam, S.S., 2006. Potential applications of hyperspectral imaging for the determination of total soluble solids, water content and firmness in mango. Master of Science thesis, McGill University, Montreal, Quebec, Canada.

Shewfelt, R., 1999. What is quality? Postharvest Biology and Technology 15: 197-200.

Shewfelt, R., 2000. Fruit and vegetable quality: an integrated view. Technomic Publishing INC, Lancaster Pennsylvania, USA, pp. 144-157.

Slaughter, D.C. and Crisosto, C.H., 1998. Nondestructive internal quality assessment of kiwifruit using near-infrared spectroscopy. Seminars in Food Analysis 3: 131-140.

Slaughter, D.C., Thompson, J.F. and Tan, E.S., 2003. Nondestructive determination of total and soluble solids in fresh prune using near infrared spectroscopy. Postharvest Biology and Technology 28: 437-444.

Sorensen, M., Raaschou-Nielsen, O., Brasch-Andersen, C., Tjonneland, A., Overvad, K. and Autrup, H., 2007. Interactions between GSTM1, GSTT1 and GSTP1 polymorphisms and smoking and intake of fruit and vegetables in relation to lung cancer. Lung Cancer 55: 137-144.

Temma, T., Hanamatsu, K., Shinoki, F., 2002. Measuring the sugar content of apples and apple juice by near infrared spectroscopy. Optical Review 9: 40-44.

The Fruits Pages, undated. Fruit nutrition facts. Available at: http://www.thefruitpages.com/contents.shtml.

United Nations, 2007. Safety and quality of fresh fruit and vegetables: a training manual for trainers. Available at: http://www.unctad.org/en/docs/ditccom200616_en.pdf.

U.S. Food and Drug Administration, 2007. Approximate pH of foods and food products. Available at: http://vm.cfsan.fda.gov/~comm/lacf-phs.html.

Valero, C., Ruiz-Altisent, M., 2000. Design guidelines for a quality assessment system of fresh fruits in fruit centers and hypermarkets. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development 2: 1-20.

Ventura, M., De Jager, A., De Putter, H. and Roelofs, F.P.M.M., 1998. Non-destructive determination of soluble solids in apple fruit by near infrared spectroscopy (NIRS). Postharvest Biology and Technology 14: 21-27.

Wagner Instruments, 2008. Fruits test. Available at: http://www.fruittest.com/ft_fruit_test.php.

Walsh, K.B., 2006. Setting and meeting objective standards for eating quality in fresh fruit. Proceedings of IVth International Conference on Managing Quality in Chains (MQUIC). ISHS Acta Horticulturae 712: 191-200.

Wang, C.Y. and Wang, P.C., 1989. Nondestructive detection of core breakdown in 'Bartlett' pears with nuclear magnetic resonance imaging. HortScience 24: 106-109.

Wayne, S.R., 1983. Quality control circle and company-wide quality control. Quality Progress 16: 14-17.

Wischik, L., 2008. Ripe fruit - choosing and storing for optimum ripeness. Available at: http://www.wischik.com/lu/lady/ripe/.

Woodcock, T., Downey, G. and O'Donnell, C.P., 2008. Better quality food and beverages: the role of near infrared spectroscopy. Journal of Near Infrared Spectroscopy 16: 1-29.

Yacob, Y., Ahmad, H., Saad, P., Aliana, R., Raof, A. and Ismail, S., 2005. A comparison between x-ray and mri in postharvest non-destructive detection method. Proceedings of the International Conference on Information Technology and Multimedia (ICIMU '05), 22-24 November 2005, Malaysia.

Yan-de, L., Yi-bin, Y., Xiaping, F. and Huishan, L., 2007. Experiments on predicting sugar content in apples by FT-NIR Technique. Journal of Food Engineering 80: 986-989.

Yibin, Y., Xiuqin, R. and Junfu, M., 2004. Methodology for nondestructive inspection of citrus maturity with machine vision. Transactions of The Chinese Society of Agricultural Engineering 20: 144-147.

Zerbini, P.E., 2006. Emerging technologies for non-destructive quality evaluation of fruit. Journal of Fruit and Ornamental Plant Research 14: 13-23.