Scientia Horticulturae 244 (2019) 22–30

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Micro-structural and quality changes in growing dark-purple eggplant (*solanum melongena* L.) as affected by the harvest season

Lucía Valerga[a], Magalí Darré[a,b], María José Zaro[a,*], Ana Arambarri[c], Ariel Roberto Vicente[a,b], María Laura Lemoine[a,b], Analía Concellón[a]

[a] CIDCA (Centro de Investigación y Desarrollo en Criotecnología de Alimentos) (CCT La Plata CONICET-UNLP), Calle 47 y 116, CP 1900, La Plata, Argentina
[b] LIPA, (Laboratorio de Investigación en Productos Agroindustriales), Facultad de Ciencias Agrarias y Forestales, Universidad Nacional de La Plata (UNLP), Calle 60 y 119, CP 1900, La Plata, Argentina
[c] LAMCE (Laboratorio de Morfología Comparada de Espermatófitas), Facultad de Ciencias Agrarias y Forestales, Universidad Nacional de La Plata (UNLP), Calle 60 y 119, CP 1900, La Plata, Argentina

ARTICLE INFO

Keywords:
Cuticle
Epidermal
Parenchyma
Respiration
Firmness

ABSTRACT

Whereas the production season is accepted to exert profound influence on fruit physiology, micro-structure and quality, very few studies have attempted to find liaisons between these traits. Herein, we determined the micro-structural and quality changes of eggplant fruit produced in *Late Spring* (mean air temperature 22 °C; max. 28 °C; min. 16 °C), *Late Summer* (mean air temperature 19 °C; max. 25 °C; min. 13 °C) and *Late Fall* (mean air temperature 11 °C; max. 15 °C; min. 6 °C), at three growing stages: *Baby* (*S1*, 9 cm length), *Commercially mature* (*S2*, 17 cm length) and *Advanced commercially mature* (*S3*, 21 cm length). We followed fruit elongation and assessed at harvest the size of epidermal and parenchyma cells, cuticle thickness, respiration rate, dry matter, firmness, seed number, seed size and seediness. The time required to reach commercial maturity was 3–4 times shorter in *Late Spring* than in *Late Fall*. Micro-structural evaluations showed that *Late Spring* fruit had epidermal and epicarp cells per unit area than *Late Fall* eggplants, which in turn presented thinner cuticles and a less compact large-celled central endocarp parenchyma. Commercially mature *Late Fall* eggplants also lighter color, showed lower respiration and were firmer than fruit growing earlier in the season. For all maturity stages fruit dry matter content was the parameter correlating best with fruit firmness (r = 0.71). *Late Summer* fruit tended to show intermediate properties, but had higher seed number, size and seediness. Overall, results show the influence that the growing season exerts on eggplant metabolism, micro-structure and quality.

1. Introduction

Eggplant (*Solanum melongena* L.) is the second *Solanaceae* fruit species cultivated in term of production volume after the tomato with 52 million tonnes produced worldwide (Knapp et al., 2013; FAOSTAT, 2016). With an annual production cycle, this subtropical species is normally cultivated starting in late spring, when the risk of chilling and freezing damage decreases (Sun et al., 1990; Passam and Khah, 1992). Fruit ontogeny is initiated by a discrete period of intensive cell division, followed by an elongation stage, which will govern final fruit size once cell proliferation ends (Gillaspy et al., 1993; Renaudin et al., 2017). Eggplants are picked at an immature stage (Lawande and Chavan, 1998) usually between 10 and 40 days after flowering (Cantwell and Suslow, 2017). However, when the production cycle is extended until the fall, the time from fruit set to maturity could take as long as 60 days (Zaro et al., 2015).

Fruits and vegetable production season is known to have great impact in both yield and quality. Various studies have shown that wide range of fruit productivity and properties during the growing cycle results from variations in pollen viability, pollinators' activity, stigma receptivity, ovule fertilization, set efficiency, growth and ripening (Abdul-Baki and Stommel, 1995; Bertin, 2005; Zhang et al., 2006). He et al. (1999) found impaired set, and decreased size in tomato produced in fall and winter compared to spring fruit. Higher prevalence of physiological disorders such as cat face, puffiness was associated with low temperatures occurring in early and late during the production cycle (Gruda, 2005). Changes in water availability, nutrient uptake, transport and allocation have been also identified as determinants of the variations in fruit traits observed between early and late harvested commodities (Haig and Westoby, 1988; Kowalska, 2008). The growing

* Corresponding author.
E-mail address: maria.zaro@agro.ulp.edu.ar (M.J. Zaro).

https://doi.org/10.1016/j.scienta.2018.09.032
Received 16 April 2018; Received in revised form 11 September 2018; Accepted 12 September 2018

season is also reported to exert dramatic effects in the quality and postharvest performance of fresh produce (Leccese et al., 2012). Summer harvested rocket (*Eruca sativa*) is less prone to dehydration, but losses chlorophyll more rapidly than spring leaves (Edelenbos et al., 2017).

Despite of the large number of works describing the seasonal changes occurring in fruit and vegetable properties, very few studies have evaluated the biological basis of such variability in metabolism and quality traits. We hypothesized that the changes in fruit properties during the growing season were associated with modifications in fruit micro-structure. In line whit this, Bertin (2005) and Segado et al. (2016) reported that the environmental conditions during tomato growth have significant impact in cell division and expansion. Instead, no works have been conducted to date to evaluate this in *Solanaceous* species other than the tomato. In the present work, we determined seasonal changes in eggplant micro-structure (cuticle thickness, epidermis, epicarp, peripheral and central endocarp parenchyma cells size and packaging), respiration rate, dry matter content, surface color and firmness to shed light on the association between fruit micro-structure, metabolic rate and texture.

2. Materials and methods

2.1. Plant material

The experiments were carried out in La Plata, Argentina (Latitude: 34°59′18″ S, Longitude: 57°56′17″ W) in an arch-type greenhouse (2.5 m height × 10 m width × 40 m length), covered with low-density polyethylene (150 μm thick); the sides were closed with an anti-aphid screen. Ventilation was provided by opening greenhouse laterals when the air temperature exceeded 25 °C. Light was provided only by natural solar radiation. Seeds from dark-purple eggplant seedlings (*Solanum melongena* L.) cv. Monarca were germinated in vermiculite and after emergence, the seed trays were placed in a different compartment with a mean daily temperature of 20 °C. At the two true-leaves stage, eggplant plants were transplanted (July 10th) and arranged in double rows. Plants were spaced 1 m between rows and 0.8 m. The plants were pruned to four stems. Irrigation was conducted every day during Spring and Summer and once a week in late Fall. Nutrient solution was pumped from fertilizer tanks through a drip irrigation system with one emitter per plant and an emitter flow rate of 4 L h^{-1}. Fertilization was applied with drip irrigation throughout the growing cycle and consisted of 80 g $plant^{-1}$ of a 10 N– 2.2 P – 24.9 K plus micronutrients commercial fertilizer. Fruit set was achieved either by natural pollination. To evaluate fruit elongation kinetics 180 eggplants from different plants were tagged after set in *Late Spring* (December, mean air temperature 22 °C; max. 28 °C; min. 16 °C), *Late Summer* (March, mean air temperature 19 °C; max. 25 °C; min. 13 °C) and *Late Fall* (May, mean air temperature 11 °C; max. 15 °C; min. 6 °C). Fruit length was determined at regular intervals throughout the growing period. For quality and micro-structural evaluation fruit was harvested in *Late Spring, Late Summer* and *Late Fall* at three growing stages: *Baby* (S1, 9 cm length), *Commercially mature* (S2, 17 cm length) and *Advanced commercially mature* (S3, 21 cm length) in the morning (09.00 to 10.00 h) and conveyed immediately to the laboratory for analysis. Fruit length, diameter, weight, respiration rate, surface color and firmness were determined. We also assessed seed number, size and seed to pulp ratio of fruit equatorial transversal sections. For the nine season-growth stage combinations, samples were taken and used to evaluate fruit micro-structure (cuticle thickness, epidermis, epicarp, peripheral and central endocarp parenchyma cells size and packaging) and dry matter content as described below. Thirty fruit were evaluated for each season and growing stage.

2.2. Length, diameter and weight

Fruit length was determined by recording the distance between fruit blossom and stem end. Fruit equatorial diameter was evaluated with a Vernier caliper. Two measurements were done by rotating the fruit 90° and averaged. Each fruit was subsequently weighed on a digital balance (Kern, Model 572, Argentine). Results for dimensions and weight were expressed in meter and kilogram, respectively. Thirty fruit were evaluated for each harvest season and growing stage.

2.3. Micro-structural analysis

To evaluate cuticle thickness fresh eggplant slices from the equatorial region and transversal to the main axis were cut and immediately fixed with FAA70 (formaldehyde: glacial acetic acid: ethanol 70%) (Johansen, 1940). Transversal thin hand sections from the outer pericarp at the equatorial region of the fruit were prepared and immersed in saturated solution of Sudan IV in 70% v/v ethanol (EtOH) for 15 min. Samples were subsequently rinsed with 70% v/v EtOH for 1 min and mounted on glycerin jelly (Johansen, 1940). The sections were subsequently examined using a Gemalux Lux light microscope and images were captured with a Moticam 1000 attached to the eyepiece of a microscope, and Motic Image Plus 2.0 software. A magnification of 400× was used. The fruit cuticles were identified by the reddish color, indicating the presence of lipophilic components (Ruzin, 1999). Cuticle thickness was manually measured using the software ImageJ (Rasband, W.S., ImageJ v. 1.43 s, National Institute of Health, Bethesda, MD, USA) and expressed in μm. Thirty measurements were done in four different eggplants and evaluated for each growing stage and production season.

To evaluate the mean size and packaging of epidermal, epicarp, peripheral and central endocarp cells transversal section of fruit equatorial zone were prepared as described above and mounted on glycerin jelly with an 80% v/v alcoholic solution of safranin. Sections were examined using a Gemalux Lux light microscope and images were captured with a Moticam 1000 attached to the eyepiece of microscope, and Motic Image Plus 2.0 software. A magnification of 100× was used. The number of cells per mm^2 was calculated in a defined area of the slice in which the number of cells present was counted using the software ImageJ1.43. Four slices from independent fruit were evaluated for each growing stage and harvest season.

2.4. Respiration rate

Fruit was weighed and placed in a 3 L flask, sealed and incubated for 15 min at 20 °C. The concentration of CO_2 in the headspace was determined using an infrared analyzer (Alnor, CompuFlow Model 8650 MN, USA). Results were expressed as rate of CO_2 evolution in mg per kg in an hour. Four measurements were done for each growing stage and harvest season.

2.5. Surface color

Fruit surface color (L*, b*, a*, Hue and Chroma) was evaluated with a colorimeter (Minolta, Model CR-400, Osaka, Japan) to obtain L* and a* values. Results were analyzed by following the changes in L* and a* values with denoted the lightness and red component, respectively. Thirty fruit were measured for each harvest season and growing stage.

2.6. Firmness

Firmness was evaluated by a compression test in a texture analyzer (TA.XT2, Stable Micro Systems Texture Technologies, Scarsdale, NY, USA) fitted with a 3 mm probe. Each sample was compressed at the equatorial region and transversal to the main fruit axis at a speed of 1 mm per sec for 8 mm. The initial slope of the force deformation curve was calculated and expressed in Newton per second. Thirty