Postharvest Biology and Technology 135 (2018) 1–7

Contents lists available at ScienceDirect

Postharvest Biology and Technology

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

Optimization of bulk modified atmosphere packaging for long-term storage of 'Fuyu' persimmon fruit

Napassawan Liamnimitr[a], Manasikan Thammawong[a,*], Chairat Techavuthiporn[b], Khandra Fahmy[c], Tetsuya Suzuki[d], Kohei Nakano[a]

[a] The United Graduate School of Agricultural Science, Gifu University, Gifu 5011193, Japan
[b] Food Science and Technology Program, Faculty of Science and Technology, Huachiew Chalermprakiet University, Samutprakarn 10540, Thailand
[c] Department of Agricultural Engineering, Faculty of Agricultural Technology, Andalas University, Padang 25163, Indonesia
[d] Gifu Prefectural Agricultural Technology Center, Gifu 5011152, Japan

ARTICLE INFO

Keywords:
Bulk modified atmosphere packaging
Long-term storage
Mathematical model
Persimmon

ABSTRACT

An optimal design procedure for bulk modified atmosphere packaging (MAP) that would enable the long-term storage of 'Fuyu' persimmon fruit for export market was proposed in this study. Initially, the lower O_2 limit of aerobic respiration was determined, based on the respiratory quotient breakpoint, and found to be 0.65 kPa. Next, the parameters of a Michaelis–Menten type respiration model were estimated, and they were used to predict the O_2 consumption rate at 1.5 kPa, which was set as the target O_2 partial pressure inside the package and is considered safe to avoid fermentation. Then, the values of the predicted respiration rate, the surface area of the packaging, and the sample weight were substituted into the mathematical model to calculate the gas composition change inside the package; as a result, the necessary O_2 permeance of the packaging film material was estimated as 2.59×10^{-7} L m^{-2} s^{-1} kPa^{-1} for the prospective bulk packaging system. Finally, the efficacy of the designed bulk MAP on the quality changes in the fruit was practically examined by comparing the MAP performance to that of fruit in an individual package (having 60-μm thick low-density polyethylene film bag) and to that of non-packed fruit (i.e., control). All the samples were stored under conditions simulating the long-term storage and subsequent transportation of fruit from Japan to Thailand. The results revealed that the O_2 concentration at a steady state in the designed bulk MAP could be established at 1.3–1.6 kPa, which successfully corresponded with the target value. Furthermore, losses in flesh firmness and color, and the external damage of fruits were reduced in the bulk MAP when compared to storage in the other two package treatments. Overall, the bulk MAP designed could be used for ca. 4 months storage of 'Fuyu' persimmon fruit and for its commercial application to maintain fruit quality and to export fruit to international markets.

1. Introduction

Persimmon (*Diospyros kaki* L.f.), in particular the cultivar 'Fuyu', is a popular fruit in many Asian countries and is highly regarded for its sweet taste and outstanding outward appearance. Crunchiness is also a key characteristic of the 'Fuyu' persimmon because of its non-astringency; otherwise, it would require a de-astringent treatment to become edible which always involves softening the fruit. Owing to its unique flavor, the consumer demand for 'Fuyu' has been increasing and is expected to become a profitable agricultural commodity. In Japan, the 'Fuyu' persimmon is recognized as a seasonal fruit because its harvest is limited from November to December; hence, the demand for its long-term storage is increasing to avoid an oversupply during the harvesting season and to continue its sale for as long as possible. In addition, there is a demand for export, which has increased recently due to the expansion of the sales of 'Fuyu' producers and distributers in markets abroad; for this reason, reliable long-term storage and long-distance transportation is required. Unfortunately, the 'Fuyu' persimmon has a short storage life, at no greater than 3 weeks at 20 °C due to the onset of ripening once harvested (Sargent et al., 1993). Generally, however, storage at low temperatures can prolong the shelf-life of a fruit by reducing both its respiratory activity and ethylene production; but fruit softening and skin darkening inevitably occur. Accordingly, improved postharvest handling techniques that extend the shelf-life of the 'Fuyu' persimmon are needed for the stabilization of its fruit supply in domestic markets and for realizing its long-term exporting potential to the overseas markets.

Modified atmosphere packaging (MAP), in combination with a low

* Corresponding author.
E-mail address: pim@gifu-u.ac.jp (M. Thammawong).

http://dx.doi.org/10.1016/j.postharvbio.2017.07.016
Received 2 June 2017; Received in revised form 20 July 2017; Accepted 31 July 2017
0925-5214/

temperature, is a widely acceptable and suitable technology for the maintenance of the quality of fruits and vegetables during their long-term storage (Cia et al., 2006; Jeong et al., 2013; Fahmy and Nakano, 2013). The modified atmosphere condition slows down the respiration rate, ethylene production, and water loss, thus reducing the enzyme activities and metabolic rate of the packed fruit or vegetable (Kader and Watkins, 2000; Kim et al., 2010; Wang et al., 2011; Selcuk and Erkan, 2015). For the 'Fuyu' persimmon, the effectiveness of MAP for the reduction of weight loss and browning, and for the delay in the softening of its flesh, has been reported already, and a low-density polyethylene (LDPE) film has been often tested as the packaging material (Cia et al., 2006; Kim et al., 2010). Nonetheless, several disadvantages of MAP have been raised; for instance, Cia et al. (2003) suggested a risk of low-oxygen injury based on the acetaldehyde and ethanol accumulation detected when the 'Fuyu' persimmon was stored in an 80-μm LDPE bag at 1 °C for 40 d. Similarly, the ethanol production was found in the headspace of a 60-μm LDPE bag after 14 weeks of storage at 0 °C (Ben-Arie and Zutkhi, 1992). These metabolites originate from anaerobic respiration, and they are the causative agents of "off-odor", which inevitably lessens the market value of the fruit. Anaerobic respiration occurs when an extremely low O_2 condition is created in the package due to a careless packaging design. However, if the O_2 concentration in the package can be equilibrated just above the tolerance limits of the freshly packed produce through an appropriate packaging design, the risk of inducing anaerobic respiration may be avoided. Furthermore, in doing so, this also retains the greatest freshness because the physiological activities are suppressed at the maximum level in the range of aerobic metabolic processes. Hence, the determination of lower O_2 limit (LOL) for the target produce commodities is the first priority when the goal is to optimize the packaging condition. To date, however, most of the MAP studies on 'Fuyu' persimmon fruit were conducted on the basis of a trial-and-error method, and so they may not provide the best packaging condition. Ideally, to achieve the long-term storage and long-distance transportation of 'Fuyu' persimmon, the MAP should be precisely designed.

In the MAP system, as to how the atmosphere is modified inside the package depends on a complex combination of factors, such as the gas permeability of the packaging film material, the surface area of the package and the weight of the packed fresh produce, as well as its respiration rate. To date, the gas composition change in MAP has been modeled based on the mass balance of each O_2, CO_2, and N_2 gaseous between inside and outside of the packaging, and its reliable and versatile application confirmed by many researchers (Torrieri et al., 2009; Mangaraj et al., 2014; Fahmy and Nakano, 2014). However, a MAP for the 'Fuyu' persimmon based on a mathematical model that takes into consideration the fruit's respiratory characteristics is yet to be designed, neither has anyone yet evaluated the storability of this fruit when packed in a well-designed MAP.

In addition, to achieve a successful packaging design, the focus should not be only on quality preservation: the handling efficiency and a reduction in transport costs should also be considered. The bulk MAP is a promising method that fulfills all of the above requirements. This method has been tested at the laboratory scale to assist in the shelf-life extension of the persimmon fruit (Chaudhry et al., 2002; Jeong et al., 2013; Fahmy and Nakano, 2013). However, based on our literature review, there is little information on the long-term quality preservation of persimmon fruit when stored under a bulk MAP.

In this study, the respiration rate and LOL of the 'Fuyu' persimmon fruit were carefully examined. Following this, the optimum gas permeability of the packaging film material was estimated in a mathematical model that was priorly used to predict the gas composition changes occurring inside a MAP. Then, the effectiveness of the designed bulk MAP for the quality preservation of the 'Fuyu' persimmon was also evaluated, specifically when stored under conditions mimicking temperature changes that would occur in the long-term storage and subsequent transportation of 'Fuyu' from Japan to Thailand.

2. Materials and methods

2.1. Plant materials

The 'Fuyu' persimmon fruit (*Diospyros kaki* L.f.) was harvested at the commercial maturity stage from the Gifu Prefectural Agricultural Technology Center, Gifu, Japan. The fruits selected were uniform in shape and size, and they lacked any wound or decay symptoms. The average weight of the fruit sample was 0.33 ± 0.02 kg. After their selection, the fruits were packed in a corrugated fiberboard box (CFB) and carefully transported to the laboratory.

2.2. Determination of the respiratory quotient

Approximately 1.6 kg of 'Fuyu' persimmon fruits were placed into a 4.8 L hermetic chamber. The chamber was then set inside a 5 °C incubator (MIR-154-PJ Panasonic, Osaka, Japan). This chamber has both inlet and outlet ports that were linked individually to the plastic tube. The tube coupled to the outlet port of the chamber was connected to a semiconductor-type CO_2 sensor (GMP221 CO_2 probe Vaisala, Vantaa, Finland) equipped with an aspiration pump (GM70 Vaisala, Vantaa, Finland) and further along linked to a zirconia-type O_2 sensor (MC-8G Iijima Electronics Corporation, Aichi, Japan). The N_2 gas was flushed into the chamber via the inlet tube until the O_2 concentration inside the chamber dropped to 3 kPa. Then, the inlet tube of the chamber was removed from the N_2 gas cylinder and immediately reconnected to the outlet port of the O_2 sensor, to create a closed system. Changes in both the O_2 and CO_2 concentrations inside the chamber were then recorded at 10-min intervals by a data recorder (TR-V550 Keyence, Osaka, Japan). The measurements were stopped when the O_2 concentration inside the chamber fell to 0 kPa. The collected data on gas concentrations was used for estimating the respiratory quotient (RQ) value. The RQ value of the fruit was calculated from the slope of the regression line relating the increase of the CO_2 concentration with the decrease of the O_2 concentration inside the chamber, as shown in the following equation.

$$RQ = \Delta C_{CO_2}/\Delta C_{O_2} \quad (1)$$

where RQ is the respiratory quotient, and ΔC is the slope of the gas concentrations in the chamber (O_2 and CO_2) (% h^{-1}).

For determination of the slope of the gas concentrations in the chamber, sequential sets of 25 data points for each O_2 and CO_2 concentration were selected, and these were subjected to regression analysis to estimate ΔC_{O_2} and ΔC_{CO_2}, respectively. The calculation continued, by shifting down one step and computing the slope of the next dataset, as the method for obtaining a moving average. After the calculation of RQ values as mentioned above, the RQ values were then plotted against the moving average of 25 data points of the O_2 concentration to observe the changing pattern of RQ. This experiment was run in triplicate.

2.3. Determination of the respiration rate

The O_2 consumption rate of the 'Fuyu' persimmon at 1, 2, 5, 10, and 21 kPa O_2 were measured by the flow-through method (Nakamura et al., 2004). Briefly, approximately 1.6 kg of fruits were weighed and put into the 4.8-L hermetic chamber with inlet and outlet ports (as described in Section 2.2). The chamber was then placed inside the incubator (MIR-553 Sanyo, Osaka, Japan) and set at 5 °C. The gas mixture, which was generated by a gas blender (GB-3C Kofloc, Kyoto, Japan) consisting of mass-flow controllers connected to high purity O_2 and N_2 gas cylinders, was divided into two lines. The first line served as the inlet gas measurement, and the second line flowed into the chamber via the inlet port at the flow rate of 0.100 L min^{-1} that was maintained by the mass-flow controller (SEF-E40 Horiba Stec, Kyoto, Japan). The gas composition from the inlet port was exchanged by the sample's