Journal of Food Engineering 216 (2018) 11–19

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Thermally buffered corrugated packaging for preserving the postharvest freshness of mushrooms (*Agaricus bispours*)

Suman Singh, Kirtiraj K. Gaikwad, Myungho Lee, Youn Suk Lee*

Department of Packaging, Yonsei University, Wonju, Gangwon-do, 220-710, South Korea

ARTICLE INFO

Article history:
Received 29 May 2017
Received in revised form
9 July 2017
Accepted 15 July 2017
Available online 21 July 2017

Chemical compounds studied in this article:
Tetradecane (PubChem CID: 12389)
melamine (PubChem CID: 7955)
catechol (PubChem CID: 289)
sodium phosphate (PubChem CID: 24243)
phosphate-buffered saline (PubChem CID: 24978514)
EDTA (PubChem CID: 6049)
DTT (PubChem CID: 446094)

Keywords:
Postharvest
Button mushroom
Packaging
Thermally buffered
Freshness

ABSTRACT

This research successfully developed a novel thermally buffered package using a paraffin-based thermo regulating material (5 °C) microencapsulated in melamine powder (MMP). MMP was used to coat a poly-textile, and the results were compared with those of a commercially available TRM (temperature regulating material), i.e., tetradecane. The major real-world difficulty of containing the liquid phase was overcome in this study via microencapsulation. A corrugated package constructed of MMP poly-textile and lined with LDPE bag liners containing 400 g of MMP provided a sufficient thermal buffering capacity to maintain the temperature inside the package at 5 °C while the package was held at ambient temperature for 30–60 min. A similar experiment with mushrooms (*Agaricus bispours*) packed inside the thermally buffered package was performed to determine whether it could provide effective thermal buffering during transport and temporary storage. The MMP and MMP-coated poly-textile were characterized using TGA, DSC, SEM, and FTIR to evaluate their thermal, chemical, and morphological properties. The quality of the mushrooms packed into the thermally buffered package was determined by measuring the pH, color, texture, weight loss, and PPO activity. The thermally buffered package, which combines the effects of a pure MMP bag liner and an MMP + poly-textile package, demonstrated excellent ability to control temperature. All of the quality aspects of the mushrooms were within acceptable limits during the storage study. This developed package will solve some of the restrictions faced by mushroom producers and distributers in order to maintain stable quality throughout the storage period.

1. Introduction

South Korea exports and imports considerable quantities of fresh food to and from international markets. Controlling the temperature of packages during transport is becoming a more prominent issue as on-line shopping becomes more common. During transport, food requires cold temperatures to maintain freshness. A major issue is the undesired warming of food when packages are exposed to warm temperatures on airport tarmacs and temporary un-refrigerated storage during air transportation because it can adversely affect food quality and export value. Temperatures can be maintained using small freezers, larger cold storage enclosures, and warehouses as well as refrigerated trucks during transport. For many high-value food products, protecting the cold chain is a crucial aspect to ensure food safety and food quality. Temperatures ranging from 2 to 8 °C can slow microbial and chemical changes in food products (Likar and Jevšnik, 2006; Laguerre et al., 2013; Krížek et al., 2014; Singh et al., 2016a,b; Gaikwad et al., 2016; Ahn et al., 2016). However, the paperboard containers typically used for food shipments have limited thermal insulation and poor thermal buffering capacities. Warm temperature spikes during transit can last for several hours and cause spoilage of perishable food in packages.

The white button mushroom (*Agaricus bispours*) is commonly recognized for its nutritional, organoleptic, and medicinal properties and is very popular with consumers (Gao et al., 2014). The shelf life of button mushrooms is only 3–4 days because weight loss, browning, and texture loss diminish their commercial value. Mushrooms are conventionally packed in PET containers and refrigerated at 4–5 °C. However, temperature fluctuations during distribution to supermarkets and home delivery can cause the quality of the mushrooms to deteriorate. Thus, maintaining the

---

* Corresponding author.
E-mail address: leeyouns@yonsei.ac.kr (Y.S. Lee).

http://dx.doi.org/10.1016/j.jfoodeng.2017.07.013
0260-8774/© 2017 Elsevier Ltd. All rights reserved.

freshness of mushrooms during postharvest storage in thermally buffered packaging would preserve their quality and benefit both the mushroom industry and consumers.

Thermo regulating material can maintain package temperature by changing its phase from liquid to solid and vice versa to absorb and release latent heat when isothermal conditions change (Jin et al., 2010). In general, the TRM transition temperature should match the heating and cooling needs of the situation at hand, where the latent heat of the selected TRM should be high and the nucleation rate should be very fast. High thermal conductivity assists in charging and discharging stored energy. During melting and recrystallization, small volume change and low vapor pressure are desirable characteristics for an ideal TRM. Most TRMs are liquid at ambient temperatures, making them difficult to incorporate directly into packaging structures and refrigeration equipment (Fang et al., 2009). Encapsulation has proved to be a successful technology for minimizing the environmental reactivity of TRM materials, preventing leakage, and increasing heat transfer, making them useful in packaging and refrigeration applications (Alkan et al., 2011; Tyagi et al., 2011; Sharma et al., 2014: Gaikwad et al., 2017a,b).

Alkane paraffins have several favorable attributes apart from their melting and rapid nucleation properties. For example, they can undergo very long freeze and melt cycles. Commercial paraffin waxes are cheap and have moderate thermal storage densities (~200 kJ/kg or 150 MJ/m^3) and a wide range of melting temperatures. They undergo negligible subcooling and are chemically inert and stable with no phase segregation. The major problem is containing the liquid phase upon melting (Farid et al., 2004). Undesirable effects can be improved by modifying the paraffin with a highly thermally conductive material and encapsulating it in an outer shell of a less flammable and more stable material.

Encapsulating paraffin in a melamine-based shell results in very high stability against the worst environmental conditions, providing an effective solution to these problems. This study evaluated thermally buffered corrugated packaging to prevent temperature fluctuations in perishable food in order to maintain product freshness through the entire distribution chain. The packaging provided a 120 h buffering time during which the inside temperature of the package and its contents (mushrooms) remained at 5 °C.

2. Experimental

2.1. TRM as a functional material

The paraffin-wax-based TRM selected for this study has a melting point of 5 °C and a heat capacity of 216 J g^{-1}. Melamine-based microencapsulated powder (MMP) with a mean particle size of 5.11 μm, tetradecane (TET), and an MMP coated poly-textile (0.7 mm) were procured from FMS Cold Chain Solution, Gyeonggi-do, Korea. The functional packaging system for food exports program was followed, i.e., 5–10 °C for the safe transport and short-term storage of fresh produce such as mushrooms (Canada Gap Food Safety Manual).

2.1.1. Particle size and morphology of TRM

Scanning electron microscopy (SEM; LEICA S 360, Leica Cambridge Ltd., USA) operated at an acceleration voltage ranging from 10 to 15 kV was used to observe the morphology of the samples. After lyophilization, dry samples and fibers were stuck to conductive carbon tape mounted on aluminum stubs and then sputtered with gold to make them conductive. The diameters of the electrospun materials were determined from the SEM micrographs at the original magnification using Adobe Photoshop CS4 software.

2.1.2. Differential scanning calorimetry (DSC)

DSC analysis of the materials was performed on a Perkin Elmer DSC 7 applying various heating–cooling cycles from −60 °C to 60 °C in a nitrogen atmosphere with a refrigerating cooling accessory (Intracooler 2, Perkin Elmer, US). A scan rate of 10 °C/min was applied to observe the influence of this parameter on the thermal properties. The amount of material used for the DSC experiments was adjusted to approximately 10 mg. The enthalpy results obtained were thus corrected depending on the TRM content of the packaging. The thermal stability of TRM was studied by repeating DSC thermal cycling for up to 100 cycles.

2.1.3. Thermal gravimetric analysis (TGA)

The thermal properties of the material were analyzed using a thermal-gravimetric analyzer (TGA-4000, Perkin Elmer Co., Netherlands). During testing, 4–10 mg of clean, dry samples were heated from 60 °C to 650 °C at a rate of 20 °C/min. Nitrogen was used as the purge gas at a flow rate of 20 ml/min. For TGA, the material was scanned from 10 °C to 800 °C at a rate of 20 °C/min (ASTM E1131), again using nitrogen as the purge gas at a flow rate of 20 ml/min. The thermal stability of the samples was characterized by measuring the weight (mass) loss with increasing temperature.

2.1.4. FTIR

FTIR was used to document the changes in the chemical structure of the MMP, MMP coated poly-textile, and TET samples. The spectra were acquired using an FTIR spectrometer (PerkinElmer, USA) for wavenumbers in the range of 400–4000 cm^{-1} with a resolution of 1 cm^{-1}.

2.2. Preparation of thermally buffered corrugated board package

Total four rectangular corrugated boxes with 4 mm fluted corrugated board having dimensions of 270 (L) mm × 180 mm (W) × and 150 (H) mm were constructed (Fig. 1). In case of first corrugated box (MMP + poly-textile + MMP), the poly-textile (coated with MMP) were used inside the walls of the box and then for additional insulation LDPE bag liners uniformly filled with 400 g of MMP placed inner walls (all sides) of the corrugated box. Second box (MMP + poly-textile), were constructed with the use of poly-textile (coated with MMP) in all sides of the box. Third box (Tetradecane), were constructed by using LDPE bag liners filled with commercially available tetradecane. Finally, the fourth box (Control), were constructed without any additional insulation materials, that is only corrugated box.

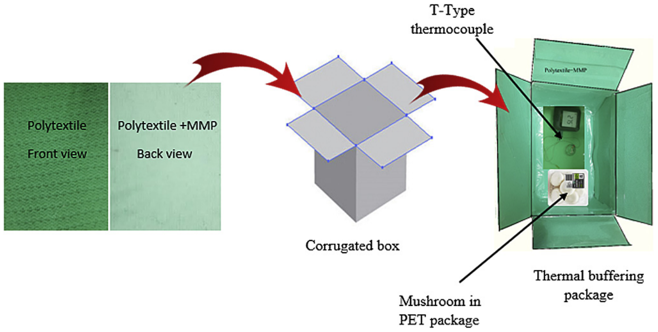

Fig. 1. Thermally buffered boxes with microencapsulated melamine powder coated poly-textile.