Physiological behavior and quality of fresh ginseng stored in modified atmospheres generated by several package films

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Revised: 9 November 2012 / Accepted: 26 December 2012 / Published online: 19 January 2013
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Abstract Physiological behaviors and quality attributes of fresh ginseng (*Panax Ginseng*) stored in modified atmospheres generated by several package films were investigated. The chemical compositions were also measured before and after storage. The respiration rates of fresh ginseng were inhibited effectively by film package, especially in package with lower gas permeability coefficient film. The polyphenol oxidase (PPO) activity reduced markedly and high Hunter L^* value was maintained. Significant differences ($p < 0.05$) in firmness, weight loss, decay rate and pectin content were found between 0.10 mm packages and 0.05, 0.07 mm packages after 5 months of storage. The best quality parameters of fresh ginseng were obtained from the combination of 0 °C–0.10 mm. Significant difference ($p < 0.05$) in total saponin content was not found, and the highest total saponin content was also obtained from the combination of 0 °C–0.10 mm. The content of total sugar and reducing sugar increased significantly ($p < 0.05$), especially for package film with higher gas permeability coefficient. The storage life of fresh ginseng was extended significantly by film packages to 5 months with good quality and lower decay rate, especially for package film with low gas permeability coefficient.

Keywords Fresh ginseng · Physiological behavior · Quality · Modified atmospheres · Package film

Introduction

Ginseng (*Panax Ginseng*) is the functional health herb that has been used in traditional medicine for a long time in Asian

countries. Ginseng is usually dried for storage, processing and marketing due to deterioration within weeks after harvest. Storage of fresh ginseng plays important role in postpones supply and consumer's demand, especially in extending processing period.

Modified atmospheres packaging (MAP) combined with low temperature has been recognized as beneficial and rather inexpensive way to improve storage life of fresh horticultural commodities (Geeson et al. 1985; Zagory and Kader 1988; Kader 1986). The basic principle of MAP is that the given product is packaged using a selected film, and a desired atmosphere develops naturally as a consequence of the products' respiration and gas diffusion through the film (Moleyar and Narasimham 1994; Zagory 1995; Lee et al. 1996; Lee and Kim 1979). Optimal concentrations of O₂ and CO₂ are created passively inside the packages, as result of gaseous exchange between the atmosphere on the inside and outside of package and respiration by the produce which consumes O₂ and produces CO₂. Packaging films with different gas permeability coefficients have significant effect on regulating gas composition and respiratory metabolism of product inside package (Hening and Gibert 1975). Moreover, gas permeability coefficients of package film may not change to the same extent as respiration rate with temperature, and hence the atmosphere inside the package will be altered (Exama et al. 1993).

Little research has been done on fresh ginseng stored in modified atmospheres generated by several package films with different thickness to extend storage life. The objectives of this study were to investigate the effects of film thickness with different gas permeability coefficients and temperatures on the physiology and quality attributes of fresh ginseng. The chemical compositions and some important quality attributes of fresh ginseng were also determined before and after storage.

Materials and methods

Plant materials Samples of fresh ginseng (six-year old) were harvested in September from the Jiaohe ginseng farm

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in Jilin Province, China. The harvested fresh ginseng was transported to laboratory and stored at 5 °C. And then ginseng roots were sorted by size, shape and appearance for use in experiment.

Film permeability The film used for fresh ginseng packaging was low-density polyethylene (LDPE, 0.05, 0.07 and 0.10 mm in thickness), whose gas permeability coefficients are given in Table 1. The gas permeability of film was measured by injecting mixed gas of 78 % N₂, 5 % CO₂ and 17 % O₂ into a 10×15 cm pouch with 200 ml syringe. Pouches were stored at 0 and 10 °C. The changes in gas concentrations inside the pouches were determined by gas chromatography (Shimaduz GC-2010, Tokyo, Japan) equipped with a thermal conductivity detector (TCD). Helium was used as carrier gas and the flow rate was 30 ml·min⁻¹. The column, injector and detector temperatures were 50, 80 and 100 °C, respectively. The column was WG100 with molecular sieve 5 A and Porapak Q 80/100 mesh. The gas permeability coefficients were calculated from the changes in gas partial pressure and expressed as mol·m m⁻² h⁻¹ Pa¹ (Banks et al. 1995).

Packaging film and storage conditions The fresh ginseng was selected at random and samples of 2 kg were sealed into 0.05, 0.07 and 0.10 mm LDPE film pouches (30×40 cm). The 18 pouches were stored at 0 and 10 °C, respectively. Each treatment consisted of 6 pouches, of which 3 pouches were used for monitoring the atmosphere composition. The void volume of package was determined by subtracting the volume of ginseng from the total volume within the pouch as measured by water displacement (Christie et al. 1995). The volume of ginseng was determined by immersing ginseng in water completely in a 5,000 ml jar that was placed on digital weighing balance (Mettler, PM6100, Tokyo, Japan) with an accuracy of 10⁻²g, and calculated based on the equation at given temperature: $V = \text{Weight of displaced water } (W_d) / \text{water density } (\rho)$. The initial void volume of per package was regulated into 1,500 ml by using 500 ml syringe. The evolution of CO₂ and O₂ consumption inside the package were monitored by gas chromatography (Measurement equipment

and conditions were same as measurement of film permeability as stated above). Gas sample of 1 ml was drawn by using gas-tight syringe through a septum from each package. The measurements were carried out by triplicates. Finally, the packages were opened to evaluate the quality attributes of fresh ginseng after 5 months of storage.

Mathematical model for determination of respiration rate To determine the respiration rate of fresh ginseng in MAP, the basic volume balance given in equations was used (Akimoto and Maezawa 1997; Hu et al. 2003). The changes in partial pressure of O₂, CO₂ and N₂ in packages were modeled by considering a gas volume balance in package. The changes in the free volume of gas within package were considered based on gas in or out of package through diffusion in proportion and CO₂ production and O₂ consumption by respiration of produce. The equations on change of the free volume were established based on gas production by respiration, transmission through package film and accumulation in package with time and can be expressed as follows:

$$\frac{dV_S}{dt} = \frac{dV_C}{dt} + \frac{dV_O}{dt} + \frac{dV_N}{dt} \quad (1)$$

$$\frac{dV_C}{dt} = \frac{A}{L} K_C (P_{Ca} - P_C) + R_C W \quad (2)$$

$$\frac{dV_O}{dt} = \frac{A}{L} K_O (P_{Oa} - P_O) + R_O W \quad (3)$$

$$\frac{dV_N}{dt} = \frac{A}{L} K_N (P_{Na} - P_N) \quad (4)$$

where V is the free volume of gas in pouch (ml), t is storage time (h), A is surface area of pouch (m²), L is thickness of film (m), K_C , K_O and K_N are the gas permeability coefficient through packaging film for CO₂, O₂ and N₂ (mol·m m⁻² h⁻¹ Pa¹), R_C and R_O are CO₂ production rate and O₂ consumption rate (mmol kg⁻¹ h⁻¹), W is weight of product (kg), P_{Ca} , P_{Oa} and P_{Na} are partial pressure of CO₂, O₂ and N₂ outside pouch (kPa), P_C , P_O and P_N are partial pressure of CO₂, O₂ and N₂ inside pouch (kPa).

PPO activity PPO activity was determined essentially as described by Murr and Morris (1975). A 10 g sample from 10 ginseng roots was homogenized in 20 ml 0.02 M phosphate buffer (pH 6.0). The homogenate was centrifuged at 17,000×g for 20 min at 4 °C and the supernatant collected as the crude enzyme extract. A 1 ml of enzyme extract was added to 1 ml of 0.01 M catechol in 1 ml of 100 mM

Table 1 Gas permeability coefficients of different thickness films at different temperatures. (×10⁻⁷ mol·m m⁻² h⁻¹ Pa⁻¹)

Thickness of film (mm)	0 °C		10 °C	
	CO ₂	O ₂	CO ₂	O ₂
0.05	10.1±3.12 ^a	3.0±1.31 ^a	11.2±2.16 ^a	3.8±1.18 ^a
0.07	8.2±2.13 ^a	1.9±0.63 ^b	9.8±3.14 ^a	2.6±1.22 ^a
0.10	5.0±1.15 ^b	1.0±0.34 ^b	7.0±2.26 ^b	1.7±0.62 ^b

Means followed by different letters are significantly different according to least significant difference (LSD) at the $P < 0.05$ level ($n = 20$)

phosphate buffer, pH6.0. The absorbance of the chromogen developed was measured at 411 nm. Enzyme activity at 25 °C is expressed as OD min⁻¹ protein of the extract. Enzyme protein in the extract was estimated using the Folin phenol reagent (Lowry et al. 1957).

L* value The appearance color of fresh ginseng was determined by using a chromameter (model CR 400; Minolta Corp., Japan). A tristimulus colorimeter with an 11 mm aperture and diffuse illumination (C light source) was calibrated with a white standard calibration plate ($Y=92.9, x=0.3136, y=0.3200$). Expression of color was characterized as Hunter color indexes L^* , a^* and b^* , where L^* indicates the lightness, a^* means the color axis from green to red, b^* the blue-yellow color axis. Measurement was carried out in 10 ginseng roots from different packages per treatment and defined at four points which two points were set middle parts and two points was fixed on the top and bottom parts for each fresh ginseng, respectively. The changes in the browning of fresh ginseng were shown in Lightness (L^* value).

Quality evaluation The firmness of each ginseng root was measured by Fruits Hardness Tester (model FHR-5, Takemura Electric Works, LTD, Japan) equipped with 5 mm plunger. The measurement was made at 3 different points on each ginseng root. Dial readings were assessed in kg force and then values were multiplied by 9.807 Nkg⁻¹ to Newton (N).

Weight loss was determined by monitoring the weight of the fresh ginseng in the packages before and after storage. Weight loss was expressed as the percentage of weight loss with respect to the initial weight.

The decay rates were performed after 5 months of storage at different temperatures and the number of ginseng manifesting decay symptoms was determined in each treatment and expressed as the decay percentage. The evaluation was scored on a 5-point scale: 0=excellent, 5=very bad, ginseng with scale above 3 was considered commercially unacceptable as decay. Measurement of ten ginseng roots was carried out for each treatment.

Measurement of chemical compositions Total saponin was determined by method as follows: 2 g of pulverized ginseng sample was taken and the extraction of ginseng saponin was carried by refluxing with 20 ml methanol in soxhlet extractor for 12 h at 60 °C. After removal of the solvent by evaporation *in vacuo*, the extract was dissolved in distilled water. This solution was partitioned into ether and aqueous layer, and the aqueous layer was then extracted with *n*-butanol (*n*-BuOH) saturated with water. The *n*-BuOH layer was concentrated *in vacuo* and lyophilized to afford total saponin. The dried extract was then dissolved in 10 ml methanol and the extracted solution of total saponin was obtained. Saponin Re was used as standard of ginseng saponin, the absorbance was measured

at 560 nm by an infrared spectrophotometer (FTIR-8100, Shimadzu, Japan). The analysis of saponin was carried out before and after storage.

Total sugar was determined by high performance liquid chromatography (Shimadzu, LC-10A) equipped with NH2P-50 column (4.6 mmφ × 250 mm) and RI detector. The column was packed with SUS 316. The mobile phase was acetonitrile: water=75: 25 at a flow rate of 1.0 mlmin⁻¹ and injection volume is 20 µl as described by Ajlouni et al. (1995). A 20 g sample from ten ginseng roots was homogenized with 20 ml 75 % acetonitrile. The homogenate was centrifuged at 12,000×*g* for 20 min. The supernatant was taken as sample to measure the sugar content. Standard of solutions of fructose, glucose and sucrose were employed at a concentration of 5 mg ml⁻¹. Final results were expressed as mg g⁻¹ fresh weight.

Reducing sugar was examined using 3,5-dinitro-salicylic acid (DNS) method as described by James (1995). The absorbance of each sample solution was measured at 540 nm on spectrophotometer (FTIR-8100, Shimadzu, Japan). Total reducing sugars were calculated based on the calibration curve of glucose.

Soluble pectin was extracted as described by Bartley et al. (1982). Soluble pectin was precipitated from 80 % acetone and estimated as an-hydro-galacturonic acid using 3-phenyl-phenol (Blumenkrantz and Asboe-Hansen 1973).

Statistical analysis The experimental design was completely randomized and three replicates of each treatment were carried out. Data for the physical and chemical parameters were subjected to analysis of variance. Mean comparisons were performed using least significance difference at the $P < 0.05$ level.

Results and discussion

Changes in atmosphere compositions and respiration rates Changes in gas partial pressures in MAP at different temperatures are shown in Fig. 1. Atmosphere compositions in MAP were different inside packages with various film thicknesses. O₂ decreased and CO₂ increased obviously before 3 months of storage, and then reached the steady state that fluctuated around CO₂ 5.9–6.5 kPa and O₂ 13.2–12.2 kPa in 0.10 mm packages, CO₂ 5.8–6.1 kPa and O₂ 13.3–12.4 kPa in 0.07 mm package, CO₂ 4.0–4.4 kPa and O₂ 14.5–14.1 kPa in 0.05 mm package at 10 °C (Fig. 1), respectively. For storage at 0 °C (Fig. 1), gas concentrations fluctuated around CO₂ 3.2–3.4 kPa and O₂ 15.2–15.0 kPa in 0.10 mm pouch, CO₂ 2.5–2.7 kPa and O₂ 15.8–15.5 kPa in 0.07 mm package, CO₂ 2.5–2.7 kPa and O₂ 116.5–16.1 kPa in 0.05 mm package, respectively.

Gas permeability coefficients of different thickness films at different temperatures are shown in Table 1. Gas permeability

Fig. 1 Changes in gas partial pressures and respiration rates in modified atmosphere package of fresh ginseng at different temperatures ($n=10$)

coefficients decreased with increase in film thickness and increased with rise in temperature. Of the three packaging films used in the MAP, the film with high gas permeability coefficient (0.05 mm) gave the lowest CO₂ concentration and highest O₂ concentration in package, while low gas permeability coefficient film (0.10 mm) gave highest CO₂ concentration and lowest O₂ concentration. The medium gas permeability coefficient film (0.07 mm) package was relatively high in CO₂ and low in O₂ concentrations throughout storage (Fig. 1). Modified atmosphere were created by the interaction of gas production by respiration, gas transmission through packaging films and accumulation in package (Christie et al. 1995). It appeared that the metabolic activity of respiration was markedly suppressed in MAP and this inhibition was more effective in package with lower gas permeability coefficient of film (Murr and Morris 1975; Roy et al. 1996). In general, gas permeability coefficient of film increases as temperature increases, while CO₂ permeability coefficient responds more quickly than that of O₂ permeability coefficient. This implies

that the film could be appropriate for MAP at one temperature may not be appropriate at other temperatures.

Changes in respiration rates of fresh ginseng in MAP are shown in Fig. 1. Respiration rates of fresh ginseng decreased gradually during the 5 months of storage at 0 and 10 °C. For 10 °C (Fig. 1), respiration rates were much higher at 10 °C than that at 0 °C, indicating that temperature was more important factor for affecting respiratory metabolism of fresh ginseng. The respiration rate decreased from initial 20.3 mmol kg⁻¹ h⁻¹, 3-month 12.9 and 10.6 mmol kg⁻¹ h⁻¹, and declined to 9.8 and 8.1 mmol kg⁻¹ h⁻¹ after 5-month of storage for 0.05 mm and 0.07 mm packages, respectively. While respiration rate decreased markedly from initial 20.3 mmol kg⁻¹ h⁻¹ to 3-month 8.2 mmol kg⁻¹ h⁻¹, and then decreased gradually to 6.6 mmol kg⁻¹ h⁻¹ after 5-month of storage for the combination of 10 °C and 0.10 mm package. For 0 °C (Fig. 1), the respiration rate decreased from initial 13.8 mmol kg⁻¹ h⁻¹, 3-month 8.4 mmol kg⁻¹ h⁻¹, and then slightly declined to 8.1 mmol kg⁻¹ h⁻¹ at the end of storage for 0.05 mm package. For 0.07 and 0.10 mm

Fig. 2 Effect of film thickness on PPO activity ($n=10$) and L^* value ($n=20$) of fresh ginseng in modified atmosphere packaging stored at different temperatures (black square 10 °C, white square 0 °C)

packages, respiration rates were relatively higher in 0.07 mm packages than that in 0.10 mm film package for 3 months, but the same changing trend was showed after 3 months, fluctuating around $6.3\text{--}6.5\text{ mmol kg}^{-1}\text{ h}^{-1}$ at 0 °C. It indicated that the degree of inhibition was increased with increasing film thickness. But it showed that there were the similar level of respiration rates in the packages with 0.07 and 0.10 mm film from 3-month to 5-month of storage at 0 °C.

Metabolic processes of plant including respiration are sensitive to temperature. The biological reaction of plant to temperature is expressed as temperature coefficient (Q_{10}) that respiration rate increases fold every 10 °C rise in temperature. In this experiment, Q_{10} values was only 1.2–1.0 in the range of 0.05–0.10 mm packages, indicating that respiratory metabolism of ginseng was insensitive to temperature change. Even though large increase in temperature, they

could not greatly increase in respiration rate. Sharples and Johnson (1987) reported that variations in susceptibility to physiological disorders caused by low O_2 or high CO_2 are as influenced by effects of climatic and growing conditions on the structure, mineral composition and maturity of the fruit when harvested. Ginseng is perennial and weak-light plant that is grown under cool climatic conditions and at a very low rate. Ginseng used in this experiment was six-year old. It indicated that fresh ginseng with lower metabolic activity has relative higher tolerance to low O_2 and high CO_2 concentrations could be stored near 0 °C.

Changes in PPO activity Effect of film thickness on PPO activity of fresh ginseng MAP stored at different temperatures is shown in Fig. 2. PPO (EC 1.14.18.1) is responsible for enzymatic browning of many edible plant products, especially fruits and vegetables during postharvest handling and processing. The enzymatic browning can be defined as an initial enzymatic oxidation of phenol compounds into slightly colored *o*-quinones in the presence of O_2 catalyzed by PPO (Murr and Morris 1975). The browning of ginseng is a major problem that can modify the properties of ginseng and affect its appearance. In this experiment, PPO activity remained much lower at 0 °C than that at storage temperature of 10 °C (Fig. 2). PPO activities in 0.10 mm packages was the lowest, indicating that inhibition of respiratory metabolism was important to decrease PPO activity and consequently inhibiting enzymatic browning.

Changes in L^* value Effect of film thickness on L^* value of fresh ginseng MAP stored at different temperatures is shown in Fig. 2. Hunter L^* value analysis showed similar trend as PPO activity that they decreased as the rise in temperature and increased with thickness of film. It was considered that L^* value was used as indicator of physiological metabolism of fresh ginseng in packages. Fresh ginseng in MAP was very slight brown and with low discoloration. The storage life of fresh ginseng in MAP was significantly extended for 5 months with good quality and relative lower decay rate.

Changes in quality attributes Changes in quality attributes fresh ginseng after 5 months of storage are shown in Table 2. Significant differences ($p<0.05$) in firmness, weight loss and decay rate were found between 0.10 mm packages and 0.05, 0.07 mm packages after 5 months of storage. The best quality parameters of fresh ginseng were obtained from the combination of 0 °C–0.10 mm.

Firmness of ginseng roots declined during extended storage period, especially for 0.05 mm packages and at higher temperature. Knee and Bartley (1981) reported that concentration of soluble pectin in apple fruit increased during softening and it has been suggested that this is a result of the degradation of cell wall pectin. For fresh ginseng,

Table 2 Changes in quality attributes of fresh ginseng after 5 months of storage

Temperature (°C)	Film thickness (mm)	Firmness ^a (N)	Weight loss (%)	Decay rate (%)
0	0.05	83.5±2.12 ^a	7.3±0.54 ^a	6.3±0.22 ^a
	0.07	89.2±1.54 ^a	6.2±0.33 ^a	4.4±0.31 ^a
	0.10	100.3±1.85 ^b	4.1±0.35 ^b	2.8±0.41 ^b
10	0.05	72.2±3.16 ^a	8.9±0.65 ^a	8.0±0.32 ^a
	0.07	79.3±2.13 ^a	7.5±0.74 ^a	7.3±0.27 ^a
	0.10	85.3±2.47 ^b	5.8±0.68 ^b	4.8±0.78 ^b

Means followed by different letters are significantly different according to least significant difference (LSD) at the $P<0.05$ level ($n=10$)

^a Initial value of firmness is 118.3±1.0 N in fresh ginseng, respectively

similar results (Table 3) were obtained. It was considered that MAP with lower storage temperature effectively inhibited the decomposition of pectin and reduced firmness loss significantly.

Weight losses increased with the decrease in thickness of film at different temperatures. For the effects of temperature, there was the lower weight loss at 0 °C than that at 10 °C, especially in the package for lowest gas permeability coefficient film. It was concluded that much more respiratory substrate was consumed by respiration and much more moisture in package permeated out through the film at higher temperature, especially in 0.05 mm package.

Decay rate increased as decrease in film thickness and increase with rise storage temperature. The lowest decay rate was obtained from the storage with combination of 0 °C and 0.10 mm thickness. Fresh ginseng packaged with lower permeability coefficient film had lower decay rate due to inhibition of physiological metabolism under low O₂ and high CO₂ conditions in MAP.

Changes in chemical compositions Changes in total saponin, total sugar, reducing sugar and pectin contents in fresh

ginseng after 5 months of storage are shown in Table 3. Significant difference ($p<0.05$) in total saponin content was not found among packaging films at different temperatures, and the highest total saponin content was also obtained from the combination of 0 °C–0.10 mm. There were significant difference ($p<0.05$) in contents of total sugar and reducing sugar between 0.07, 0.10 mm packages and 0.05 mm packages after 5 months of storage.

Saponin is well-known the major bioactive compound in ginseng. The total saponin content was not remarkably changed during 5 months of storage. It decreased 2.6–6.0 % from initial 48.6 to 47.3–45.7 mg g⁻¹ at 0 °C and 3.7–7.2 % from 48.6 to 46.8–45.1 mg g⁻¹ at 10 °C for ginseng sealed in 0.10, 0.07 and 0.05 mm packages, respectively. It showed that activity of physiological metabolism affected the change in total saponin content, the relative higher total saponin content was maintained by the combination of 0 °C–0.10 mm package. Similar observations were made by Yum and Lee (1998) for CA storage of fresh ginseng. It was considered that saponin in fresh ginseng could be maintained effectively by inhibiting respiratory metabolism in MAP, especially in packaged film with lower gas permeability coefficient at low temperature.

Total sugar (sum of sucrose, fructose and glucose) content increased during storage, especially in 0.05 mm packages and at high temperature. In ginseng roots, sucrose, fructose and glucose was the major soluble sugar components accumulated, with sucrose predominating. In generally, starch granules in fresh ginseng were hydrolyzed into soluble sugars as the storage period extended. In this experiment, this increase was a consequence of starch degradation and the progressive catabolism of soluble sugars by respiration. The conversion of starch to sugar occurred slowly due to repressed respiration rate of ginseng stored in MAP. It was considered that the increase in reducing sugar and total sugar to supply the respiratory substrates for respiration was from decomposing oligosaccharide or starch in fresh ginseng.

Reducing sugars in fresh ginseng are an important quality factors that affect the color and appearance of ginseng during

Table 3 Changes in total saponin, total sugar, reducing sugar and pectin contents in fresh ginseng after 5 months of storage

Temperature (°C)	Film thickness (mm)	Total saponin (mg g ⁻¹)	Total sugar (mg g ⁻¹)	Reducing sugar (mg g ⁻¹)	Pectin (mg g ⁻¹)
0	0.05	45.7±1.32 ^a	38.9±0.36 ^a	32.6±0.65 ^a	15.6±0.84 ^a
	0.07	46.8±1.15 ^a	34.8±0.55 ^b	24.2±0.76 ^b	16.7±0.42 ^a
	0.10	47.3±0.92 ^a	29.4±0.87 ^b	19.8±0.39 ^b	17.7±0.23 ^b
10	0.05	45.1±0.63 ^a	44.3±1.22 ^a	35.0±0.42 ^a	14.8±0.35 ^a
	0.07	45.9±1.55 ^a	35.4±0.91 ^b	27.7±0.62 ^b	15.2±0.56 ^a
	0.10	46.8±1.26 ^a	32.9±0.41 ^b	23.5±0.84 ^b	16.8±0.64 ^b

Means followed by different letters are significantly different according to least significant difference (LSD) at the $P<0.05$ level ($n=20$)

Initial contents of total saponin, total sugar, reducing sugar and pectin are 48.6±1.33, 13.1±0.56, 9.2±0.34 and 19.4±0.84 mg g⁻¹ in fresh ginseng, respectively

processing since non-enzymatic browning reactions. Reducing sugar increased markedly during storage. Significant differences ($p < 0.05$) were found between 0.05 mm thinner film with high gas permeability coefficient and 0.07, 0.10 mm thicker film with low gas permeability coefficient, and the highest content of reducing sugar was observed in 0.05 mm film packages. The changes in reducing sugar were also affected significantly by storage temperature. At 10 °C, reducing sugar increased 367 %, 201 % and 155 % from initial 9.2 to 43.0, 27.7 and 23.5 mg g^{-1} for 0.05, 0.07 and 0.10 mm packages, respectively. For 0 °C, reducing sugar increased 254 %, 163 % and 115 % from initial 9.2 to 32.6 mg g^{-1} , 24.2 and 19.8 mg g^{-1} , respectively.

Respiration in plants is the oxidative breakdown of starch, sugar, and organic acids to simple molecules CO_2 and H_2O , with a concurrent production of energy. One of the primary effects of MAP is the reduction of respiration rate, which decreases the rate of substrate depletion, CO_2 production, O_2 consumption and release of heat (Roy et al. 1995). As a result, physiological metabolism of fresh ginseng was slowed down and storage life was extended.

Pectin content in fresh ginseng decreased 20 %, 14 % and 9 % from initial 19.4 mg g^{-1} to 15.6, 16.7 and 17.7 mg g^{-1} at 0 °C, respectively. For 10 °C, pectin content decreased 24 %, 22 % and 13 % from initial 19.4 mg g^{-1} to 14.8, 15.2 and 16.8 mg g^{-1} at the end of storage for 0.05, 0.07 and 0.1 mm film packages, respectively. The pectin content reduced with the increment of temperature. It indicated that higher level of pectin was maintained in packages film with low permeability coefficient due to effectively inhibit the respiration of fresh ginseng in MAP during storage. It was also shown that the firmness of fresh ginseng was maintained by reducing the decomposition of pectin in MAP with lower gas permeability coefficient film (Table 2). It suggested that higher freshness and better quality of fresh ginseng was achieved in MAP with lower gas permeability coefficient film under low storage temperature.

Conclusion

The storage life of fresh ginseng was extended about 5 months in MAP with an O_2 concentration of 12.2–15.0 kPa and CO_2 concentration of 3.4–6.5 kPa. The respiration rates of fresh ginseng were inhibited effectively by film package, especially in package with lower gas permeability coefficient film. The higher L^* value was obtained from reduced PPO activity in MAP. Although reducing sugar and pectin content increased significantly, the better quality attributes of fresh ginseng were obtained from the combinations of 0 °C–0.10 mm with higher firmness, lower weight loss and lower decay rate. Firmness of fresh ginseng stored in MAP was almost the same as that at harvested at 0 °C. The total saponin content was maintained effectively. It suggested the storage life of fresh ginseng could be

extended by film packages with good quality, especially for package film with low gas permeability coefficient at low temperature.

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