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Comparison of postharvest changes in mango (cv Cogshall) using a Ripening class index (Rci) for different carbon supplies and harvest dates

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ABSTRACT

The length of time between harvest and the onset of the climacteric rise in fruit respiration depends both on the harvest stage and the storage conditions of mango fruit (*Mangifera indica* cv Cogshall). We therefore propose classifying fruit according to a Ripening class index (Rci) that takes both storage time and climacteric stage into account. Batches of fruit thus obtained are more homogeneous than those sorted according to their storage time or their climacteric stage alone, as shown by the lowest root mean square error values obtained for the majority of the physico-chemical criteria measured, such as total soluble sugars, starch, and total soluble solids contents, titratable acidity, pH, firmness and the ratio of total soluble sugars to total organic acids. The advantage of this classification system for monitoring postharvest changes in mangoes stored at 12 or 20 °C has been demonstrated. The Rci was used to study the impact of agronomic conditions such as the leaf-to-fruit ratio and harvest stage on the changes in physico-chemical criteria traditionally used as quality descriptors. Sugar content increases with the increase in carbon supply and the harvest stage, whereas the titratable acidity and the hue angle decrease during ripening. This type of index can be used to validate the relevance of harvest indicators by verifying the homogeneity of the changes in stored batches or for more effectively assessing the impact of a storage technique on fruit metabolism.

1. Introduction

The effects of production conditions (climate, crop cultivation techniques) on fruit composition and quality (Hewett, 2006) and the variability of fruit batches at harvest can lead to wide variations in the physiological changes in the products (Tijskens et al., 2003). Each fruit will develop according to its own "agronomic" history and its harvest stage (Souty et al., 1999; Léchaudel and Joas, 2006; Bugaud et al., 2007), which explains the variability observed in stored batches. This is especially true in the case of climacteric fruit, generally harvested at a green stage in order to allow time for ripening and market release. This is why non-destructive techniques are proposed to objectively characterise fruit batches after harvest. These include Near Infrared Spectrometry (Schmilovitch et al., 2000; Saranwong et al., 2004; Gomez et al., 2006; Van Dijk et al., 2006), acoustic resonance impulse (Ito and Sugiyama, 2002; Valente and Ferrandis, 2003), changes in fluorescence (Bron et al., 2004), laser imaging (Qing et al., 2007), and TRS (Time-resolved Reflectance Spectroscopy) (Eccher Zerbini et al., 2006). Combining non-destructive descriptors such as compression with a reflectance measurement (Ruiz-Altisent et al., 2006) or an acoustic frequency (signal proportional to a slight shock) with a Near Infrared Spectrometry measurement (Zude et al., 2006) may also be of interest. Moreover, as in the case of empirical criteria of fruit maturity (Hoehn et al., 2003), it is necessary to develop references adapted to each case in order to take the specific character of species and varieties into account to ensure that these non-destructive ripening assessment techniques are reliable.

In the case of mango fruit, recent research has shown that a ripening index based on the chromatic values of the skin (a^*, b^*) may be an interesting harvest indicator (Jha et al., 2007). Nevertheless, given the diversity of colouration between cultivars and the impact of production conditions such as position of the fruit in the canopy on skin colour, it is necessary to determine whether or not colour can be an adapted descriptor for each fruit (Vásquez-Caicedo et al., 2002). Mangoes are generally harvested on the basis of empirical criteria at the "sprung green" or "ripe green" stages (Mendoza and Wills, 1984; Jha et al., 2007). To study the effect of cultivation techniques on biochemical changes in fruit dur-

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ing storage, it is therefore necessary either to have large batches, with the risk of high variability (Tijskens et al., 2003), or have a method for classifying fruit ripening stages. This classification can be based on respiration rate changes during ripening (Lalel et al., 2003; Palomer et al., 2005), which are typical of climacteric fruit. If no respiration rate measurement is available, it might be useful to combine different characteristics such as firmness and the sugar/acid ratio, also a function of each cultivar (Vasquez-Caicedo et al., 2006). As a result, it seems difficult to have a sole descriptor for the ripening stage, especially since the changes in certain metabolites during storage is not necessarily linked to ethylene action in the case of climacteric fruit (Jeffery et al., 1984). Storage time may also be of interest for classifying fruit during ripening.

Therefore, to determine the effect of agronomic conditions on the quality of ripe mangoes, a new ripening index is suggested, based on the sorting of fruit according to ripening stage. We present the construction of this ripening index, which takes both the climacteric stage of fruit (one of the most important indicators of fruit ripening) and storage time (to include physiological senescence due to, for example, water loss and metabolite consumption for cellular maintenance) into consideration. Fitted curves of changes in various quality traits are established from observed data as a function of either storage time, climacteric stage or Ripening class index. To evaluate the accuracy of these fitted curves, values of root mean square error (RMSE) for quality traits are compared. The advantages of a Ripening class index (Rci) are then given for physical and biochemical indicators on fruit with different growth conditions, harvest dates and storage temperatures. The impact of the leaf-to-fruit ratio and harvest stage on mango ripening during storage on the basis of this index is presented.

2. Materials and methods

2.1. Experimental conditions and treatments

The study was conducted on 12- and 14-year-old mango trees (*Mangifera indica* cv Cogshall) grafted on 'Maison rouge', in Reunion Island during the 2002 and 2004 growing seasons, respectively. All trees were well irrigated every two days at 100% replacement of evaporation. We observed the development of flower panicles each year at the orchard scale in order to assess the full bloom stage. The full bloom stage corresponded to the date when more than 50% of the panicles on all the trees were open (the estimated error margin due to the heterogeneity of flower panicles opening during a flowering episode is about five days).

During the 2002 growing season, selected branches at the top of the trees were girdled, sometimes defruited and defoliated at 60 d after bloom (DAB), in order to establish ratios of 10 and 100 leaves per fruit (i.e., 50 leaves for five fruit and 100 leaves for one fruit, respectively). The cell division phase and fruit set are finished at this stage of 'Cogshall' mango fruit development. Branches were girdled by removing a 10–15 mm wide strip of bark. To maintain constant leaf-to-fruit ratios within each treatment, all new emerging leaves were removed. Four harvest dates were staggered over the last five weeks of the fruit growing season, corresponding to 100, 107, 115 and 123 DAB. Fifteen fruit were harvested for each leaf-to-fruit ratio (10 and 100 leaves per fruit) at each harvest date, and then stored at 20 °C and 82–85% RH.

During the 2004 growing season, carefully selected branches (see 2002 procedure) were girdled, sometimes defruited and defoliated at 60 DAB, in order to establish a unique ratio of 100 leaves per fruit. Thirty fruit from this leaf-to-fruit ratio were harvested at 120 DAB and separated into two batches. A first batch of 15 fruit was stored at 20 °C and 82–85% RH. The second batch of 15 fruit was stored at 13 °C and 92–97% RH for 12 d and then stored at 20 °C and 82–85% RH for ripening.

During storage, both for the 2002 and 2004 experiments, fruit were observed every day to determine five maturity stages. The first one was the day following harvest (green stage) and then four postharvest stages based on fruit colouration: half green (green), green-ripe (light green), half ripe (more red than yellow) and ripe (more yellow than red). Each fruit was considered as a replicate; for each maturity stage (green to ripe), three fruit (=three replicates) were analysed.

2.2. Measurements of fruit quality

Density was calculated using Archimedes' principle, by measuring the fruit fresh mass in the air and its upward force when the fruit was immersed in water (the fruit was placed in an immersed basket hanging from a balance). The fruit density (d, dimensionless) is deduced as $d = m/|m - r|$, where m is the fruit fresh mass (kg) and r is the upward force (kg).

The flesh colour of each fruit was assessed with a Minolta Chroma Meter CR300 (Konica Minolta, Japan). The CIELAB coordinates (L^*, a^*, b^*) were measured on the internal side of the flesh after having cut the two cheeks of the fruit, to calculate hue angle ($H = \tan^{-1}(b^*/a^*)$, in degrees), where b^* is the yellow/blue and a^* is the red/green colour coordinate. H varies between 0°, 90°, and 180°, and represents a totally red, yellow and green colour, respectively. The flesh of the whole fruit was ground using a Grindomix blender (Retsch, Haan, Germany), homogenised (Polytron PT1600E, Kinematica AG, Switzerland), and then subsampled and frozen at −20 °C for later analysis.

Three grams of ground fresh flesh were homogenised in 30 mL distilled water. pH and titratable acidity, expressed as milliequivalents of acid per 100 g, were measured using an automated titrimeter (TitroLine easy, Schott, Mainz, Germany). Titration was conducted with a 0.1N NaOH solution up to an 8.1 pH endpoint concentration. Other analyses were done after thawing flesh samples. Starch was determined by enzymatic hydrolysis to glucose (Léchaudel et al., 2005), and concentrations of sucrose, glucose and fructose were measured using a high-performance liquid chromatography (HPLC) system (Dionex Co., Sunnyvale, CA, USA) (Léchaudel and Joas, 2006). The HPLC conditions were: CarbopacPA1 guard-column and column, 25 μL injection loop, isocratic elution with a 200 mM NaOH and purified water mixture (85:15, v/v), flow rate of 1 mL min^{-1} and amperometric detection (type ED40). Sugar peaks were confirmed by comparison with standard solutions.

Firmness was measured using a TAXT2 analyser (Stable Micro Systems, UK) and expressed as the rupture force to apply to a 5 mm diameter probe on the lateral face of a cheek.

2.3. Respiration rate assessment and construction of the Ripening class index (Rci)

Fruit respiration rates were measured using a closed system method. Fruit was placed in individual 2 L air-tight jars at 20 °C. Carbon dioxide and oxygen changes inside these containers were measured every 15 min for 2 h by gas chromatography, with an Agilent M200 apparatus equipped with two manifolds and two columns: 8 m Porapak Q, thermostated at 55 °C, and MS-5A 4 m thermostated at 60 °C, with helium and argon as carrier gases, respectively. Both of them were fitted with thermal conductivity detectors. The fruit were then placed in crates at ambient atmosphere at 20 °C until the next measurements. The apparent respiration rates were calculated by linear regression from CO_2 curves, and adapted from Ravindra and Goswani (2008). respiration