Color of Minimally Processed Potatoes as Affected by Modified Atmosphere Packaging and Antibrowning Agents

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ABSTRACT

Minimal processing of potatoes was studied by using different treatments of cut potatoes in combination with modified atmosphere packaging. Different packaging materials and peeling methods were evaluated. An L-cysteine (0.5%) and citric acid (2%) mixture prevented browning of potatoes effectively. Active modification of the atmosphere inside the package was necessary to achieve extended shelf-life. Nitrogen flushing was more effective than other gas treatments with a highly permeable multilayered polyolefin packaging material. Hand peeling and lye peeling resulted in better quality, but abrasion peeling was undesirable for fresh potatoes. The shelf-life of the minimally processed products could be extended to nearly 3 wk under refrigerated storage.

Key Words: potatoes, minimally processed, browning, modified atmosphere, packaging

INTRODUCTION

MINIMALLY PROCESSED FRUITS and vegetables are becoming an important sector of new products due to their fresh-like character and convenience (Kim et al., 1993). Application of partial processing increases perishability due to increased metabolic activities and decompartmentalization of enzymes and substrates. This may cause browning, softening, and off-flavor development (Watada et al., 1990; Rolle and Chism, 1987).

Modified atmosphere packaging (MAP) can extend storage life of fruits and vegetables by controlling respiration rate, senescence and ripening (Zagory and Kader, 1988). MAP can also decrease the rate of browning reactions due to reduced O_2 level and elevated CO_2 level in the surrounding atmosphere (Herner, 1987). The most important quality defect in some fresh-cut fruits and vegetables is enzymatic browning caused by oxidation of phenolic compounds by polyphenol oxidases in the presence of oxygen. Ascorbic acid, citric acid and some sulfur-containing amino acids have been used as sulfite alternatives to prevent enzymatic browning, although they were not as effective as sulfites (Rice, 1983; Molnar-Perl and Friedman, 1990; Dudley and Hotchkiss, 1989).

Potatoes are extremely sensitive to enzymatic browning. There have been several reports on browning inhibition in potatoes (Sapers and Miller, 1993; Molnar-Perl and Friedman, 1990). Sapers and co-workers (1995) studied the inhibition of browning in pre-peeled potatoes through treatments such as use of ascorbic acid derivatives, surface digestion by NaOH, heated ascorbic acid/citric acid solutions and vacuum and pressure infiltration. Research has also been done on MAP (including vacuum packaging) of fresh-cut potatoes with different treatments. About 2 wk shelf-life for fresh-cut potatoes could be achieved by vacuum packaging after treating potatoes with antibrowning agents (Anderson and Zapsalis, 1957; Langdon, 1987; O'Beirne and Ballantyne, 1987). However, vacuum packaging of fresh-cut produce would create anaerobic conditions and thus may not be safe due to possible growth of anaerobic pathogens, like *C. botulinum* (Hanlin et al., 1995; Hotchkiss and Banco, 1992; Farber, 1991).

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The objective of our study was to develop procedures to extend shelf-life of minimally processed potatoes by using proper preparation methods, antibrowning agents and modified atmosphere packaging.

MATERIALS & METHODS

POTATOES (Russet-Burbank, grade A) were obtained from Basic American Foods (Blackfoot, ID), and stored at 5°C with 85% relative humidity until used. Packaging materials were provided by Cryovac Division, W.R. Grace & Co., Duncan, SC. Polypropylene package containers (17.5 × 12.5 × 8.5 cm) with air-tight covers were purchased from Consolidated Plastic Company, Inc. (Twinsburg, OH).

Measurement of respiration rates

Respiration rates of potatoes were measured by a closed system in which potatoes were placed into gas-tight glass jars (3.8L). The metal cover of the jars was modified by attaching two tube fittings (Swagelok Quick Connectors) to the cover for gas flushing. A sampling port was constructed onto the cover using a septum for obtaining gas samples.

Potatoes were peeled by an abrasive peeler (Reynolds Electric Co., Maywood, IL) and cut into French-fry strips (cross-sec., 0.95 × 0.95 cm) using a vegetable slicing machine (Urschel Laboratories, Valparaiso, IN) in our pilot plant. Cut potatoes (500g) were placed in each jar. After sealing with vacuum grease (Dow Corning), the jars were stored at four temperatures (2, 5, 10 and 20°C) for about 2 days. Gas compositions were measured at about 12 hr intervals using a gas chromatograph (Gow-Mac Instrument Company, Gas Chromatograph Series 580), equipped with a thermal conductivity detector and a CTR 1 column. Respiration rates were calculated by using the following formula (Morales-Castro, 1992);

$$RR = (\Delta C \times V)/(t \times W)$$

where RR is the respiration rate (mL/kg.hr.); ΔC, the change in concentration of CO_2 or O_2; V, the free volume (mL) in the container; t, time (hr); W, the weight (kg) of potatoes in the container.

To determine the effect of tissue damage on respiration rate, 1 kg whole unpeeled or abrasion-peeled whole potatoes, or 500g French-fry cut potatoes were placed into separate jars. The jars were stored at 2°C and respiration rates were measured.

Respiration rate of french-fry cut potatoes were also measured under different atmospheric compositions. Cut potatoes (500g) were placed into the jars, sealed, and the jars were flushed with N_2 gas for 4 min to completely replace the air. An appropriate vacuum was pulled using a vacuum pump and manometer attached to the jars through a fitting on the cover. The desired levels of O_2 and CO_2 were flushed into the jars to get predetermined gas compositions with the following O_2 (%)/CO_2 (%) proportions in N_2: 21/0, 10/2, 10/10, 5/5, 5/10 and 3/10, and the jars were stored at 2°C. Respiration rates were measured by measuring gas composition changes as described. All respiration rate measurements were done in three replicates.

Effects of packaging materials on gas composition

Two holes cut at opposite sides of package containers were used for installation of a tube fitting (Swagelok Quick Connectors) and a septum for gas flushing and gas sampling. A large window (16 × 10 cm) was made in the cover by removing a rectangular piece to provide gas transmission. Four multilayered polyolefin Cryovac packaging materials (PD-900 bag, PD-961EZ bag, PD-941 bag and RD-106 film) were tested. The O_2 and CO_2 permeabilities of the material in cc/m²/day @73°C and 1 atm (provided by the supplier) were: PD-900 has O_2 and CO_2 per-

meability of 3,000 and 9,800, respectively. PD-961EZ 7,000 for O_2 and 20,500 for CO_2, PD-941 16,544 and 36,000, respectively. The O_2 permeability of RD-106 was 11,226. After applying vacuum grease to ensure air tightness, and inserting 400g French-fry cut potatoes, the containers were covered with packaging films and sealed with the cover frame. The packages were then, flushed with a gas mixture (9% CO_2, 3% O_2 and balance N_2) for 3 min to completely replace air in the package before the septum was closed. The gas mixture was made by mixing the three pure gases in predetermined proportions by precisely adjusting flow rates. Changes in gas compositions in packages were measured periodically until a state of equilibrium was reached during storage at 2°C.

Effect of different antibrowning agents on color

Dipping solutions of ascorbic acid, citric acid, L-cysteine and combinations were tested on potatoes in a preliminary experiment. Five solutions (control, water; 0.5% L-cysteine; 0.5% L-cysteine plus 2% citric acid mixture; 5% ascorbic acid; 0.1% potassium metabisulfite) were tested on packaged potatoes. The cut potatoes were dipped into solutions for 3 min and a 400g sample was placed into each package container. Four packages per treatment were prepared using the PD-941 material. Packages were flushed with gas mixture containing 9% CO_2, 3% O_2 and the balance N_2 for 3 min and then stored at 2°C. Color changes were measured by a Hunterlab colorimeter (HunterLab 45°/0°, D25L Optical Sensor, Hunter Associate Laboratories Inc., Reston, VA). A sample (≅200g) was transferred into the sample container (13 × 13 × 5 cm) of the colorimeter and Hunter ''L-values'' were measured two times after rotating the container 90°. This procedure was repeated three times after removing the samples each time for a total of six readings / sample.

Effect of different gas compositions on color

Cut potato samples were prepared and dipped into 0.5% L-cysteine and 2% citric acid mixture for 3 min. The potatoes (400g) were packaged using the PD-941 material and flushed with different gases. The treatments were: control (air), gas mixture (9% CO_2, 3% O_2 and balance N_2), 9% CO_2 in N_2, and 100% N_2. Five packages per treatment were prepared, and stored at 2°C. Changes in color and gas composition were measured during storage.

Effect of peeling method on color

Three different peeling methods were evaluated in relation to color changes. Potatoes were peeled by the abrasive peeler, a hand-peeler and a lye solution. For lye peeling, potatoes were dipped in 17% sodium hydroxide solution at 85°C for 3 min. Treated potatoes were transferred into a cold water bath and soft loosened skin was removed by pressurized cold water. The potatoes were then cut into French-fry strips and dipped into 0.5% L-cysteine and 2% citric acid mixture for 3 min. After placing 400g sample into each package container and covering with PD-941 material, the packages were flushed with N_2 gas for 3 min. Five packages for each treatment were prepared and changes in color and gas composition were measured during storage at 2°C.

Statistical analysis

Color data for each treatment were analyzed by ANOVA and Fisher LSD multiple comparison tests using statistical software (Minitab, Inc.).

RESULTS & DISCUSSION

RESPIRATION RATE of potato strips was affected by temperature, gas composition of the atmosphere, and extent of tissue damage. Temperature had a great influence on respiration rate as with all fresh produce. Increasing the temperature from 2°C to 10°C resulted in about threefold increase in respiration rate (Fig. 1a). Temperature must be controlled precisely during storage of packaged fresh-cut potatoes to prevent formation of an anaerobic condition.

Peeling and further cutting increased respiration rate. Intact potatoes had a respiration rate of 1.22 mL CO_2/k·hr at 2°C, while peeled and sliced potatoes had 2.55 and 6.1 mL CO_2 kg·hr, respectively (Fig. 1b). Respiration processes take place in mitochondria and oxygen reaches the mitochondria by passing through the skin, intercellular spaces and membranes. Peeling and cutting increase the respiration rate because of removal of

skin, reduction in gas diffusion path in tissues and increased permeability of membranes (Rolle and Chism, 1987). Enzymatic degradation of membrane lipids leads to production of free fatty acids and the oxidation of these fatty acids results in the release of CO_2 after slicing potato tubers (Brecht, 1995). Wound respiration is also hypothesized to be a consequence of elevated ethylene production, although in potato slices ethylene production has been reported to be very low: 1–8 μL/kg·h at 7.2°C and 2.5% O_2 level (Kader et al., 1989). Therefore, the induced respiration in potato slices might be due to removal of skin and other physical barriers to gas diffusion, and degradation of membranes causing oxidation of free fatty acids.

Composition of the surrounding atmosphere affected respiration rate. Although the effect of carbon dioxide was not clear in potato slices, the level of oxygen significantly affected respiration rate (Fig. 1c). Decreasing O_2 from 21% to 3% resulted in about 4-fold reduction in respiration rate (from 6.1 to 1.7 mL CO_2/kg·hr). Reducing the O_2 level surrounding fresh fruits and vegetables reduces their respiration rates in proportion to the O_2 concentration (Kader et al., 1989). This is probably due to reduction of activity of oxidases such as polyphenol oxidase (PPO), ascorbic acid oxidase and glycolic acid oxidase with low O_2 affinity than due to cyctochrome oxidase which has high O_2 affinity (Kader, 1986). Elevated CO_2 also reduces respiration rate, and CO_2 was reported to inhibit some steps in the Krebs cycle through inactivating some enzymes (Kader, 1986).

The equilibrium atmosphere after 2 days with different packaging materials varied due to differences in permeabilities. PD-900 resulted in an anaerobic atmosphere, containing about 9.3% CO_2 and 0.6% O_2 and would therefore not be suitable for our package design with 218.75 cm^2 film surface area and 400g potato. Anaerobic conditions can lead to off-flavors and odors due to anaerobic metabolism of the produce (Zagory, 1995) and introduces concern for anaerobic pathogens, like *C. botulinum* (Nguyen-the and Carlin, 1994; Hotchkiss and Banco, 1992), and are not desirable. PD-961EZ resulted in 7.1% CO_2 and 1.4% O_2 at equilibrium. The packages with RD-106 had 5.9% CO_2 and 3.5% O_2, while PD-941 resulted in an atmosphere containing 6% CO_2 and 2.1% O_2 at equilibrium. Therefore, except for PD-900, the other materials tested could be used in our package design, and the quantity of potato could be varied to achieve the desired gas compositions in the package. PD-941 was selected for further experiments due to its permeability which resulted in a final O_2 level of 2–3%. We considered this O_2 level sufficiently high to prevent anaerobic environments, if temperature is controlled carefully during handling and marketing. PD-961EZ material resulted in lower final O_2 level (1.4%) and better color retention (data not shown). However, the low O_2 level could cause anaerobic condition readily in any lack of adequate temperature control.

MAP alone did not prevent browning of the potatoes. Dipping treatment was essential in packaged potatoes. Since sulfite has been undesirable due to its adverse effects on some asthmatics FDA has limited its use in food products (Sapers, 1993). Therefore, various antibrowning solutions were compared with sulfite. The mixture of 0.5% L-cysteine and 2% citric acid gave the best results on abrasion peeled and packaged potato slices (Fig. 2). The control and the 0.5% L-cysteine dipping treatment resulted in significantly lower L-values than the other treatments. The cysteine-citric acid mixture, 5% ascorbic acid and 0.1% bisulfite had similar L-values (Fig. 2), although cysteine-citric acid was best visually. Therefore, this solution was as effective as bisulfite and chosen to be the best inhibitor solution. L-cysteine has been shown to be an effective inhibitor (Friedman and Bautista, 1995; Molnar-Perl and Friedman, 1990). Cysteine reacts with phenolic substrates and quinones to inhibit formation of colored products (Sapers, 1993; Dudley and Hotchkiss, 1989). Citric acid is a chelating agent and acidulant, reducing pH and chelating copper in the active site of polyphenol oxidases and, therefore, inactivating the enzymes (Lee, 1991). Thus, the cysteine-citric acid mixture showed the
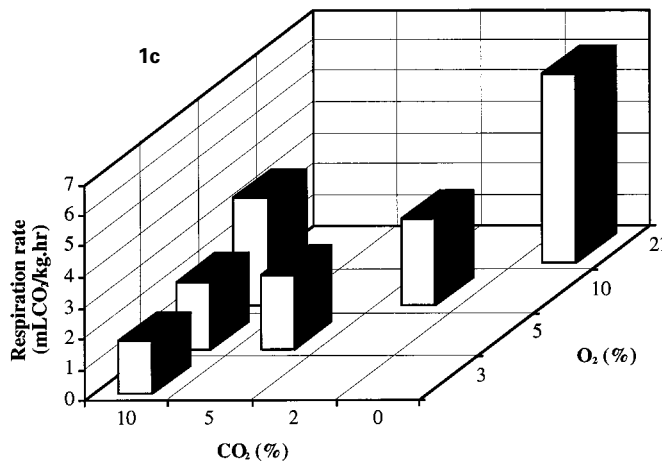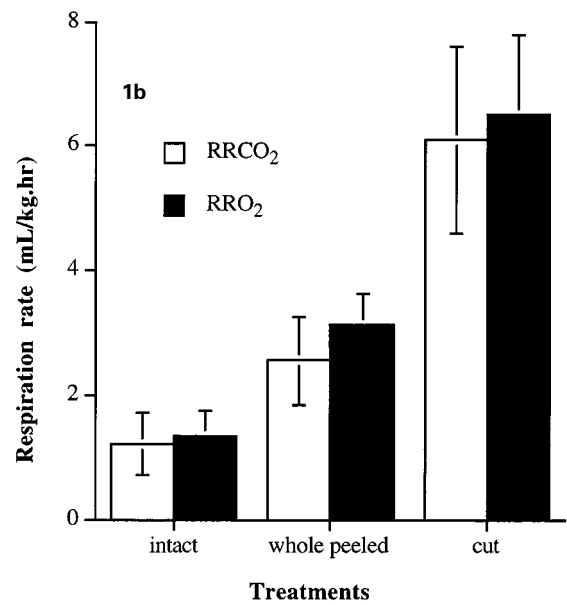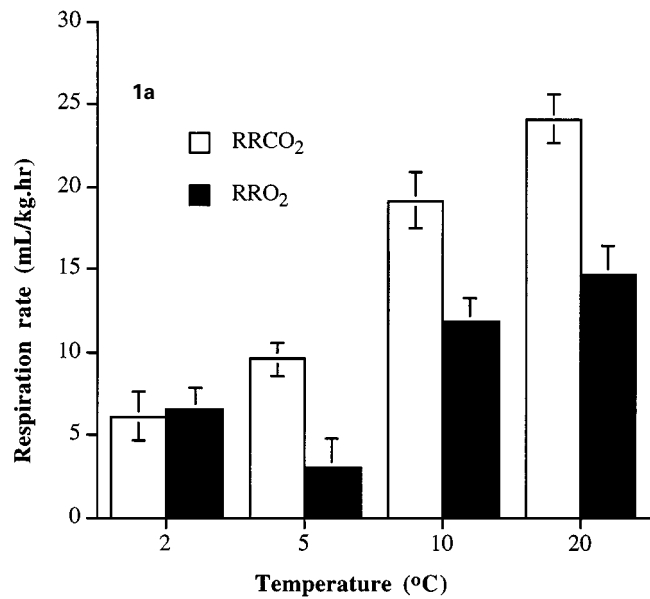
Fig. 1a—Effect of temperature on respiration rate of potato slices. $RRCO_2$ = mL CO_2/kg·hr; RRO_2 = mL O_2/kg·hr.
Fig. 1b—Effect of tissue damage on respiration rate of potatoes. $RRCO_2$ = mL CO_2/kg·hr; RRO_2 = mL O_2/kg·hr.
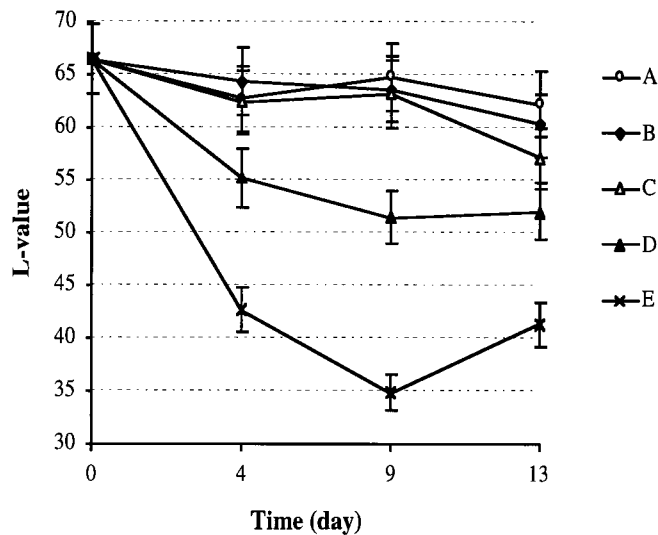**Fig. 1c—Changes in respiration rate ($RRCO_2$) with different modified atmospheres.**

Fig. 2—Effect of dipping solutions on color changes of packaged potato strips in modified atmosphere. A = 0.5% L-cysteine/2% citric acid; B = 5% ascorbic acid; C = 0.1% potassium metabisulfite; D = 0.5% L-cysteine; E = control (water).

combined effects of these two compounds on enzymatic browning and resulted in excellent prevention of browning reactions.

Enzymatic browning is closely related with concentration of oxygen and carbon dioxide in the package. The oxygen concentration inside the package must be decreased to an acceptable minimum level as soon as possible to prevent browning. Except for the control (air), the other three gases resulted in insignificant color changes (Fig. 3a). The control resulted in significantly lower L-values due to the high oxygen level inside the packages initially. It took about 10 days for the O_2 level to reach an equilibrium level of 2.5% from the initial 21% level (Fig. 3b). Due to exposure of potatoes to the high O_2 level, the degree of browning was higher. It is advantageous to have almost no O_2 initially inside the packages, because the initial temperature of the product is usually higher than the storage temperature, which would increase the browning rate. Active modification of the atmosphere inside the packages is essential for potato slices. All treatments resulted in almost the same levels of final O_2 and CO_2 except the control which had slightly higher CO_2 and lower O_2 levels. Nitrogen flushing alone and 9% CO_2 in N_2 flushing did not cause anaerobic conditions inside the packages due to the permeability of packaging material, although the initial oxygen levels in the packages were almost negligible (Fig. 3b). This was because by the time the intercellular O_2 in the tissues and the residual O_2 in the packages were consumed, sufficient O_2 had diffused into the package to prevent an anaerobic condition. The 9% CO_2 in N_2 flushing resulted in a high degree of exudate on the surface, which could stimulate microbial growth. This may be due to damage to the plant cell membranes by high CO_2 as reported for microbial cell membranes by Hao and Brackett (1993). However, the color values were not different
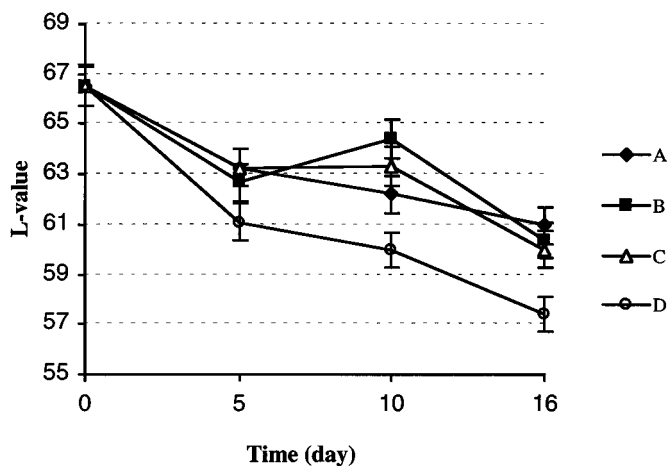
Fig. 3a—Effect of initial gas composition on color changes of potato slices treated with antibrowning solutions in modified atmosphere packages. A = 100% N_2; B = 9% CO_2/3% O_2 in N_2; C = 9% CO_2 in N_2; D = control (air).

Fig. 3b—Change in O_2 and CO_2 composition in modified atmosphere packages with different gas treatments. A = air (CO_2); B = 100% N_2 (CO_2); C = air(O_2); D = 100% N_2 (O_2).
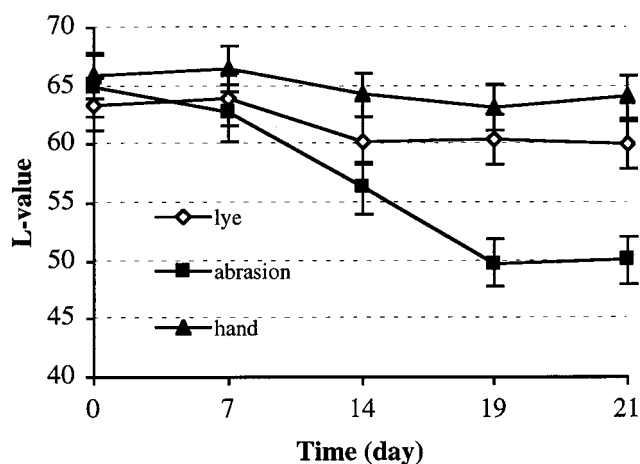
Fig. 4—Effect of peeling methods in combination with antioxidant treatment on color changes of modified atmosphere packaged potatoes.

from the N_2 flushed samples. Therefore, nitrogen flushing appeared to be the best choice in our packaging system, because it was the most economical and simplest.

Degree of tissue damage during processing influenced the extent of browning. Different peeling methods resulted in significantly different color (Fig. 4). The best method was hand peeling with a sharp hand peeler or knife. There was only slight difference between hand-peeled and lye-peeled potatoes in terms of color change. A nearly 3 wk shelf-life was obtained with these two treatments. Lye peeling resulted in a 1 to 2 mm deep ''cooked'' layer on the surface of the potatoes. Although this cooked layer would not be desirable in whole peeled potatoes, it was less apparent in case of French-fry cut potatoes, because only a small part (0.95 × 0.95 cm) of the peeled surface appears at the tips of the potato strips. However, the abrasion peeling resulted in only a 5–7 day shelf-life because of the extensive tissue damage on the surface of the potatoes. A tissue layer > 1 cm thick was observed to be damaged, causing extremely dark color at the tips of the strips. Sapers et al. (1995) reported that the severity of browning in pre-peeled potatoes was related to surface damage during peeling. This was due to the fact that damaging the tissue cells upon cutting or peeling decompartmentalized polyphenol oxidases and phenolic substrates, causing the browning reaction to occur in presence of O_2 (Huxsoll et al., 1989; Lee, 1991). Thus, the greater the tissue damage, the greater the amount of enzymes and substrates reacting together and, therefore, the greater the degree of browning.
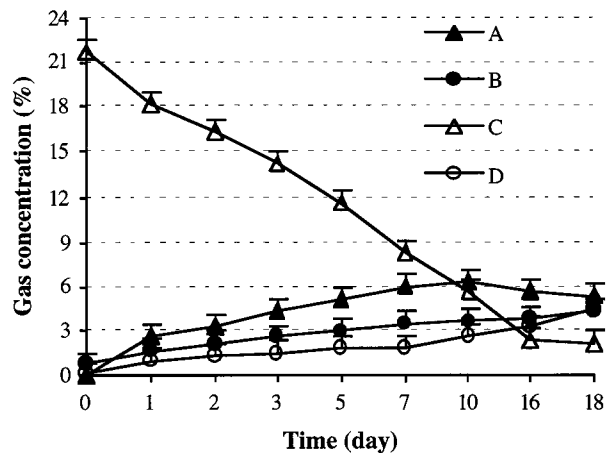
CONCLUSIONS

THE SHELF-LIFE of minimally processed potatoes could be extended to nearly 3 wks under refrigerated storage by using MAP systems. Potatoes should be peeled by either a hand peeler or a lye solution. Abrasion peeling appears to be undesirable due to extensive damage to the tissues. A cysteine (0.5%) and citric acid (2%) mixture was effective in preventing browning. Optimum packaging conditions were obtained with a multilayered polyolefin packaging material in combination with active modified atmosphere using N_2 gas.

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