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Bruise susceptibility of banana peel in relation to genotype and post-climacteric storage conditions

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ABSTRACT

The aim of this study was to understand the genotypic factors and post-climacteric storage conditions that affect bruise susceptibility of banana peel. Putative physicochemical indicators of bruise susceptibility, including peel electrolyte leakage (PEL), total polyphenolic content, hardness, water content, and peel thickness, were investigated. Bruise susceptibility is the lowest impact energy needed to produce visible bruising by an object dropped on post-climacteric banana fruit from a pre-determined height, converted into impact energy (20–200 mJ with a 20 mJ increment). The bananas were stored either at 18 °C throughout ripening or at 13 °C between the 2nd and 6th day after ethylene induction. Five cultivars with contrasting susceptibility to impact bruises were used. Neither Grande Naine nor hybrid Flhorban925 bruised at the maximum impact energy (200 mJ) during ripening whatever the storage conditions. A gradient in bruise susceptibility was observed among the other cultivars: French Corne > Fougamou > hybrid Flhorban916. Bruise susceptibility increased during ripening and was higher in bananas stored at 18 °C. The lower ripening temperature resulted in a two-day delay to fruit maturity as well as in bruise susceptibility. Bruise susceptibility was positively correlated with PEL ($R = 0.78$) and to a lesser extent negatively correlated with hardness ($R = -0.45$), and was not correlated with polyphenolic content. In conclusion, membrane permeability provides the first clue to understanding bruise susceptibility.

1. Introduction

Mechanical damage is one of the main factors leading to postharvest deterioration in bananas, cooking bananas, and plantains. Mechanical damage can be caused by distributors or by consumers in supermarkets when handling ripe bananas. A sharp blow, for example caused by one ripe fruit falling against another, or onto a hard surface, can cause impact bruises characterized by undesirable brownish to black marks on the peel. The injury generally begins to appear a few minutes after impact and covers the impact area (Dadzie and Orchard, 1997). Symptoms are visible in all the epidermal layers of the peel but the pulp is not necessarily affected (Tronchet, 1971). Because the appearance of fruit is more important on the export than on the local market, bruised bananas are usually unsaleable. Some cultivars, including plantain (Ferris et al., 1993) and Prata Ana (Maia et al., 2011), are known to be susceptible to impact bruising. Recently, the Flhorban916 hybrid, created in the CIRAD (*Centre de Coopération Internationale en Recherche Agronomique pour le Développement*) banana breeding program, was rejected by breeders and by the banana export sector mainly because of its susceptibility to impact bruising. However, another hybrid Flhorban925 is promising since it did not bruise at all during testing in European markets.

Susceptibility to impact bruising is consequently an important postharvest quality trait that needs to be taken into account in both selection and postharvest processes. Several methods are available to assess banana bruise susceptibility (Banks and Joseph, 1991; Akkaravessapong et al., 1992; Kajuna et al., 1997). The method proposed by Banks and Joseph (1991) assesses the threshold of impact bruising by measuring the impact caused by dropping an object on pre- or post-climacteric fruit from a pre-determined height. This method is simple and does not require expensive equipment. The first objective of the present study was thus to check if this method is capable of simulating the level of bruise susceptibility observed empirically among cultivars or in the postharvest chain.

Second, postharvest factors that affect bruise susceptibility need to be identified so that corrective action can be taken. Temperature and humidity are the main post-climacteric parameters that can be controlled. Some authors have suggested that bruise susceptibility is independent of temperature (Klein, 1987) or humidity (Akkaravessapong et al., 1992), whereas others have reported relationships with temperature in fruit grown in temperate areas

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Table 1
Changes in temperature (in °C) during the banana ripening process.

	Day before ethylene induction[a]	Days after ethylene induction									
		1	2	3[a]	4	5	6[a]	7	8[a]	9	10[a]
High temperature treatment (HT)	18	18	18	18	18	18	18	18	18	18	18
Low temperature treatment (LT)	18	18	18	13	13	13	13	18	18	18	18

[a] Days when physicochemical parameters were assessed.

(Thomson et al., 1996; DeMartino et al., 2002). In banana, the post-climacteric temperature is usually reduced to 13 °C (a temperature close to the one that causes chilling injury) by commercial ripeners to extend shelf-life (Joas, 1987). Although exposure to low temperatures is known to cause chilling injury in tropical fruit (Rinaldo et al., 2010), to date, no information is available on the effect of this postharvest practice on the bruise susceptibility of ripe bananas. This is an important point, as the lower temperature we used in our study mimics the ripening process of bananas exported to temperate countries. The second objective of the present study was thus to evaluate the impact of a decrease in temperature during ripening on bruise susceptibility.

Third, the physicochemical parameters linked to variations in bruise susceptibility among cultivars need to be identified to provide information on the physiological mechanisms of banana bruising susceptibility or resistance. Data suggest that bruising is the result of enzymatic browning (Klein, 1987; Kajuna et al., 1997). The first step is hypothesized to be a decrease in peel resistance to mechanical damage due to loss of cell and membrane integrity. Once impact damage occurs, contact between cytoplasmic enzymes (polyphenol oxidase and peroxidase) and phenolic compounds originally stored in the vacuole becomes possible. The consequences are hypothesized to be oxidation of phenolic compounds to quinones, which subsequently polymerize to brown pigments (Rinaldo et al., 2010). Differences in browning among cultivars may thus depend on different factors such as total phenolic content, membrane and cell wall integrity, and the activity of phenolic oxidizing enzymes (Rinaldo et al., 2010). The third objective of the present study was thus to identify the physicochemical parameters involved in bruise susceptibility by focusing on parameters indicating membrane and cell integrity (electrolyte leakage, hardness, thickness, water content) and one parameter indicating browning potential (total polyphenol content).

2. Materials and methods

2.1. Material

Five banana cultivars were used: Grande Naine (AAA, Cavendish subgroup, GN), Fougamou (ABB, Pisang Awak subgroup, FOU), French Corne (AAB, Plantain subgroup, FC), and two hybrids produced in CIRAD's breeding program, Flhorban916 (AAA, F916) and Flhorban925 (AAA, F925). They were chosen based on previous empirical observations made in supermarkets suggesting they had contrasting susceptibility to impact bruising. All the bananas were grown at the *Pôle de Recherche Agroenvironnementale de la Martinique* (PRAM, Martinique, French West Indies; latitude 14°37′ N, longitude 60°58′ W, altitude 16 m) on continental alluvial soil. Similar agronomic and cropping practices (suckering, bunch management) were used. Between February and May 2011, three bunches representing three biological repetitions were harvested from F916, F925, FOU and GN, and from FC in January 2012. A total of between 60 and 70 bananas from each bunch were used for all the analyses, i.e. 6–7 bananas per treatment (2 postharvest treatments × 5 ripening stages, see below). The flowering-to-harvest time, which indicates fruit age, was first calculated for each cultivar to be sure bananas with the same green life were used for the study (28 ± 5 days measured at 20 °C; Chillet et al., 2008). During the period of bunch growth, the mean daily temperature was 26.0 ± 0.5 °C. Depending on the amount of rainfall, 4–5 mm of water per day was supplied by drip irrigation.

2.2. Experimental conditions

The banana hands were rinsed and dipped in fungicide (bitertanol, 200 mg L^{-1}) for 1 min. The bananas were separated and each banana was placed in a plastic bag with 20 μm respiration holes then stored in boxes for 6 days at 18 °C. The bananas were stored in a room at 18 °C and underwent ethylene treatment (1 mL L^{-1} for 24 h) to trigger the ripening process. After 24 h, the room was ventilated. The bananas were then separated into two lots. One lot was kept at 18 °C for 10 days after ripening induction (high temperature treatment, HT). The other was kept at 18 °C until the 2nd day after ripening induction, then at 13 °C from the 2nd to the 6th day, and finally at 18 °C from the 6th to the 10th day (Table 1). In this treatment (low temperature treatment, LT), the temperature was reduced during ripening to simulate the real storage conditions commonly used during ripening in European ripeners (Joas, 1987). The increase in temperature after six days of ripening simulated shelf stocking in the supermarket.

2.3. Physical and chemical analyses

Banana physicochemical parameters were assessed before ripening (day 0), and at the 3rd, 6th, 8th, and 10th day after ethylene induction. All analyses of the bruise susceptibility of fresh bananas, rheological measurements, and peel electrolyte leakage were performed at 25 °C by storing the bananas at this temperature for 2–3 h before analysis.

Bruise susceptibility was evaluated on whole bananas following the method of Banks and Joseph (1991). Impacts were obtained by dropping a 19-mm stainless steel ball (28.0 g) down a guiding tube from a range of standard heights. Impact energies (E, mJ) for the 10 drop heights were calculated from $E = mgh$, where m is the mass of the ball, g is the gravitational constant (9.81 m s^{-2}), and h is the drop height. Finally, 10 energies from 20 to 200 mJ with a 20 mJ increment were applied. Bruise susceptibility was estimated as the lowest impact energy producing a visible bruise with a brown to black mark on one of three bananas after they had been stored for 24 h at 25 °C. The less the impact energy required to produce a visible bruise, the more susceptible the banana was to impact bruising.

The rheological characteristics were measured using a TA-XT2 penetrometer. A cylindrical metal borer with a surface area of 19.6 mm^2 penetrated the fruit at constant speed (2 mm s^{-1}) to a depth of 15 mm. The maximum force applied to break the peel represented the peel hardness (expressed in N). After the peak, there was a plateau that corresponded to the firmness of the pulp (expressed in N).

Peel thickness was measured with a TA-XT2 penetrometer. The probe was initially placed at a distance of 1 cm from the base of the penetrometer. After a piece of peel was placed on the base, the probe reached the sample at 1 mm s^{-1} and was withdrawn from the sample as soon as the force reached 0.04 N. The difference between