Note

The Quality of King Oyster Mushrooms Stored with a Master Packaging System Consisting of Inner Individual Packs and an Outer Liner Bag to Be Dismantled at a Retail Display

Mijin Jeong1, Duck Soon An1, Seung Ju Lee2 and Dong Sun Lee1*

1Department of Food Science and Biotechnology, Kyungnam University, 11 Woryeongbuk 16-gil, Masanhappo-gu, Changwon 631-701, South Korea
2Department of Food Science and Biotechnology, Dongguk University, 26, Pil-dong 3 ga, Jung-gu, Seoul 100-715, South Korea

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To better handle variable temperature regimes in produce distribution, a master packaging system consisting of a double-layered gas barrier has been applied to fresh king oyster mushrooms. A secondary master package wrapping four individual 350 g packages was designed to be dismantled when moved to the 10°C retail display from the presale storage at 0°C. Different numbers of microperforations (10, 15 and 20) were tested on the inner individual packages as a control variable to create and maintain beneficial modified atmospheric conditions around the mushrooms. The microperforated individual packages could all attain an effective range of modified atmosphere during the two stages of storage at 0 and 10°C while the package with 15 microperforations best reached the desired modified atmosphere of 1−3% O2 and 10−15% CO2. The individual packages in the master packaging system had better preservation in quality attributes, such as weight loss, mold/yeast count and texture retention, compared with the control perforated packages of a normal atmosphere.

Keywords: modified atmosphere packaging, microperforation, temperature change, distribution, quality

Introduction

Fresh mushrooms have high respiration rates and are very perishable, which limits their shelf life (Cliffe-Byrnes and O’Beirne, 2007). Modified atmosphere packaging (MAP) at a chilled temperature effectively preserves the quality and freshness of mushrooms (Roy et al., 1995; Kim et al., 2006; Li et al., 2007). However, the high respiration rate excludes most polymeric films from direct simple use in the MAP bags of fresh mushrooms because of the anoxic conditions developed inside the package. Microperforations or highly permeable windows have been applied to match the high respiration of the mushrooms and thus create a beneficial modified atmosphere (Li et al., 2007; Sandhya, 2010). Particularly, a high temperature exposure with temperature abuse in the product distribution chain may induce an imbalance between the produce respiration and the package’s gas permeation. Unlike the produce storage warehouse and the transportation vehicle that are well controlled at low temperature, the display cabinets in retail markets have a wide variation of temperatures around 10°C. To resolve the temperature-vari-ant regimes in produce distribution, the concept of a master packaging consisting of double layers of a gas barrier has been proposed and introduced for fresh fruit packaging (Jeong et al., 2011). The master packaging system consisting of a liner bag as a secondary package (master package) and the primary individual packages contained within it creates the desired modified atmosphere (MA) for the fruit during transportation and wholesale distribution at low temperatures. At the higher temperature retail level, the outer layer of the master package is dismantled to expose the individual packages to an ambient atmosphere, providing higher gas permeation to match the increased mushroom respiration. An elaborate combination of individual primary and secondary packages

*To whom correspondence should be addressed.
E-mail: dongsun@kyungnam.ac.kr
in terms of the gas permeability properties is critical for the successful application of the master packaging concept. The design should take account of the pre-sale storage and the retail display temperature conditions that affect produce respiration.

Mushrooms are best preserved in the optimal MA conditions of an O₂ concentration of 1 – 3% and a CO₂ concentration of 10 – 15%, which can be attained by microperforated film (Burton and Twyning, 1989; Mannapperuma and Singh, 1994). Thus, a master packaging system for mushrooms would be better to exploit the microperforated film for creating an optimal MA under a produce supply chain consisting of a dynamic temperature regime. This work designed master packaging systems for king oyster mushrooms and tested their effectiveness in preserving mushroom freshness. The experimental package systems were screened from preliminary trials, which measured the internal atmosphere developed inside the packages of many different designs. On the basis of the findings of the preliminary experiments, the number of microperforations on the individual inner packages was examined as an important independent variable.

**Materials and Methods**

King oyster mushrooms (*Pleurotus eryngii* (De Candolle ex Fries) Quel) harvested in Jindong, Changwon, South Korea were transported immediately to the laboratory and used for experiments on the day of harvest. Four mushroom stems with caps weighing 87 ± 20 g each were placed on an expanded polystyrene tray (25 × 17 × 2.5 cm) and then wrapped with a 30 µm thick oriented-polypropylene (OPP) film bag (29 × 21 cm) to reach an average weight of 350 g. This individual package of OPP film was then heat-sealed. Four individual packages were aligned in parallel, packaged again with a 35 µm thick low density polyethylene (LDPE) film bag (50 × 60 cm when in folded tube) and the opening was sealed by a mechanical tie. The erected master package had a rectangular shape, which could be placed in a corrugated box (32 × 24 × 20 cm) with physical stability. To obtain the high gas permeability required for balancing the mushroom respiration, the outer master package was mechanically pierced by a specialized needle to have 8 microperforations of 500 µm in size. Different numbers of 500 µm microperforations (10, 15 and 20) were made on the individual packages as a design variable to attain the desired MA. Perforated packages of the same weight (350 g) with 4 holes of 6 mm were also prepared as a control packages for comparison. This control is similar to current commercially available packages in the market.

The prepared packages were stored at 0°C and a relative humidity (RH) of 60%. The master packages stored for a prescribed period of time were dismantled to take out the individual packages, which were then moved to the simulated retail display condition of 10°C and 50% RH, and stored for 3 more days. The control packages were also subjected to the same temperature regime. The secondary or primary packages taken from the storage and simulated retail display were measured for O₂ and CO₂ concentrations in the headspace. For the master packaging system, the gas atmosphere of the outer liner bags was measured before testing the inner individual package units. The mushrooms from the packages were subjected to fruit quality measurements. All package measurements were conducted at least in triplicate, except for the replication of the gas composition of the outer master packages. The significant differences in the package atmosphere and the quality attributes between the treatments were evaluated with an ANOVA and Tukey’s Honestly Significant Difference (HSD) test at α = 0.05 (Daniel, 1978).

The O₂ and CO₂ concentrations were analyzed using a gas sensor (Model CheckMate 9900, PBI-Dansensor, Ringsted, Denmark). The quality attributes were measured when opening the package. The weight loss was expressed as a percentage difference from the initial weight after weighing the mushrooms to an accuracy of 0.1 g. The inner color of the cut surface of the vertically halved mushroom was measured using a color difference meter equipped with a halogen lamp (Model JC 801, Color Techno System Corporation, Tokyo, Japan). The flesh cutting strength was obtained from the maximum peak when the mushroom stem sample, trimmed into 5 × 1.5 × 1.5 cm dimensions, was cut at a speed of 60 mm/min by a 0.26 mm thick knife on a Rheometer Compac-100 (Sun Scientific Co., Tokyo, Japan). To determine the mold/yeast count, a 30 g sample was aseptically transferred to a sterile stomacher bag and blended with 90 mL of 0.05% peptone water in a stomacher (Stomacher 400 Circulator, Seward Ltd., UK) at 200 rpm for 2 min. The solution was serially diluted with 0.05% peptone water, and 0.1 mL of the diluted solution was plated onto Potato Dextrose Agar (Difco Laboratories, Detroit, MI, USA), which was incubated for 5 days at 25°C.

**Results and Discussion**

The individual packages with 10 – 20 microperforations created and maintained an MA of 1 – 3% O₂ and 9 – 15% CO₂ when located inside the master package after 7 days and up to 21 days in storage at 0°C (Figure 1B). A smaller number of microperforations resulted in slightly higher CO₂ and marginally lower O₂ concentrations. Master packages of the outer liner containing 4 individual packs had stable gas concentrations of 4 – 7% O₂ and 8 – 10% CO₂ for the same period of storage (Figure 1A). The differences among the
The gas composition changes of the master package (A) and the inner individual packages (B) of different microperforations containing 350 g of king oyster mushrooms during the chilled storage (0°C) and simulated retail display (10°C). The solid line is for the chilled storage and the dotted line for the simulated retail display.

Secondary packages were much less than those observed for the inner individual packages contained within them. Additionally, the differences after 15 days were not statistically significant even for slightly lower CO2 concentrations in the master package containing less microperforations. Overall, all three designed systems of individual/master packages at 0°C were shown to attain MA conditions very close to the optimal MA window of 1 – 3% O2 and 10 – 15% CO2 concentrations around the mushrooms (Nichols and Hammond, 1973; Roy et al., 1995; Sandhya, 2010; Singh et al., 2010).

When moved to 10°C after dismantling the outer master packages, the individual packages experienced some increase in both O2 and CO2 concentrations (Figure 1B). This packaging atmospheric change seems peculiar because the usual response of fresh produce in MA packaging exposed to increased temperature is a high CO2 build-up and an O2 depletion due to the relatively higher temperature dependence of respiration than that of package gas permeability (Exama et al., 1993; Tano et al., 1999). Compared with usual produce MA packages, the individual packages separated from the master package at a higher temperature are atypical and very complicated in their dynamics. High temperature increases the respiration rate and the gas permeability of the package layer, and the removal of the outer packaging layer increases the gas transfer and partial pressure differential across the package film. The film/microperforation combination also
makes the dynamics of the package atmosphere more complicated (Exama et al., 1993), and thus, a thorough understanding of this behavior requires further extensive study on a variety of package designs and storage conditions.

The CO₂ concentration increase at 10°C was the highest in the package with 10 microperforations (up to 20%), and the O₂ concentration increase was the highest in the package with 20 microperforations (up to 7%) (Figure 1B). Considering the optimal window of 1−3% O₂ and 10−15% CO₂, the package with 10 microperforations exceeded the higher concentration limit of CO₂, and the package with 20 microperforations went beyond the upper concentration limit of O₂. Regarding the package capability to retain an atmosphere within the optimal MA, a package with 15 microperforations seemed to be the best among the tested packages even though it approached the limits of the optimal window. The number of microperforations has been reported elsewhere to be an effective design variable for attaining the desired MA in fresh produce packaging (Ibaraki et al., 2000). The perforated bag of the control package had an atmospheric gas composition throughout the storage at 0°C and subsequently at 10°C. Because the master packaging system maintains the beneficial MA around the mushroom, the question arises whether the microperforated packages alone without double bagging can have the similar effect. Another control of a microperforated OPP without outer liner bag was not tested in this study, and thus, the question cannot be answered directly here. In future studies, the effect of double bagging may be investigated explicitly by comparing two microperforated counterparts with and without double bagging. In a limited trial on persimmon packaging, the microperforated packages alone without double bagging had a potential to maintain an optimal MA during high temperature distribution but were not effective for preserving the quality because of relatively high O₂ and low CO₂ concentrations that developed during the presale chilled storage (Jeong, 2011). Currently, the question is how much and whether these packages’ MA observed in Figure 1 could help preserve the quality and freshness of the contained mushrooms, which is described below. The MA of a reduced O₂ and an increased CO₂ concentration within the tolerance limits is known to suppress physiological changes such as respiration, ethylene production and nutrient deterioration (Akbudak, 2008; Brandenburg and Zagory, 2009; Sandhya, 2010).

As shown in Figure 2, the mushrooms contained in the microperforated individual packages in a master package had significantly less weight loss during storage at 0°C and subsequent simulated retail display at 10°C compared with those in the perforated control package. After 21 days at 0°C plus 3 days at 10°C, mushrooms in the control package suffered from 3.8% loss while the other treatments had only 0.4% loss. The double layer of microperforated plastic films in the master packaging system helped reduce the moisture loss or transpiration during the presale stage by decreasing the humidity differential across the mushroom surface. Thereafter, in the simulated distribution, the microperforated film bag of

![Fig. 2. The weight loss of king oyster mushrooms in different microperforated packages during chilled storage (0°C) and simulated retail display (10°C) conditions. The solid line is for the chilled storage and the dotted line for the simulated retail display. The error bars represent the HSD at α = 0.05 for each time point (n = 4). ○: control package; △: 10 microperforations; ◇: 15 microperforations; □: 20 microperforations.](image-url)
the inner package also effectively suppressed moisture loss. Compared with the perforated control package, the MAP of the microperforated film could alleviate the aggravated water loss problem, which often occurs together with mushroom growth during high temperature abuse (Tano et al., 1999; Singh et al., 2010).

Mushrooms in individual packages wrapped with an outer liner film showed significantly lower mold/yeast counts than those in the control packages during 0°C storage (Figure 3). The inhibition of microbial growth can be attributed to the low O₂ (1−7%) and high CO₂ (9−20%) atmosphere of those packages. The MA of low O₂ and high CO₂ concentrations has been reported to slow down the growth of aerobic spoilage microorganisms on fresh produce including mushrooms (Lee et al., 1996; Vankerschaver et al., 1996; Simon et al., 2005; Almenar et al., 2007; Simon et al., 2010). Differences in the microbial count among the master package treatments were only slight and mostly not significant even though the package with 10 microperforations showed a consistently lower count after 15 days. Furthermore, a CO₂ concentration difference less than 4% between the treatments did not produce a significant enough impact to change the microbial growth profile. The mold/yeast count was increased drastically for all the packages at the 10°C simulated retail display subsequently after storage at 0°C. Marginally lower counts, sometimes with statistical significance, were retained for the mushrooms in the master packaging system during the simulated display stage at 10°C.

The cutting strength or the toughness of the stored mushroom stems increased most in the control package among the tried packages at the chilled storage (0°C) and the subsequent display condition (10°C) (Figure 4). Even with slight differences between treatments, the mushrooms in the master package treatments seemed to retain the texture of the stem better than the perforated control packages, which could be associated with moisture loss as reported by Simon et al. (2005). As shown in Figure 4, high distribution temperature (10°C) storage of the individually separated packages after chilled (0°C) storage in the master pack, having accelerated moisture loss, increased the toughness of mushrooms. The toughening of the mushroom tissue parallels the softening of the cap part caused by protein and polysaccharide losses and increases in the chitin content, which are related to its aging (Tano et al., 1999; Zivanovic et al., 2000). The reductions in moisture loss and mushroom development are beneficial for texture preservation and can be manipulated by the package conditions (Simon et al., 2005). While moisture loss is prevented by a moisture barrier, mushroom development can be inhibited by an MA of low O₂ and high CO₂ concentrations (Nichols and Hammond, 1973; Lopez Briones et al., 1993; Singh et al., 2010).

The surface color changed little during storage at 0°C and then at 10°C with negligible differences among the treatments. The ‘L’ and ‘a’ values stayed constant at about 95 and 0, respectively, and the ‘b’ value increased from 6 to 9 during the whole storage period (specific data omitted). The surface

![Image](image_url)

**Fig. 3.** The mold/yeast count of king oyster mushrooms in different microperforated packages during chilled storage (0°C) and simulated retail display (10°C) conditions. The solid line is for the chilled storage and the dotted line for the simulated retail display. The error bars represent the HSD at α = 0.05 for each time point (n = 3). ○: control package; △: 10 microperforations; ◇: 15 microperforations; □: 20 microperforations.
color of the mushrooms seems to be relatively insensitive to MA conditions (Simon et al., 2010).

Conclusively, the master packaging system consisting of four individual microperforated OPP film packages inside a microperforated LDPE film bag was effective to preserve the quality of king oyster mushrooms through presale storage at 0°C and retail display at 10°C. The effectiveness of maintaining mushroom quality was reasoned to come from the maintenance of a package atmosphere close to an optimal MA of 1−3% O2 and 10−15% CO2. Even though there have been some differences in the package atmosphere among the different microperforations on the individual packages, the improved degree of quality preservation was not significantly different among the microperforated packages in the master pack.

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References

Fig. 4. The texture of king oyster mushrooms in different microperforated packages during chilled storage (0°C) and simulated retail display (10°C) conditions. The solid line is for the chilled storage and the dotted line for the simulated retail display. The error bars represent the HSD at α = 0.05 for each time point (n = 15). ○: control package; △: 10 microperforations; ◇: 15 microperforations; □: 20 microperforations.


