Food Packaging and Shelf Life 11 (2017) 10–15

Contents lists available at ScienceDirect

Food Packaging and Shelf Life

journal homepage: http://www.elsevier.com/locate/fpsl

Short communication

Shiitake mushroom packages tuned in active CO_2 and moisture absorption requirements

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ARTICLE INFO

Article history:
Received 1 August 2016
Received in revised form 24 October 2016
Accepted 7 November 2016
Available online xxx

Chemical compounds studied in this article:
Calcium hydroxide (PubChem CID: 6093208)
Sodium carbonate (PubChem CID: 10340)
Polyvinylpyrrolidone (PubChem CID: 6917)

Keywords:
Active package
CO_2 absorption
Moisture absorption
Modified atmosphere
Fresh produce

ABSTRACT

Active packages of shiitake mushrooms with CO_2- and moisture-absorbing sachet or pad were designed and tested in their effectiveness in quality preservation for a given shelf life of 5 days at 10 °C. Sachets of sodium carbonate (SC) and mix of SC and calcium hydroxide (CH), and SC-impregnated cotton pad were characterized in their CO_2 and moisture absorption properties to calculate proper amounts of the active components capable of scavenging the required amounts of CO_2 and water vapour. The demands of CO_2 and water vapour absorptions to maintain the desired modified atmosphere (MA) and avoid moisture condensation inside the packages were determined from mass balance relationships comprising the mushroom respiration/transpiration and gas transmission through the package layer. Super-absorbent polymer (SAP) of polyacrylate was added as a supplement material to bring about the water vapour absorption required further to attain non-saturated humidity condition. Sachet combined of SC and SAP attached inside the package of 180 g mushrooms maintained its atmosphere of 10.7–11.6% O_2 and 7.1–8.9% CO_2 concentrations at steady state helping to preserve the quality best. Proper combination of CO_2 and moisture absorbers can be useful tool to create the desired MA and alleviate saturated humidity conditions in packages of the commodities sensitive to high CO_2 and moisture condensation.

1. Introduction

Shiitake mushroom is one of most common edible mushrooms all over the world and rich in variety of nutrient with special flavour (Parentelli et al., 2007). During postharvest storage, shiitake mushroom is sensitive to saturated humidity and high CO_2 concentration. Very high relative humidity (*RH*) with some temperature fluctuation results in moisture condensation on mushroom surface favouring microbial growth and deterioration, consequently reducing its shelf life (Rux et al., 2015). Besides the sensitivity to moisture, shiitake mushroom is also susceptible to high level of CO_2 concentration (Parentelli et al., 2007). Shiitake mushroom suffers from physiological damages due to high CO_2 concentration causing degradation of sensory quality. So controlling both humidity and CO_2 concentration in the mushroom package can provide the benefit of quality preservation.

Using active CO_2 and water absorbents in mushroom package may be a solution to retard mushroom deterioration caused by saturated humidity and high CO_2 concentration. Mahajan, Rodrigues, Motel, and Leonhard, (2008) and Rux et al. (2015) developed moisture absorbers and humidity regulating trays, respectively, for extending shelf life. In our previous work (Wang, An, Rhim, & Lee, 2015), shiitake mushroom could also be kept well in quality by innovative multifunctional films which could absorb excessive CO_2 and moisture in the package to have the desired modified atmosphere and alleviate saturated moisture condensation. In practical terms, simpler application of CO_2 scavenger and water absorbent even with some crudeness would give some benefits of the mushroom preservation. Sachet or pad system to be made or fabricated in an easy way may be feasible practical approach. Besides, the active packaging in whatever form is required to be designed to tune with the needs of produce (Cagnon, Méry, Chalier, Guillaume, & Gontard, 2013). Modified atmosphere and humidity conditions may be two important factors in designing of the quality-preserving produce packaging (Singh, Giri, & Kotwaliwale, 2014).

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http://dx.doi.org/10.1016/j.fpsl.2016.11.002
2214-2894/

Thus, the objectives of this study are 1) to develop an easy-to-use package design method for shiitake mushroom using customized active CO_2/moisture absorptive sachet or pad for the purpose of attaining the desired MA and non-moisture condensation conditions, and 2) to validate its effectiveness on keeping the mushroom quality.

2. Materials and method

2.1. Active sachet and pad with functions of CO_2 and moisture absorption

Active compounds of sodium carbonate (SC) and calcium hydroxide (CH) for CO_2 absorption were used for preparing sachet or pad. They were selected or combined considering humidified condition inside fresh produce packages where CO_2 production respiration and transpiration occur simultaneously: SC is unique and can be effective there due to involvement of moisture in its CO_2 scavenging reaction while CH is the mostly widely used product self-reacting with CO_2 gas (Lee, 2016). SC was from Oriental Chemical Industries (Tokyo, Japan) and CH was from BuhungLime (Cheongju, Korea). Super absorbent polymer, polyacrylate (SAP), was used for a moisture absorber wrapped in a sachet. 191 μm thick Tyvek film (1070 D, DuPont Inc., Wilmington, Delaware, USA) was used as sachet film material for CO_2 absorber and SAP. Tyvek sachet bags of proper size were heat-sealed by an impulse sealer (NA-450, Hana Co. Ltd, Daejeon, Korea) after containing the required amounts of CO_2 absorber or SAP. The sachet size was 4.0×4.0 cm in the test of measuring CO_2 absorption capacity and moisture absorption, and the size of 8.5×6 cm was used for mushroom packaging experiment.

For preparation of active pad, compressed cotton pad ($5.6 \times 5.6 \times 0.5$ cm, 100% natural cotton) was procured from the Etude Co. Ltd. (Seoul, Korea). Active pad was prepared by immersing a cotton pad into 40% (wt) of SC solution for 1 min, and drying the SC-impregnated cotton pad in an oven at 60 °C for 24 h. Then the dried cotton pad was coated with 1% of polyvinylpyrrolidone (Sigma Aldrich, St Louis, MO, USA) solution and made flat by pressing using a Carver press (MODEL 3895.4NEO, Carver Co. IN, USA), and dried at 80 °C for 24 h. The final dimension of SC-cotton pad is approximately $6 \times 6 \times 0.23$ cm. Through this process, cotton weight increased from 0.49 g to 5.98 g with inclusion of 5.49 g SC. The pad was cut into different sizes when needed.

2.2. Packaging design for shiitake mushrooms

Shiitake mushroom packages at 10 °C were designed following the simplified principles to meet their absorption requirements of CO_2 and water vapour by using the absorbers. CO_2 and moisture produced from the mushroom in excess more than desired levels would be taken as demands for their absorption by active absorbers (sachet or pad). Matching the demands to the characteristics of CO_2 and water absorbers was the key idea in designing the active packages of the mushrooms. Tailoring the package conditions to the commodity requirements is expected to be achieved better by systematic considerations on mechanistic principles involved rather than trial-error approach (Cagnon et al., 2013).

The package unit of 180 g mushrooms in a 30 μm thickness oriented polypropylene (OPP) film bag (27×21 cm) with 15 micro-perforations of diameter 98 μm was selected to offer proper level oxygen concentration around 10% based on the preliminary mathematical simulation as described previously (Wang, An et al., 2015), where CO_2 concentration was not considered due to negligible variation of O_2 concentration with presence of CO_2 absorber giving different CO_2 concentration.

Then the requirement of CO_2 absorption to keep steady state 4% concentration (0.04 atm) optimal for shiitake mushroom (Parentelli et al., 2007) was calculated based on the mass balance; the amount of CO_2 required to be absorbed with active sachet or pad for shelf life of 5 days (t_s), n_{CO_2} (mol) was estimated by Eq. (1).

$$n_{CO_2} = \left[\frac{ND_{CO_2}A_p(0 - P_{CO_2})}{L_d}\left(\frac{101325}{RT}\right) + \frac{\overline{P}_{CO_2}S(0 - P_{CO_2})}{L} + WR_{CO_2}\right] \times t_s \quad (1)$$

where N is the number of perforations in the package (15), D_{CO_2} is the gas diffusivity of CO_2 in air (0.052 $m^2\,h^{-1}$), A_p is the area of a perforation ($\pi(9.8 \times 10^{-5})^2/4 = 7.54 \times 10^{-9}\,m^2$), L is the thickness of the plastic packaging film (30 μm), L_d is the corrected perforation length of gas diffusion resistance given as the perforation depth plus $1.1 \times$ diameter of the perforation (1.38×10^{-4} m), R is the gas constant (8.314 $m^3\,Pa\,K^{-1}\,mol^{-1}$), T is the storage temperature (283 K), P_{CO_2} is the equilibrated partial pressure of CO_2 in packaging headspace (0.04 atm), $\overline{P}_{CO_2}$ represents the CO_2 permeability of the polypropylene film (0.119 mol μm $m^{-2}\,h^{-1}\,atm^{-1}$) (Lee, Woo, & Lee, 1994), S is the surface area of the package ($2 \times 0.27 \times 0.21 = 0.1134\,m^2$), W is the produce weight (0.18 kg), t_s is the shelf life (120 h), R_{CO_2} is the produce respiration rate in CO_2 production (2.83×10^{-5} mol $kg^{-1}\,h^{-1}$ or 0.346 μg $kg^{-1}\,s^{-1}$), which could be determined for 0.10 atm of O_2 partial pressure (P_{O_2}) and 0.04 atm of CO_2 partial pressure (P_{CO_2}) by an enzyme-kinetics based respiration model (Lee, Haggar, Lee, & Yam, 1991).

$$R_{CO_2} = \frac{V_m P_{O_2}}{K_m + (1 + P_{CO_2}/K_i)P_{O_2}} \quad (2)$$

where V_m (3.479×10^{-3} mol $kg^{-1}\,h^{-1}$ or 42.5 μg $kg^{-1}\,s^{-1}$), K_m (0.000) and K_i (0.175) are the respiration parameters given by An and Lee (2015).

The requirement of moisture absorption in the mushroom package was determined from the mass balance on the package assumed to be equilibrated in temperature of 10 °C and non-condensing RH of 100% for shelf life of 5 days. The required amount of moisture to be absorbed, n_{H_2O} (mol) consists of its transpiration coupled to respiration heat (Kang & Lee, 1998), vapour-phase diffusion through the perforations and permeation through the plastic film:

$$n_{H2O} = \left[\frac{Q_r W}{L_h} + \frac{ND_{H_2O}(RH - 1)P_s}{L_d}\left(\frac{1}{RT}\right) + \frac{\overline{P}_{H_2O}S(RH - 1)P_s}{101325L}\right] \times t_s \quad (3)$$

where Q_r is the respiration heat (J $kg^{-1}\,h^{-1}$) linked to respiration R_{CO_2} by the simplified relationship of $Q_r = \left(\frac{2816000}{6}\right) \times R_{CO_2}$ (Kang & Lee, 1998), L_h is the latent heat of moisture evaporation at 10 °C (4.459×10^4 J mol^{-1}), D_{H_2O} is the water vapour diffusivity in air (0.083 $m^2\,h^{-1}$), RH is the relative humidity of outside environment in decimal, P_s is the saturated water vapour pressure at 10 °C (1227 Pa), $\overline{P}_{H_2O}$ represents typical water vapour permeability of the plastic (OPP) film (2.55 mol μm $m^{-2}\,h^{-1}\,atm^{-1}$ at 10 °C) (Kulchan, Boonsupthip, & Suppakul, 2010; Lee, Yam, & Piergiovanni, 2008).

From the above analyses of Eqs. (1) and (3), n_{CO_2} was determined as 0.057 mol and n_{H_2O} as 0.683 mol. Then the conditions of active sachet and pad to satisfy those demands were estimated from their absorptive characteristics to CO_2 and water vapour, which were measured from independent experiments under the condition of 10 °C and 100% RH as described by Wang, Jo, An, Rhim, and Lee (2015). In short, the CO_2 absorption capacity was measured in the hermetically closed glass jar system, which kept the Tyvek film absorber sachet (4.0×4.0 cm with 4.0×10^{-3} mol scavenger being 0.424 g of SC alone or SC/CH mixture of 0.223 and 0.156 g each) or SC-cotton pad of 1.5×1.5 cm