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Compositional and functional dynamics of dried papaya as affected by storage time and packaging material

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ABSTRACT

Papaya has been identified as a valuable source of nutrients and antioxidants, which are beneficial for human health. To preserve the nutritional properties after drying, appropriate storage specifications should be considered. This study aimed to investigate the quality and stability of air-dried papaya in terms of quality dynamics and behavior of bio-active compounds during storage for up to 9 months in two packaging materials: aluminum laminated polyethylene and polyamide/polyethylene. Samples with moisture content (MC) of 0.1328 g g^{-1} and water activity (a_w) of 0.5 were stored at 30 °C and relative humidity (RH) of 40–50%. The MC, a_w, degree of browning (DB) and 5-hydroxymethylfurfural (HMF) content were found to notably increase as storage progressed. On the contrary, there was a significant decrease in antioxidant capacity (DPPH, FRAP and ABTS), total phenolic (TP) and ascorbic acid (AA) contents. Packaging in aluminum laminated polyethylene under ambient conditions was found to better preserve bio-active compounds and retard increases in MC, a_w and DB, when compared to polyamide/polyethylene.

1. Introduction

Food security is a critical issue in many countries around the world, while globalization has placed a strain on leading agricultural countries to provide the world's food supply. Thus, innovative solutions that are economically and socio-culturally appropriate must be devised and implemented to ensure food security, not only with respect to food quantity, but also increased attention must be given to food quality attributes, particularly nutritional content and safety. Post-harvest losses not only include physical losses in quantity, but also highly significant degradation of essential bio-active compounds and overall quality attributes. Therefore, minimizing post-harvest losses of agricultural perishables through the entire value chain, from farm to fork, is one of the key pathways of alleviating poverty, increasing food security and improving nutrition.

Papaya is an important fruit crop, which serves as a good source of vitamins A and C as well as calcium, potassium and magnesium. Vitamin C (ascorbic acid) in papaya ranges between 35.4 and 187 mg per 100 g fresh weight, which is higher than that observed in other tropical fruits such as passion fruit, banana and pineapple (Bautisa-Baños, Sivakumar, Bello-Pérez, Villanueva-Arce, Hernández-López, 2013). Also, phenolic compounds such as ferulic acid, caffeic acid and rutin have been detected in papaya fruits (Rivera-Pastrana, Yahia, & González-Aguilar, 2010). Lately, many clinical studies have exemplified that these beneficial bio-active compounds exhibit a protective effect against cancer as well as neurological and cardiovascular diseases. These effects are due to certain biochemical properties, such as free radical scavengers, hydrogen donors, singlet oxygen quenchers and metal ion chelators (Ikram et al., 2009).

Considerable post-harvest losses occur in fresh papaya due to its rapid senescence, which causes high perishability. Consequently, postharvest processing is required to extend shelf life and preserve quality. Convective air drying of papaya is the most common preservation method of fruits that allows for greater flexibility in the availability and marketability of products, regardless of high production volume. By convention, dried papaya can be consumed directly or used as an ingredient in snacks, chocolates, breakfast cereals and other foodstuffs. Nowadays, there is even an increasing demand for natural products, including high quality dried fruits in which nutritional properties have minimal

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alteration. A study by Udomkun, Nagle, et al. (2015) already presented optimal drying parameters for conservation of bioactive compounds during drying of papaya.

In food industries, packaging materials and storage conditions are considered as the last step in product development to extend the conservation of dried fruits. During storage and distribution, dried fruits can experience a wide range of environmental conditions, such as high temperature and humidity as well as exposure to light and oxygen, which can trigger various physicochemical changes. These factors have been reported to facilitate browning reactions, causing undesirable color changes. Additionally, chemical reactions can degrade antioxidants such as polyphenols, carotenoids and vitamin C, which is a particular concern for consumers as it decreases the nutritional value (Hymavathi & Khader, 2005). Lavelli and Vantaggi (2009) found that dried apples were relatively stable during storage and had optimal conservation of antioxidants as long as the proper packaging materials were used. Pua et al. (2008) suggested that aluminum laminated polyethylene (ALP) pouches with storage conditions of 28 °C and relative humidity less than 75% were better suited for preserving qualities of jackfruit powder. Also, Dak, Sagar, and Jha (2014) agreed that ALP is more effective to retain anthocyanins and phenolic compounds in dried pomegranate arils than packaging without aluminum coating. Overall, it should be noted that properties of the packaging materials play an important role for shelf life stability of dried fruits.

Ultimately, the challenge in modern food sciences is not only to minimize the chemical degradation reactions, but also to maximize the conservation of beneficial nutrients during storage. The previous study by Udomkun, Nagle, et al. (2015) mainly focused on the effect of drying parameters on the qualities of dried papaya products. However, a comprehensive investigation about the effects of storage conditions on the quality of dried papaya was not presented. Therefore, the objectives of this study were to examine the effects of two packaging materials, namely aluminum laminated polyethylene and polyamide/polyethylene, on browning occurrence and bio-active compounds properties, particularly antioxidants and ascorbic acid contents, in papaya samples during long-term storage.

2. Materials and methods

2.1. Raw materials

Papayas (*Carica papaya* L. cv. Pluk Mai Lie) harvested from a commercial orchard in Nakhon Nayok province, Thailand, were purchased from a local import company. Fruits of uniform shape, weight (1.0 ± 0.2 kg fruit^{-1}) and ripening stage (three quarters ripeness indicated by 70 ± 10% of skin yellowness) were selected. The initial moisture content (83.5 ± 2 g 100 g^{-1}), soluble solids content (9.8 ± 0.4 °Brix), titratable acidity (0.15 ± 0.02 g citric acid 100 g^{-1}) and pH (5.3 ± 0.2) were measured. Before preparation for drying, fruits were stored under refrigeration at a temperature of 10 ± 1 °C and relative humidity (RH) of 20–35%.

2.2. Sample preparation

2.2.1. Osmotic pretreatment

Papaya samples were treated osmotically according to the procedure described in a previous study (Udomkun, Mahayothee, Nagle, & Müller, 2014). Papayas were hand-peeled and cut into dimensions of 20 × 30 × 20 mm using a specially-designed stainless steel cutter. The samples were rinsed with fresh water and then soaked in 2.5% (w v^{-1}) calcium lactate ($Ca{\cdot}C_6H_{10}O_6$) solution. The samples were allowed to soak for 1 h at controlled temperature (20 ± 2 °C), then blanched at 60 ± 2 °C for 1 min. Subsequently, they were immersed in a hypertonic solution of 30 °Brix at a starting temperature of 60 ± 2 °C and then allowed to stand at room temperature for 6 h. The solution was prepared by dissolving 99.9% refined sucrose in water to obtain the required osmotic concentration and then pH was adjusted to 4.0 using citric acid. The weight ratio of osmotic solution to fruit samples was 1:1. After removal from the solution, the samples were rinsed with water, drained and blotted with absorbent paper to remove the surface water before drying.

2.2.2. Convective drying

After pretreatment, papaya samples were placed on a round 24 cm diameter perforated dryer tray. Convective drying was conducted using the through-flow chamber of a high-precision hot air laboratory dryer (Institute of Agricultural Engineering, Tropics and Subtropics Group, Universität Hohenheim, Germany). A description of the experimental dryer has been given by Argyropoulos, Heindl, and Müller (2011). The drying experiments were carried out according to optimal conditions described in previous studies (Udomkun, Nagle, et al., 2015; Udomkun, Argyropoulos, et al., 2015). Samples were dried at a temperature of 70 °C, constant specific humidity of 10 g kg^{-1} dry air and air velocity of 0.2 m s^{-1} until moisture content of 13.5 ± 0.05 g per 100 g.

2.3. Packaging and storage

Two commercially-available packaging materials were used in this study, namely 15 × 18 cm pouches made from aluminum polyethylene (ALP) and polyamide/polyethylene (PA/PE) barrier films. The ALP laminate consisted of 15 μm polyethylene terephthalate (PET), 95 μm low density polyethylene (LDPE) and 7 μm aluminum layers. The PA/PE film was a laminate of 30 μm polyamide PA6 and 60 μm high density polyethylene (HDPE). Film thickness was measured using a hand-held digital micrometer (Mitutoyo, Mitutoyo Corporation, Kanagawa, Japan) with an accuracy of 0.001 mm. Measurements were performed randomly at fifteen different locations of the film and the mean thickness was computed. Light transmissivity of the packaging materials was determined by measuring the percentage of transmittance (% *T*) using a UV–VIS spectrophotometer UV-3101PC (Shimadzu, Kyoto, Japan) at 600 nm according to ASTM standard D1746. Three replicates of each film were measured and the average value was reported. Oxygen transmission rate (OTR) of packaging materials was analyzed at 38 °C and 90% RH using an oxygen permeability analyzer Model 8003 (Illinois Instruments, Johnsburg, IL, USA) according to ASTM F2622. In addition, water vapor permeability (WVP) was measured at 25 °C and 50% RH using a WVP analyzer Model 7002 (Illinois Instruments, Johnsburg, IL, USA) following ASTM F1249. The properties of packaging materials used in this study can be found in Table 1.

Table 1
Comparison of aluminum laminated polyethylene (ALP) and polyamide/polyethylene (PA/PE) films used in storage packaging.

Materials	Thickness (μm)	Light transmissivity* (%)	Water vapor permeability** (kg m^{-2} day^{-1} Pa^{-1})	Oxygen transmission rate*** (L m^{-2} day^{-1})
ALP	117	0	6.44×10^{-8}	0.0213
PA/PE	90	95	2.25×10^{-7}	0.1200

* At 600 nm.
** At 38 °C, 90% RH.
*** At 25 °C, 50% RH.