Journal of Plant Physiology 196 (2016) 70–78

Contents lists available at ScienceDirect

Journal of Plant Physiology

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

Physiology

Factors affecting ethylene and carbon dioxide concentrations during ripening: Incidence on final dry matter, total soluble solids content and acidity of mango fruit

Thibault Nordey[a,*], Mathieu Léchaudel[a], Michel Génard[b], Jacques Joas[c]

[a] *CIRAD, UPR HORTSYS, 97455 Saint-Pierre, La Réunion, France*
[b] *INRA, UR 1115, Plantes et Systèmes de Culture Horticoles, 84000 Avignon, France*
[c] *CIRAD, UMR QUALISUD, 34398 Montpellier, France*

A R T I C L E I N F O

Article history:
Received 2 December 2015
Received in revised form 14 March 2016
Accepted 14 March 2016
Available online 6 April 2016

Keywords:
Ripening
Gas exchange
Ethylene
Climacteric respiration
Quality

A B S T R A C T

Ripening of climacteric fruits is associated with pronounced changes in fruit gas composition caused by a concomitant rise in respiration and ethylene production. There is a discrepancy in the literature since some authors reported that changes in fruit gas compositions differ in attached and detached fruits. This study presents for the first time an overview of pre- and post-harvest factors that lead to variations in the climacteric respiration and ethylene production, and attempts to determine their impacts on fruit composition, i.e., dry matter, total soluble solids content and acidity.

The impact of growing conditions such as the fruit position in the canopy and the fruit carbon supply; fruit detachment from the tree, including the maturity stage at harvest; and storage conditions after harvest, i.e., relative humidity and temperature were considered as well as changes in fruit skin resistance to gas diffusion during fruit growth and storage.

Results showed that fruit gas composition vary with all pre and post-harvest factors studied. Although all mangoes underwent a respiratory climacteric and an autocatalytic ethylene production, whatever pre and post-harvest factors studied, large differences in ethylene production, climacteric respiration and fruit quality were measured. Results suggested that the ripening capacity is not related to the fruit ability to produce great amount of ethylene. In agreement with precedent studies, this work provided several lines of evidence that gas composition of fruit is related to its water balance. Our measurements indicated that skin resistance to gas diffusion increased after the harvest and during storage. It was so suggested that the faster ripening of detached fruit may be explained in part by changes in fruit water balance and skin resistance to gas diffusion caused by fruit detachment.

1. Introduction

Fruit ripening is an unavoidable and irreversible physiological process during which the overall fruit quality radically changes. In just a few days, fruit quality improves until it reaches its optimum and then declines until the fruit becomes inedible due to over-ripening. Stakeholders within the supply chain have to manage fruit ripening in order to provide the best fruit quality to consumers. For climacteric fruits such as bananas, mangoes and avocados, this is a real challenge because they are highly perishables that cause considerable economic losses.

Ripening of climacteric fruits is associated with pronounced changes in fruit gas composition caused by a concomitant rise in respiration and ethylene production (Burg and Burg, 1962). The impact of fruit gas changes on ripening processes has been the focus of numerous studies. The increase in ethylene production initiates a cascade of events that lead to many interactive signaling and metabolic pathways responsible for ripening progress in climacteric fruits (Bapat et al., 2010; Liu et al., 2015; Paul et al., 2012), although studies on cantaloupe melon (Pech et al., 2008) and tomato (Jeffery et al., 1984) suggest that some ripening processes such as the accumulation of sugar and the degradation of organic acids are not regulated by ethylene. The involvement of the respiration rise in the ripening process is unclear. Several studies report the absence of or a reduced rise in respiration when fruits are ripened on the tree, despite a pronounced peak in ethylene production (Bower et al., 2002; Saltveit, 1993; Shellie and Saltveit,

---

* Corresponding author.
E-mail address: thibault.nordey@cirad.fr (T. Nordey).

http://dx.doi.org/10.1016/j.jplph.2016.03.008
0176-1617/

1993). This result has been interpreted by these authors as evidence that the rise in respiration is an artefact caused by stress or fruit detachment.

It was previously reported that several factors may induce variations in the climacteric respiration and in ethylene production, including the environment encountered by the fruit during its development (Bower et al. 2002; Joas et al., 2012), the fruit physiological age at harvest (Song and Bangerth, 1996), fruit detachment from the tree (Bower et al., 2002; Shellie and Saltveit, 1993) and storage conditions (Eaks, 1978; Finger et al., 1995; Mendoza et al., 2016).

Until now, it was assumed that changes in fruit gas composition have been assumed to result from changes in ethylene metabolism and/or respiration rate. However, these changes may also be attributed to variations in fruit skin resistance to gas diffusion. This would be consistent with the numerous studies stating that fruit surface features such as the presence of cracks and the thickness of the cuticle and the hypodermis vary during fruit development and as a function of growing conditions (Gibert et al., 2005; Milad and Shackel, 1992; Paul et al., 2007).

For climacteric fruits, changes in fruit gas concentration cannot be separated from the ripening process (Paul and Pandey, 2014). A piecemeal approach has been employed until now for studying sources of variations in gas changes during ripening, by focusing either on pre-harvest factors or on post-harvest factors. This study therefore presents for the first time an overview of pre- and post-harvest factors that lead to variations in the climacteric respiration and ethylene production, and attempts to determine their impacts on fruit composition, i.e., dry matter, total soluble solids content and acidity. To establish whether these changes in gas composition are related to change in skin features, it is proposed in this study to measured changes in skin resistance to gas diffusion during fruit growth and storage after harvest.

Mango fruit was chosen because quality management of this fruit is a major limit to its sale (Tharanathan et al., 2006). Mango fruits grow in tropical and sub-tropical areas characterized by large temperature and air moisture changes, are picked up at different maturity stages, and are stored in different conditions of air moisture and temperature (Joas et al. 2012; Litz, 2009). Several studies reported that the ripening of mango and its quality considerably change with fruit growing conditions, harvest date, and storage conditions (Hofman et al., 1995; Léchaudel and Joas, 2007; Singh et al., 2013). The first part of this study focuses on factors involved in variations in fruit gas content. The impact of (i) growing conditions such as the fruit position in the canopy and the fruit carbon supply; (ii) fruit detachment from the tree, including the maturity stage at harvest; and (iii) storage conditions after harvest, i.e., relative humidity and temperature were considered as well as (iv) changes in fruit skin resistance to gas diffusion during fruit growth and storage. The second part of this study was dedicated to measuring and to discussing changes in fruit composition, i.e., dry matter, total soluble solids content and acidity, related to changes in fruit gas content.

2. Material and methods

2.1. Fruit sampling

The study was carried out on mangoes (*Mangifera indica* L.) of the Cogshall cultivar. Fruits were grown in the CIRAD orchard collection of Reunion Island (20°52′ 48″ S, 55°31′ 48″ E), composed of 19-year-old trees in 2009, grafted on the 'Maison Rouge' cultivar. Trees were well irrigated, spaced 5 × 6 m apart, and were approximately 3 m high.

To evaluate how growing conditions influence the climacteric respiration and the ethylene production, three growing conditions were differentiated during the 2011–2012 growing season: sunny and shaded fruit with normal carbon supply and sunny fruit with low carbon supply. This was done by girdling branches at 60 Days After full Bloom (DAB) inside or outside the canopy and by defruiting and defoliating branches to establish a fixed leaf-to-fruit ratio of either 25 leaves or 100 leaves per fruit. Branches were girdled by removing a 10–15-mm-wide band of bark. The 100 leaf-to-fruit ratio (L/F) corresponded to the non-limiting condition of carbohydrate supply for fruit growth (Léchaudel et al., 2005). Changes in CO_2, O_2 and C_2H_4 internal concentrations of fruits attached to the tree during their development, were nondestructively measured on four to six attached fruits undergoing the different tested growing conditions between 60 and 165 DAB.

To test the impact of the harvest date on fruits gas composition, nine to 11 sunny fruits that were grown with a normal carbon supply were harvested at 63, 78, 92, 113 and 125 DAB, during the 2011–2012 growing season and left to ripen under normal storage conditions. The respiration rates of these harvested fruits were measured daily. Ethylene concentrations were measured in these fruits one day after they were harvested, the day when the maximal respiration rate value was assessed, and two days later.

To evaluate the impact of the fruit detachment on fruit gas concentration, non-destructive measurements of internal concentrations in ethylene (C_2H_4) and carbon dioxide (CO_2) were made on five attached fruits at 100 DAB during the 2010–2011 growing season. These fruits were then detached and their internal carbon dioxide and ethylene concentrations were measured 6 h after they were harvested and the following days.

To test the impact of the fruit water losses during storage on the climacteric respiration of mango, sunny fruits harvested at 92 DAB during the 2009–2010 growing season with a normal carbon supply were divided into two batches of four fruits. The respiration rates of fruits from the first batch that were let to ripen in dry atmosphere, i.e., 50% relative humidity at 20 °C, were measured and compared to the respiration rates of fruits from the second batch that were let to ripen in normal storage conditions, i.e., 20 °C and 90% relative humidity.

To evaluate how storage temperature affects the climacteric respiration of detached fruit, mangoes were divided into three batches of four fruits harvested at 106 DAB. The respiration rates of fruits from the first batch that were left to ripen under normal storage conditions, i.e., 20 °C and 90% relative humidity, were measured daily. Fruits from the second and third batches were initially stored at 7 °C and 12 °C, respectively, with 90% relative humidity for 20 days, and then left to ripen under normal storage conditions, i.e., 20 °C and 90% relative humidity. The respiration rates of fruits from the second and third batches were measured daily while they were stored under normal storage conditions.

To assess changes in fruit skin resistance to CO_2, O_2 and C_2H_4 diffusion, non-nondestructive measurements were made at 63, 78, 92, 113 and 125 DAB during the 2011–2012 growing period for five to six sunny attached fruits with a normal carbon supply (100 L/F). To test whether there was skin resistance to gas diffusion changes after the harvest five fruits with a normal and low carbon supply were harvested at 113 DAB and left to ripen under normal storage conditions, i.e., 20 °C and 90% relative humidity. The skin resistance of these fruits was measured at the green stage, two days after they were harvested, and at the ripe stage, seven days after they were harvested. In addition, the respiration rate and the internal content in CO_2 of six other sunny fruits with normal carbon supply, harvested at 113 DAB and left to ripen under normal storage conditions, were measured daily