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Monitoring and modelling of headspace-gas concentration changes for shelf life control of a glass packaged perishable food

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ABSTRACT

Gas concentrations in the headspace of hermetically sealed glass packages of seasoned soybean sprouts were monitored and related to their microbial quality, i.e., the change in aerobic bacterial count, in order to examine the potential for using package gas changes as a primary quality index for shelf life control. Aerobic bacterial count, CO_2 and O_2 concentrations were measured from packages stored at four different temperatures: 0, 5, 10 and 15 °C. The CO_2 concentration increased and the O_2 concentration decreased with microbial growth. The microbial growth and CO_2 concentration change were described by a logistic function to yield kinetic parameters, and their temperature dependence was analysed by a square-root model. The kinetic parameters for microbial growth and CO_2 production differed in their magnitude and temperature dependence. The lag time observed for the increase in CO_2 concentration could be used as a shelf life index that corresponds to the time to reach a given microbial limit (here, 10^7 CFU/g) under different temperature conditions, particularly under conditions of temperature abuse.

1. Introduction

Many prepared foods are packaged and distributed under controlled-temperature conditions. The primary quality factor determining their shelf life is often microbial spoilage, even under refrigerated conditions. Shelf life control based on microbial quality is of prime importance when considering food quality and safety. However, a fixed shelf life control model assuming an invariant food supply chain does not take into consideration the variety of distribution conditions in actual practice; microbial quality change is so dependent on environmental variables such as temperature that shelf life determined on the basis of fixed conditions may be insufficient for a real-world marketing environment. Therefore, shelf life control based on real-time monitoring or estimation of microbial quality has been investigated (Lee, Hwang, An, Park, & Lee, 2007; Taoukis & Labuza, 2003). Because direct measurement of microbial quality can be time-consuming and labour-intensive, convenient indicators have been sought to represent the microbial status of various products. Many physical and chemical indices have been shown to correlate with microbial counts of specific spoilage microorganisms (Dainty, 1996). Volatile metabolites of microbial growth have been proposed as potential indicators of microbial quality (Ellis & Goodacre, 2001; Smolander, 2003). On a real-time basis in the food distribution chain, easily monitored indices may be obtained from gas-concentration changes in package headspace (Sutherland, 2003). A volatile index can be measured non-destructively, another merit of in-line shelf life control in the food supply chain. Innovative gas sensors may be applied to in-line detection and control of microbial food spoilage in near future (O'Mahony & O'Riordan, 2004).

This study therefore evaluated the possibility of using package headspace-gas concentration as an indicator for the microbial quality (change in aerobic bacterial count) of a prepared food, here, seasoned soybean sprouts. Changes in aerobic bacterial count have been used as a common microbial quality indicator for many perishable prepared foods (Corbo, Del Nobile, & Sinigaglia, 2006; Garcia-Gimeno & Zurera-Cosano, 1997; Lee et al., 2007; Vankerschaver, Willocx, Smout, Hendricks, & Tobback, 1996) and thus, in this study, they were compared to headspace-gas concentration changes.

2. Materials and methods

2.1. Seasoned soybean sprouts

Seasoned soybean sprouts, a typical ready-to-eat Korean food, were prepared in our laboratory. Pre-packed soybean sprouts (Daesang, Yeoju, Korea) were purchased from a supermarket in Masan, Korea, and washed in flowing water. Minced garlic (CJ Corporation, Eumsung Korea), sesame oil (CJ Corporation, Incheon,

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Korea), salt (CJ Corporation, Busan, Korea) and roasted sesame (CJ Corporation, Eumsung, Korea) were purchased from a supermarket in Masan, Korea. The washed soybean sprouts were blanched in 1-kg batches for 2.5 min in 6 L of boiling water and then cooled in water. The cooked soybean sprouts were mixed with seasonings: 19 g of minced garlic, 20 g of sesame oil, 18 g of salt, and 8 g of roasted sesame. Eight batches of the product were prepared and mixed thoroughly for the storage experiment. The product had a typical pH of 5.88, a water activity of 0.95, and a salt content of 2.8 g/100 g. The preparation, divided into 50 g portions, was filled into glass jars of 160 mL (6 cm in diameter and 7.7 cm in height), which were then hermetically sealed with a metal lug cap (Doosan TechPack, Icheon, Korea). The packaging conditions resulted in 104 mL of headspace volume. The jars were stored at 0, 5, 10 and 15 °C and removed periodically for measurement of headspace gas concentrations and microbial counts.

2.2. Microbial counting and headspace gas analysis

To measure the microbial quality of the stored product, 40-g samples of sprouts from each bottle were aseptically transferred to sterile Stomacher bags, and 80 mL of sterile 0.05 g/100 mL peptone water was added. The samples were then homogenised for 4 min at 300 reciprocations per minute in a Stomacher (400 Circulator, Seward Limited, Worthing West Sussex, England). Aliquots were plated out directly or as ten-fold dilutions in 0.05 g/100 mL peptone water onto Plate Count Agar (PCA; Difco Laboratories, Detroit, USA). Microbial colonies of aerobic bacteria were counted after incubation at 30 °C for 72 h, and are expressed as colony-forming units (CFU) per gram of sample. One millilitre of headspace gas in the bottle was sampled using a gas-tight syringe, and concentrations of O_2 and CO_2 in kPa of partial pressure were determined using a Varian Model 3800 Gas Chromatograph (Varian Inc., Palo Alto, CA, USA) equipped with an Alltech CTR I Column (Alltech Associates Inc., Deerfield, IL, USA) and a thermal conductivity detector. The temperature of the column was maintained at 40 °C with an injection temperature of 70 °C and the detector at 90 °C. Helium was used as the carrier gas at a flow rate of 30 mL/min. All of the measurements were conducted for triplicate jar packages.

3. Results and discussion

3.1. Patterns of headspace gas concentration changes concomitant with microbial spoilage

Fig. 1 shows the evolution of aerobic bacterial growth in the food product and gas concentration changes in the headspace of the seasoned soybean sprouts package. The bacterial growth at all four temperatures showed typical microbial growth patterns consisting of lag, exponential growth, and stationary phases (Fig. 1(A)). As expected, higher temperatures resulted in a shorter lag time and a faster growth rate in the exponential phase, with the stationary phase reached earlier. The lower temperatures of 0 and 5 °C had lower levels of maximum microbial counts at stationary phase. Higher maximum cell density at higher temperature has often been observed for bacterial growth on some foods (Koseki & Isobe, 2005; Lee et al., 2007; Park & Lee, 2008).

The CO_2 concentration followed a pattern of increase similar to the microbial growth curve but with a later onset of evolution (Fig. 1(B)). The arrival of maximum CO_2 concentration also lagged slightly behind the microbial stationary phase at 5, 10 and 15 °C. While there was a slight difference in maximum cell density between storage temperatures after reaching the stationary phase, maximum CO_2 concentrations were much higher at higher temperatures: a temperature increase of 10 °C increased maximum CO_2 partial pressure by more than four times. The O_2 level decreased from an initial value of ~22 kPa and reached almost complete depletion (5, 10 and 15 °C) or a constant level (0 °C) at microbial stationary phase (Fig. 1(C)). The higher rate of O_2 concentration decline at higher temperature took place together with higher CO_2 partial pressure build-up and also with higher rate of bacterial growth. It can be reasoned that aerobic bacterial growth consumed the oxygen, producing carbon dioxide. The differences in the extent of maximum growth and respiratory metabolism of the microbial flora with temperature would have resulted in higher degrees of CO_2 accumulation at higher temperature. Other oxidative reactions and microbial flora change due to package atmosphere change would also have contributed to this phenomenon. The lower solubility of CO_2 at higher temperature would be another cause of

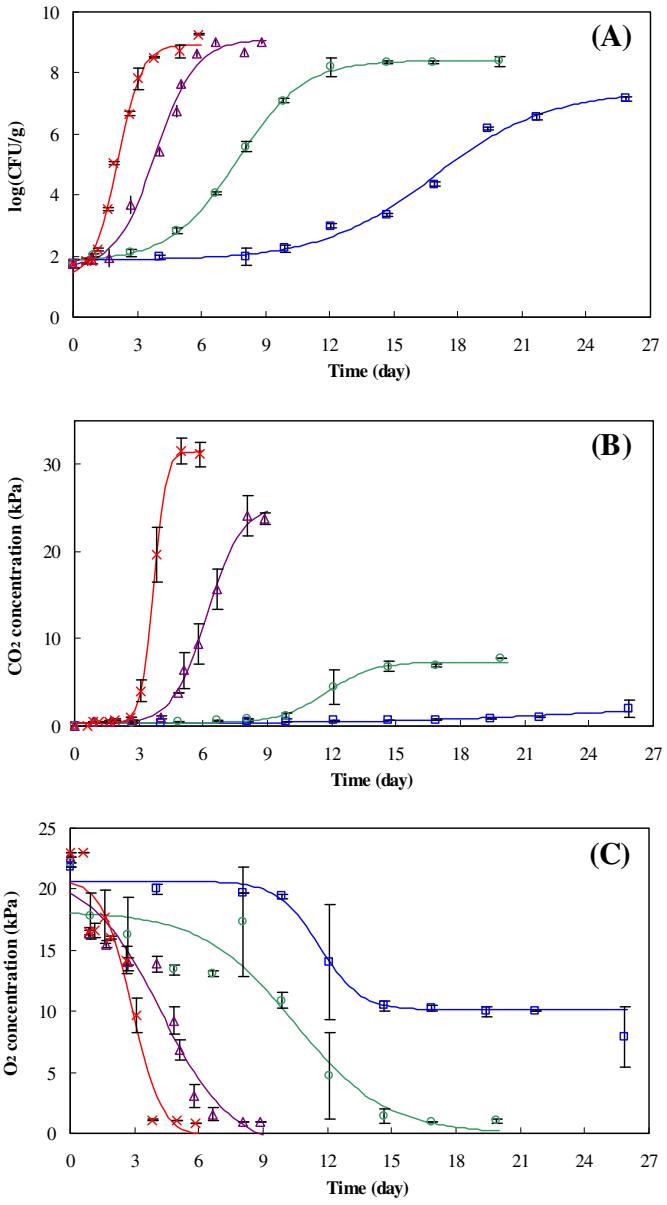

Fig. 1. Changes in total aerobic bacteria counts of seasoned soybean sprouts and gas concentrations of the package headspace at different temperatures ($n = 3$). 50 g sprouts in 160 mL glass jar package. Description of microbial count on seasoned soybean sprouts and their package headspace gas changes by the logistic equation. Solid lines are fitted by Equation (1). Vertical bars are standard deviations. □: 0 °C; ○ : 5 °C; △: 10 °C; ×: 15 °C.