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Effects of waxing, microperforated polyethylene bag, 1-methylcyclopropene and nitric oxide on firmness and shrivel and weight loss of 'Manila' mango fruit during ripening

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ABSTRACT

The mango export market demands varieties with high fruit quality and firmness. The 'Manila' mango has high sensory quality, but does not yet reach export markets largely due to high weight loss, shrivel and rapid firmness loss during ripening. Application of 1-methylcyclopropene (1-MCP) alone or combined with a microperforated bag (MP bag) or nitric oxide (NO) alone or combined with waxing were studied for efficacy to delay fruit softening, shrivel and weight loss. The waxing alone or combined with NO maintained fruit firmness up to 18 d at 13 °C and reduced weight loss and shrivel, whereas the MP bag with 1-MCP reduced weight loss and shrivel but firmness was maintained only for 10 d at 13 °C. Treatments applied did not have an effect on color, TSS and TA changes during ripening. Pectinesterase (PE) and polygalacturonase (PG) activities in exocarp tissue were not related to firmness loss. However, in waxed fruit, PE and PG activities in the mesocarp only partially explained the softening process. The weight loss of 'Manila' mango is directly related to the shriveled appearance of the fruit, as well as contributing to firmness loss.

1. Introduction

Mango (*Mangifera indica* L.) is considered one of the favorite fruit in the world due to its attractive color, delicious taste, pleasant fragrance and nutritional value (Tharanathan et al., 2006). The potential export market of mango fruit to the USA is estimated at 100 million 4.53 kg boxes per year (National Mango Board, 2014), and this market demands mainly varieties with good visual quality, regular size and good firmness such as 'Tommy Atkins', 'Ataulfo', 'Keitt', 'Haden', 'Kent' among others. Mexico is the seventh producer of mango fruit in the world and is the leading exporter to the USA market (FAOSTAT, 2014). However, Mexico also produce others mango varieties with higher sensory quality such as 'Manila' that have little participation in this market due to low firmness and tendency to shrivel (SAGARPA, 2014).

Mango is a climacteric fruit, and its short ripening period is one of the limiting factors affecting the economic value of the fruit (Mahto and Das, 2013). 'Manila' mango fruit is a polyembryonic variety that has a high metabolic rate compared to 'Tommy Atkins', 'Haden' or 'Kent' which are monoembryonic varieties. Also 'Manila' variety has histological differences including fewer layers of epidermal cells, thinner hypodermic cell walls, thinner cuticle and larger mesocarp cells than 'Haden' fruit (Barbosa-Martínez et al., 2009). These histological and physiological characteristics explain differences in water loss, postharvest diseases, mechanical damage and fruit perishability (Barbosa-Martínez et al., 2009). These characteristics contribute to the short postharvest life of 'Manila' mango. Therefore, it is necessary to look for alternatives that improve the handling performance of this variety and give it a higher participation in the export market.

Different methods have been used to extend the shelf life of mango fruit and reduce losses. These methods include refrigeration, modified atmospheres through use of polyethylene bags (with or without microperforations), wax coating and the use of ripeness regulators (Tharanathan et al., 2006) such as 1-MCP

Abbreviations: 1-MCP, 1-methylcyclopropene; NO, nitric oxide; MP bag, microperforated bag; TSS, total soluble solids; TA, titratable acidity; PE, pectinesterase; PG, polygalacturonase; NPS, sodium nitropusiate.

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(Blankenship, 2001) and NO (Wills et al., 2000). A combination of these can also be adopted to extend the shelf life of fruit (Tharanathan et al., 2006).

The MP bag and wax coating are used to delay transpiration. The MP bag has been used to modify CO_2 and O_2 levels around fruit and reduce weight loss in apples (Watkins and Thompson, 1992) and acid lime (Ramin and Khoshbakhat, 2008). The wax coating is mainly applied to delay moisture loss and to give glossiness, and for enhancing shelf life and maintain postharvest quality of several fruit including mango (Baldwin et al., 1999; Hoa and Ducamp, 2008), and pomegranate (Barman et al., 2011).

1-MCP is considered the most effective ethylene action inhibitor since it is active at extremely low concentrations, readily available for commercial use, and nontoxic (Sisler and Serek, 1997). 1-MCP extended the shelf life of mango cv. 'Ataulfo' (Muy-Rangel et al., 2009) and banana (Jiang et al., 1999). On the other hand, NO is an important signaling molecule known to inhibit ethylene production during ripening and/or storage (Wu et al., 2014). NO extended the shelf life of strawberry (Wills et al., 2000), peach (Zhu et al., 2006) and mango (Zaharah and Singh, 2011).

However, the use of these blockers of ethylene action or inhibitors of its synthesis have to be evaluated for each fruit. Muy-Rangel et al. (2009) indicated in 'Ataulfo' mango that 1-MCP decreased the weight loss whereas the chitosan edible films resulted in higher weight loss, which suggests that the fruit metabolic rate affected the weight loss. Ketsa et al. (2013) indicated a synergistic effect of 1-MCP and polyethylene bags on the shelf life of bananas, and Jeong et al. (2003) reported a similar result in avocado fruit treated with 1-MCP and waxing. In contrast, Basseto et al. (2005) reported higher weight loss in guava fruit treated with 1-MCP, although respiratory activity was markedly reduced. It is therefore necessary to assess the effects of ripening regulators together with techniques that regulate weight loss and shrivel to control firmness changes. The objective of this study was to evaluate the effectiveness of ripeness and transpiration regulators to extend the shelf life of 'Manila' mango fruit, based mainly on their effects on physical appearance (degree of shrivel), weight loss and firmness.

2. Materials and methods

2.1. Fruit material, postharvest treatments and storage conditions

'Manila' mango fruit were harvested at 75% maturity from commercial orchards in Guerrero, Mexico (16°28′18″N, 98°24′55″O). After harvest, all fruit were dipped in 1% sodium chloride solution in water to check the ripeness stage (Lizada, 1991). Fruit without defects were selected for medium size, good quality and shape, and placed in plastic boxes. All fruit were submitted to hot water treatment (7 min at 53 °C) to anthracnose control (Jeffries et al., 1990), and then were cooled in air (6 h), packed in corrugated cardboard boxes (16 fruit per box) and the boxes were placed on a pallet. A perforated plastic film was placed around the pallet to reduce the weight loss and the pallet was transported to the laboratory at Autonomous University of Queretaro in a refrigerated vehicle at 13 °C and stored 8 h at 13 °C before the application of the treatments.

Two different experiments were carried out. The first was designed to evaluate the 1-MCP and MP bag effects. The second was designed to evaluate NO and waxing effects on the fruit quality and enzymatic activities. The optimal conditions of 1-MCP application were determined in a preliminary experiment in which, three sets of 54 mature green fruit were treated with 0, 0.3 and 0.5 mg L^{-1} of 1-MCP (SmartFresh®) for 5 h and the fruit were stored for 19 d at 13 °C. External and internal quality, weight loss, total soluble solids (TSS), titratable acidity (TA), shrivel and metabolic integrity of mitochondria by the tetrazolium chloride test (Steponkus and Lanphear, 1967) were evaluated. Fruit treated with 0.3 mg L^{-1} 1-MCP showed delay in ripening, less shrivel and maintained mitochondrial integrity compared to the control fruit. Exposure to 0.5 mg L^{-1} 1-MCP blocked the ripening process and strongly altered the mitochondrial integrity. Therefore, treatment with 0.3 mg L^{-1} 1-MCP for 5 h at 13 °C and 90–95% RH was selected for experiment 1. After 1-MCP treatment, the fruit were removed from the chambers and placed in commercial corrugated cardboard boxes with and without MP bag (Prime Pro®, 40401 perforations m^2, and 48 μm thickness), and were closed with Velcro® strips. All fruit were stored at 13 °C with 90–95% RH for up to 21 d. Six fruit were taken at each sampling time for each treatment group for quality evaluations. The experiment was consisted of four treatments: fruit packing with MP bag (MP bag), fruit treated with 1-MCP (1-MCP), fruit with combined treatments (1-MCP + MP bag) and control fruit.

For the second experiment, the optimum conditions of the NO application were also determined in a preliminary experiment. An aqueous solution (1 mM) of sodium nitroprusiate (NPS) was used as an NO doner, which was exposed under a fluorescent lamp with irradiance of 2,00,000 μW m^{-2} for 3 or 6 h to release the NO (Frank et al., 1976; Arnold et al., 1984).

Two sets of 54 mature green fruit were infiltrated in the NPS solution (3 and 6 h of light exposure) in a chamber under partial vacuum (33.86 kPa) for 3 min. A third set of fruit was infiltrated with distilled water under the same vacuum conditions (control group). After that, the fruit were washed, drained, and maintained for 22 d at 13 °C evaluating their external and internal quality, weight loss, TSS, TA and shrivel. Infiltration of NPS solution exposed to light for 3 h did not modify the ripening process of mango fruit nor did it cause any damage. The fruit treated with NPS exposed for 6 h to light showed damage on the exocarp of the fruit and decreased visual quality. This results showed that the exposure of the NPS solution for 3 h to the light and infiltrated to 33.86 kPa for 3 min were the best conditions.

After the NPS or water treatments, the fruit were washed in water, drained and divided in four groups: control fruit, NO fruit treated, fruit treated with wax, and wax + NO. For waxing, fruit were manually coated with a sponge impregnated with TFC 210 wax (carnauba base, total solids of 22.4%, Natural Shine from Pace Int.) and air dried at room temperature. Fruit were packed in commercial corrugated cardboard boxes for mango exports and were stored at 13 °C with 90–95% RH. The boxes were stacked into the cold room. Six fruit were taken from each group at 4 d intervals and analyzed for fruit quality and enzymatic analysis.

2.2. Physical analysis

2.2.1. Weight loss

The fruit were weighed at the beginning and end of the storage on a digital balance (Ohaus Scout Pro 400 g × 0.01 g). The rate of cumulative weight loss was determined by the difference of the initial weight and final weight and compared with initial weight. The data was reported as a percentage of initial weight (Barman et al., 2011).

2.2.2. Firmness evaluation

Firmness of fruit was determined with a TA-HD texture analyzer (Stable Micro Systems) equipped with a 50.8 mm flat cylindrical probe at a test velocity of 2 mm s^{-1}. Each fruit was placed under the probe and the maximum force to reach 3% deformation at the equatorial diameter was registered.