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Impacts of mixed fruit loading on postharvest physiological responses and quality of horticultural produce

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ABSTRACT

Postharvest supply chain of fresh produce often involves close proximity of fruit with different ethylene sensitivities. Thus, the quality of fruit sensitive to ethylene may be affected due to the exogenous ethylene, produced by other commodities. This study was conducted to assess the impacts of a mixed fruit loading and storage on the physiological and qualitative attributes of fruits. Further on, the effectiveness of ethylene removal using conventional ethylene absorbent sachets as well as an in-house developed ultraviolet light based reactor in such mixed storage was also evaluated. High ethylene producer (apples) was stored along with non-treated green bananas and unripe kiwifruit (highly sensitive to ethylene), at 15 °C for 10 days. Post-storage analysis showed that bananas and kiwifruits stored with apples had significantly elevated respiration and ethylene production rates compared to samples stored alone. Mix loading with apples resulted in a significant decline in tissue strength from 25.01 to 6.44 N for kiwifruits; and a significant increase in total soluble sugars from 2.7 to 21.09% for bananas at the end of storage. The use of ethylene absorbent as well as the reactor reduced ethylene concentration in the storage chamber and slowed down respiration rate in the fruits. However, to preserve fruit quality to a higher extent, further research into development of ethylene removal system with higher ethylene removal rate is suggested. The results obtained also highlight the need of proper separation of fresh produce (based on ethylene sensitivity) during transportation, storage and retail display.

1. Introduction

Fruit and vegetables (F & V) are perishable products that along with root crops contribute to 40–50% of the global food waste annually (FAO, 2015). The high perishability of F & V is due to the fact that even after harvest they remain metabolically active and undergo ripening and senescence (Mahajan, Caleb, Singh, Watkins, & Geyer, 2014). Thus, to minimize the postharvest losses, slowing down these physiological and metabolic processes along the value chain is essential. Various postharvest techniques have been successfully used in delaying various physiological and biochemical activities associated with ripening and senescence of F & V. These include the use of cooling, controlled atmosphere storage, modified atmosphere packaging, ethylene management and other techniques (Bapat et al., 2010; Mahajan et al., 2014; Martínez-Romero et al., 2007).

Besides optimal storage conditions, ethylene management is of critical importance along the fresh produce value chain. Ethylene management has also been suggested as an important measure to reduce fresh produce waste (Blanke, 2014, 2015). Ethylene is a product of plant metabolism, which triggers an autocatalytic and irreversible ripening process in climacteric fruit, and expedites senescence in non-climacteric fruit (Saltveit, 1999; Wills, 2015). It is also a by–product of combustion of petrochemicals (Zagory, 1995). Ethylene concentration in the vicinity of storage facility for fresh produce has been found to be higher than normal (0.001–0.005 ppm). This was associated with ethylene produced by climacteric fruits and to the movements of trucks, tractors, forklifts within the facility (Warton, Wills, & Ku, 2000). Similarly, varying concentrations of ethylene were reported at different points in the supply chain; with 0.017–0.035 ppm at supermarkets outlet, and 0.06 ppm at whole sale markets and distribution centers (Warton et al., 2000). Study reported by Rees et. (2011) found approximately 0.05 ppm and 3.6 ppm ethylene concentrations in retail outlets and storage facilities, respectively.

Both ethylene sensitive and ethylene-producing commodities are

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often kept together (mixed loading) during storage and transport. This can be highly detrimental as ethylene has nearly the same specific mass (0.97–0.99 kg m^{-3}) as air (1.27 kg m^{-3}) and can easily diffuse from one part to the other (Blanke, 2014). Ethylene concentrations as low as 0.001 ppm could induce detrimental changes in fresh produce depending on the storage temperature, exposure time and produce sensitivity (Wills, 2015). In a study conducted by (Warton et al., 2000) empty storage room close to avocado storage room was also found to have 0.280 ppm of ethylene. Furthermore, ethylene concentrations in cargo ships prior to and during transport of fresh produce were investigated by Lawton (1991). The authors demonstrated that containers loaded with kiwifruit and apples had ethylene concentration within the range of 0.001–0.008 ppm and 5–15 ppm, respectively. On the other hand, ethylene concentration in the mixed fruit cargo of apples, pears and grapes was about 50 ppm and emanating from apples and pears. Thus, it is generally recommended to assess the compatibility of different produce prior to mixed loading transport or storage, based on their ethylene sensitivity and other factors such as temperature, moisture, and odor (Watkins, 2016). However, often due to high cost, carriers are required to load and stow different produce in the same vessel, hold, or cargo container. Wholesale market maybe poorly designed without separate facilities for loading, unloading, and ripening chamber. While, retail stores may display ethylene sensitive and ethylene producing fruit in close proximity due to space restrictions.

Therefore, this study was undertaken in order to examine the physiological and qualitative changes that may occur in mixed loading of fresh horticultural commodities. To achieve this aim, three different fruit types with varying degree of ethylene production and sensitivity were selected. This included green bananas and unripe kiwifruit (with low ethylene production, high sensitivity) and apples (high ethylene production, moderate sensitivity) (Blanke, 2014; Martínez-Romero et al., 2007). These fruits were stored in different combinations at 15 °C (to mimic average retail temperature) for 10 days. Quality attributes and physiological responses were determined prior to and at the end of storage life. In addition, the effects of ethylene removal using active sachets and an ethylene filtration device (in house developed reactor) in mixed storage of apples, green bananas and unripe kiwifruit were investigated.

2. Materials and methods

2.1. Plant material and storage

Apples (cv. Jonagold), bananas (cv. Cavendish) and kiwifruit (cv. Harvard) were obtained at commercial maturity directly from a local supplier (Frucht Express GmbH, Groß Kreutz, Germany). The fruit were transported in cooled conditions to the Department of Horticultural Engineering (Fresh Lab.), Leibniz institute for Agricultural Engineering and Bioeconomy, Potsdam, Germany. On arrival, the samples were stored overnight at 15 °C prior to the experiments. Two experiments were conducted consecutively in this study. In the first experiment, fruit samples were distributed into seven different combinations as shown in Table 1. Each combination was stored in a closed chamber (190 L) for 10 days at 15 °C (storage temperature was based on average retail condition) in dark. Gas composition (O_2 and CO_2 concentration) was not controlled but monitored by gas analyser (Checkmate 3, PBI Dansensor, Ringsted, Denmark) at regular intervals. Ethylene concentrations were measured using ETD-300 (Sensor sense, Nijmegen, The Netherlands), a laser based photoacoustic detector, along with a gas handling system. The system has a detection limit of 0.0003 ppm with a time resolution of 5 s.

Table 1
Different combinations of fruit in storage.

No.	Fruit combinations	Apples (kg)	Bananas (kg)	Kiwifruit (kg)
1	Banana	–	6	–
2	Apple	6	–	–
3	Kiwifruit	–	–	6
4	Apple + Banana	3	3	–
5	Apple + Kiwifruit	3	–	3
6	Banana + Kiwifruit	–	3	3
7	Apple + Banana + Kiwifruit	2	2	2

The second experiment was based on mixed storage of apples, bananas and kiwifruit in a ratio of 1/3, 1/3, and 1/3, respectively (Total fruit mass 6 kg). In this experiment, the impact of ethylene removal was investigated using commercial ethylene control sachets and an in-house developed reactor based on ultraviolet light. In the first test chamber (190 L), six ethylene removal sachets based on potassium permanganate (Purafil, USA) were placed, while another chamber without any ethylene removal sachets served as the control. For the second test chamber, a stainless steel reactor (diameter = 12 cm, height = 11 cm) which served an ethylene filtration device was placed inside the chamber. The reactor consisted of 3 ultraviolet lamps with maximum power output of 3W each. The major emission from the lamps was at 254 nm with a small emission (5–8%) at 185 nm. The radiation at 185 nm have high energetic photons that are capable of dissociating water and oxygen molecules present in the atmosphere to produce reactive oxygen species as hydroxyl radicals, OH and superoxide ions, O_2^-. These reactive species oxidise ethylene into carbon dioxide and water (Haibao et al., 2016). This method is been researched extensively for air purification (Haibao et al., 2016; Huang, Leung, Li, Leung, & Fu, 2011; Jeong et al., 2006). It is effective in ethylene removal (Chang, Sekiguchi, Wang, & Zhao, 2013) and has potential for application in fruit storage (Scott, Wills, & Patterson, 1971). A small air pump was used to draw the air from the chamber and pass it through the reactor. Thus, a continuous circulation of air was maintained through the reactor. In all three storage chambers, the physiological and quality parameters were measured after a storage period of 10 days.

2.2. Respiration rate and ethylene production rate measurement

Respiration rate (RR) as well as ethylene production rate of the fruits were determined before and after the 10 d storage experiment. RR was measured using a non-invasive and continuous monitoring closed system respirometer (developed in-house). The respirometer consisting of 9 acrylic glass cuvettes (8.2 L), each fitted with non-dispersive infrared CO_2 sensor (GMP222, Vaisala GmbH, Bonn, Germany). Measuring capacity of the respirometer is within the range of 0.1×10^{-3} to 5 g L^{-1}, with an automated gas flush out system to bring in fresh air for each measurement cycle as described by Rux, Caleb, Geyer, and Mahajan (2017). Fruit of the same lot (4 in number) were placed in a cuvette. Hermetic sealing was achieved with O-rings between the lid and cuvette. The respiration rate was calculated as the amount of CO_2 produced per unit mass of the fruit per unit time (mL kg^{-1} h^{-1}).

In order to measure ethylene production rate, fruits were separately stored in small jars and ethylene concentration was measured at regular interval using ETD-300 over a period of 8 h. Ethylene production rate was calculated as the amount of ethylene produced per unit time per unit mass of the fruit (μL kg^{-1} h^{-1}).

2.3. Mass loss

Four fruits of each kind per combination were marked and weighed before and after storage using an electronic balance CPA10035 (Sartorius, Göttingen, Germany). The difference in the weight between the initial and after storage measurement was calculated and averaged.

2.4. Light remittance for pigment analysis

The remittance readings can provide good information on pigment