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Changes in bioactive compounds and response to postharvest storage conditions in purple eggplants as affected by fruit developmental stage

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ABSTRACT

Fruit maturity stage at harvest influences the response to postharvest storage conditions and bioactive compounds content. In this work fruit from two purple eggplant cultivars (Monarca and Perla Negra) were harvested at 12, 15, 18, 20 and 23 d after fruit set (designated as stages I through V) and changes in size, dry weight, calyx area, cell wall material (AIR, alcohol insoluble residue), firmness, respiration, and antioxidants (peel anthocyanins and pulp carotenoids, ascorbic acid, phenolics and chlorogenic acid) were determined. In a second set of experiments the postharvest performance of fruit harvested at stages I ("baby" eggplants), III and IV (traditional harvest stages) during storage at 0 or 10 °C was assessed. Fruit growth continued until late ripening in contrast to calyx expansion and peel anthocyanin accumulation, which were relatively earlier events. Fruit dry weight decreased between stages I and III, remaining constant afterwards. "Baby" eggplants had higher antioxidant capacity, chlorogenic acid (ChA), carotenoids and ascorbic acid contents than late-harvested fruit. ChA predominated in pulp placental tissues at stage I, spreading throughout the fruit core at as ripening progressed. No marked differences in dry mass, antioxidant capacity or responses to postharvest storage regimes were found between fruit harvested at stages III and IV. Late pickings increased yields and led to less dense fruit, which had lower respiration rates. Within this harvest window, storage at 10 °C maximized quality maintenance. In contrast "baby" eggplants stored better at 0 °C. Understanding the developmental changes in bioactive compounds and postharvest performance may help in the maximization of fruit antioxidant properties as well as in the selection of the optimal handling conditions for each ontogenic stage.

1. Introduction

Ranking among the top 10 in terms of antioxidants (Lo Scalzo et al., 2010; Whitaker and Stommel, 2003) eggplants are, together with tomato and pepper, the most widely known solanaceous fruit crops (Doganlar et al., 2002). Although they show diverse shapes (elongated, ovoid or slender types) and colors (purple, white, green or variegated), dark ovoid American type cultivars are by far the most popular (Muñoz-Falcón et al., 2008).

Eggplants are harvested at immature stages, before full seed development and mainly based on size (Gajewski and Arasimowicz, 2004; Jha and Matsuoka, 2002). However, there is a range of ontogenic stages at which they could be marketed. For traditional distribution channels fruit are mostly picked at intermediate developmental phases, which prevent bitterness and spongy texture but do not compromise yields markedly. Once limited to the fine dining sector, consumption of "baby" vegetables has started to spread to the general public (Shaw and Cantliffe, 2005). Miniature eggplants have several appeals to consumers; they have delicate taste and are attractive and tender. In addition, they can be directly incorporated into salads, side dishes and appetizers without extensive preparation.

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Harvest maturity is known to have major influence on fruit response to postharvest storage (Kader, 1996). Full-sized eggplants are chilling sensitive and storage at 10 °C is recommended to maximize postharvest life (Concellón et al., 2007). However, whether or not there are differences in chilling susceptibility within the normal eggplant harvest window is not clear. The optimal conditions for keeping highly perishable "baby" eggplants have not been determined either. While less mature fruit may also be more sensitive to chilling (Boonsiri et al., 2007; Mohammed and Brecht, 2002), this sensitivity still needs to be established.

Fruit maturity stage at harvest may be also a main determinant of the levels of bioactive compounds (Deepa et al., 2007; Vallejo et al., 2003). In eggplant, changes in antioxidants accompanying development have been studied, but some discrepancies are found in the literature. (Esteban et al., 1992) indicated that phenolic compounds peaked at intermediate ripening stages. In contrast, (Mennella et al., 2012) in a detailed characterization of phenolic compounds in different eggplant genotypes and allied species showed that phenolics dropped during development. Unfortunately this work was conducted only at three ripening stages, starting at intermediate development and "baby" eggplants were not evaluated. In addition, the last ripening stage tested corresponded to non-commercial, senescent fruit. Consequently, the aims of the present study were to evaluate the changes in antioxidants in purple eggplants at all commercially relevant stages as well as the influence of harvest maturity on fruit response to different storage regimes.

2. Materials and methods

2.1. Physico-chemical characterization of eggplant fruit at different developmental stages

Eggplants *cv*. Monarca (M) and Perla Negra (PN) were cultivated in a greenhouse (110 m × 25 m) in La Plata, Argentina. Seven rows per cultivar located in the central zone of the greenhouse were used for fruit tagging. Two hundred and fifty fruit were tagged immediately after set. At days 12, 15, 18, 20 and 23 after set (DAFS; defined as stages I, II, III, IV, V; respectively) 50 fruit were harvested and transported immediately to the laboratory. Individual fruit size (length and equatorial diameter), weight, bulk density and calyx area were determined. Fruit were then used to analyze respiration rate, firmness, dry weight for cell wall isolation and to perform chlorogenic acid histolocalization. Peel and pulp samples were frozen in liquid N_2 and stored at −80 °C until analysis of carotenoids, total phenolics, hydroxycynamic acids, total flavonoids, anthocyanins and chlorogenic acid as described in Section 2.3. The whole experiment was repeated three times during October–December 2011.

2.2. Postharvest evaluation of eggplant fruit at different developmental stages

Eggplants *cv*. Monarca (M) and Perla Negra (PN) cultivated and tagged as indicated in Section 2.1 were harvested after 12, 18 and 20 DAFS. Stage I represented "baby" eggplants. Stages III and IV were selected for being the most common harvest maturities used commercially for early and late harvests respectively. Fruit were packed in plastic trays, covered with perforated PVC (wrap film) and stored at 0 or 10 °C (85–90% RH) for 0 or 12 d. Upon removal from the cold storage samples were subjected to a 2 d shelf life period at 20 °C (12 + 2 d). Fruit deterioration index was determined and surface color and respiration rate were evaluated as indicated in Section 2.3. Forty fruit were used for each developmental stage and temperature analyzed.

2.3. Analytical measurements

2.3.1. Calyx area

The fruit calyxes were detached from the pericarp and digitized using a Hewlett–Packard model C4480 scanner. The areas were calculated by using AutoCAD® 2014. Ten fruit were used per cultivar and developmental stage and results were expressed in cm^2.

2.3.2. Dry weight

Three grams of pulp tissue (Iw) were cut with a razor blade into small cubes and dried at 70 °C in a vacuum oven (2.5 kPa) until constant weight (Fw). Fruit pulp dry weight (DW) was calculated as:

$$DW(\%) = \frac{100 - (100 \times (Iw - Fw))}{Iw}$$

Measurements were done in triplicate for each cultivar and developmental stage. Results were expressed as percentage of fresh weight.

2.3.3. Bulk density

Individual fruit were weighed and volume was subsequently determined by water displacement in graduated jars containing stoppers that allowed total fruit immersion. Twenty fruit were evaluated for each cultivar and developmental stage.

2.3.4. Respiration rate

Carbon dioxide production was measured by incubating two fruit in 3 L hermetic jars. After 15 min the gas concentration was obtained using an IR sensor (Alnor Compu-Flow, Model 8650, United States). Three measurements were done for each cultivar and developmental stage. Results were expressed in μmol kg^{-1} s^{-1}.

2.3.5. Surface color

Peel color was evaluated with a colorimeter (Minolta, Model CR-400, Osaka, Japan) by measuring the parameters L* a* b*. Thirty fruit were analyzed for each cultivar and storage condition.

2.3.6. Firmness

Firmness was evaluated in a texture analyzer (TA.XT2, Stable Micro Systems Texture Technologies, Scarsdale, NY, USA) fitted with 3 mm probe. Each sample was compressed for 8 mm distance at the equatorial position, at the rate of 0.5 mm s^{-1}. Thirty fruit were analyzed and two measurements were done on opposite sides of each fruit. Results were calculated as the initial slope of the force deformation curve and expressed in kN m^{-1}.

2.3.7. Cell wall isolation

Fruit cell walls were isolated according to (Vicente et al., 2007). Frozen pulp tissue was ground in a mill and 7.5 g of resultant powder was added to 50 mL of ethanol and boiled for 20 min. The insoluble material was filtered and sequentially washed with 50 mL of ethanol, chloroform and methanol (1:1), and acetone, yielding the crude cell wall extract (alcohol insoluble residue, AIR). The AIR was dried overnight at 37 °C and weighed. Results were expressed as grams per kilogram on fresh weight basis. Measurements were done in triplicate for each cultivar and developmental stage.

2.3.8. Anthocyanins

Anthocyanins were extracted from the peel of at least six eggplants. The peel was frozen in liquid N_2, powdered and 0.5 g were extracted 4 times with HCl and methanol (1:99, v/v). After centrifugation (12,000 × *g* for 5 min) the supernatant was taken to 50 mL with HCl and methanol (1:99, v/v). Samples were vacuum concentrated to 2 mL, filtered through a 0.45 μm nylon membrane and 10 μL were injected into a liquid chromatograph (Model HP 1100