

PHYSICAL, CHEMICAL AND MICROBIAL CHANGES IN SHREDDED SWEET POTATOES*

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ABSTRACT

With the increasing demand for freshly cut vegetables, a substantial potential exists in developing minimally processed sweet potato products. This study was undertaken to determine the effects of semipermeable polymeric materials and modified atmosphere packaging (MAP) on quality changes and microbial growth in shredded sweet potatoes under refrigerated storage. Shredded sweet potatoes from two major commercial cultivars (Beauregard and Hernandez) were packed in low and medium O₂ permeability bags and flushed with gas composed of 5% O₂, 4% CO₂ and 91% N₂. Quality changes and microbial growth were monitored in comparison to the samples packed in air using high-O₂ permeable films. The quality of shredded sweet potatoes could be maintained for 7 days at 4C in air, but extended up to 14 days in MAP. Considering the parameters measured in this investigation, the best results were obtained by MAP using moderately O₂-permeable film (7000 cm³/atm/m²/24 h). Shredded sweet potatoes stored in MAP showed less changes in tissue firmness, dry matter, ascorbic acid and starch than shredded sweet potatoes stored in air. The MAP-stored shredded sweet potatoes consistently exhibited fewer total aerobic bacteria and enteric bacteria compared to the shredded sweet potatoes stored in air. Yeasts, molds, lactic acid bacteria, color, beta-carotene and sugars of all stored shredded sweet potatoes did not sig-

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nificantly change, regardless of treatments. Higher ethanol levels were generated in the MAP-stored shredded sweet potatoes after 10 days, but off-odors were not detected in any of the MAP-stored shredded sweet potatoes.

INTRODUCTION

Freshly cut produce has become increasingly popular, not only at institutional food service, but also at the consumer level. In fact, freshly cut produce was one of the fastest growing commodities in U.S. grocery stores during the last 10 years (International Fresh-cut Produce Association 2000). With minimal or light processing operations including washing, peeling, trimming, cutting and packaging, this type of convenience product maintains the freshness of fruits and vegetables (Alzamora *et al.* 2000).

Freshly cut products from sweet potatoes, which are highly nutritious vegetables, are only marketed on a very limited scale. With the increasing demand for freshly cut vegetables, a substantial potential exists in developing minimally processed sweet potato products. However, only a few studies (McConnell *et al.* 2000; Erturk and Picha 2002; Cobo *et al.* 2003) were conducted on this aspect of sweet potato processing. Several treatments including blanching; antimicrobial agents (chlorine and Tsunami 200R); anti-browning substances (citric acid, ascorbic acid and sulfite) and modified atmosphere packaging (MAP) were applied in these studies. The results indicate that freshly cut sweet potatoes can be stored up to 2 weeks under refrigerated conditions without significant changes in quality. However, none of these studies dealt with microbial growth in freshly cut sweet potatoes during storage. As with other minimally processed vegetables, the challenge involved in freshly cut sweet potatoes is the delivery of produce with good sensory qualities, low nutritional loss and minimal microbial growth.

In the presence of air, the shelf life of perishable produce is limited by two principal factors: (1) metabolic deterioration of the tissue and (2) growth of aerobic spoilage microorganisms. Microbiologically, products are considered to be at the end of their shelf life when the total aerobic counts reach 10^7 – 10^9 cfu/g, the yeast counts reach 10^5 cfu/g or there is visible mold growth (Curlee 1997). High microbial counts ($>10^8$ cfu/g) in combination with physical damage and physiological stress of minimal processing result in undesirable quality changes such as loss of firmness, off-odors and product sliminess. Therefore, it is important to control such factors to ensure an extended shelf life for freshly cut products. The utilization of packaging films with appropriate gas transmission rates and MAP in combination with low-temperature storage is the common approach for extending the shelf life of freshly cut fruits and vegetables (Al-Ati and Hotchkiss 2002).

This study was undertaken on two major commercially grown cultivars of sweet potatoes to determine the effects of semipermeable polymeric materials and MAP on changes in nutritional quality, color, firmness and microbial growth in shredded sweet potatoes during refrigerated storage. The results will provide benchmark data on the technical feasibility for the commercial production of shredded sweet potatoes.

MATERIALS AND METHODS

Processing and Packaging of Sweet Potatoes

Two cultivars of sweet potatoes, Beauregard and Hernandez, were harvested from the experimental fields of the North Carolina Agricultural Experiment Station in Clinton, NC or obtained from local producers in Sampson County, NC. The harvested sweet potato roots were cured at 30C and 85–90% relative humidity for 7 days, and stored at 13–15C until use. The sweet potato roots were washed with cool tap water, hand peeled with a sharp knife, mechanically shredded into 3 × 3 mm pieces with a food processor (Cuisinart DLC-8, Cuisinart, Greenwich, CT) and rinsed with cool water. The shredded sweet potatoes were then centrifuged at room temperature using a hand-driven commercial salad spinner (Zyliss, Schachenweg, Switzerland) for 60 s to remove excess water.

Four hundred fifty grams of the shredded sweet potatoes was packaged in 30 × 46 cm multilayered polyolefin gas-permeable bags (Produce [PD] 900, PD 961 or PD 941; Cryovac Sealed Air Corp., Duncan, SC) or 30 × 30 cm low-density polyethylene (LDP) plastic bags (U.S. General Administration Federal Supply, Washington, DC), and stored at 4C. For MAP treatments, the shredded sweet potatoes were placed in low-O₂ permeability film, PD-900 (3000 cm³/atm/m²/24 h) or medium O₂ permeability film, PD 961 (7000 cm³/atm/m²/24 h). The bags were flushed for 5 min with a gas mixture composed of 5% O₂, 4% CO₂ and 91% N₂ (National Welders Supply Company, Durham, NC) and heat sealed with an impulse sealer (Model MP-16; Midwest Pacific, Taiwan). For air-stored treatments, the shredded sweet potatoes were placed in PD 941 (high O₂ transmission rate of 16,500 cm³/atm/m²/24 h) or LDP, flushed with air and heat sealed as described. The LDP bags containing shredded sweet potatoes were opened for 30 min each day to maintain the O₂ concentration as close to 21% as possible. All bags of shredded sweet potatoes were stored at refrigeration temperature (4C), and two bags of each of the four treatments were initially selected (0) and at days 3, 7, 10 and 14 for analyses. Three replicates of the experiments were performed on three lots of sweet potatoes from each cultivar.

Determination of Gas Composition

At each selection date, headspace O₂, CO₂ and N₂ was determined in the bags containing shredded sweet potatoes. A 10-mL volume of headspace gas was removed from each package after puncturing the bag with a gas-tight syringe (catalog #81620; Hamilton Co., Reno, NV). The 10-mL volume of headspace was injected into a 1-mL sample loop of a Hach–Carle gas chromatograph (Series 400 AGC, EG&G Chandler Engineering, Broken Arrow, OK) equipped with a thermal conductivity detector and an 80% Porapak N and 20% Porapak Q column. The oven temperature was 95C, the output setting was 32 and the carrier gas was a mixture of He₂ (flow rate of 70 mL/min) and N₂ (flow rate of 20 mL/min). The run time was 7 min. The analysis of the headspace gases in the packages of shredded sweet potatoes was routinely performed to monitor changes in gas composition over time. One headspace determination was taken from six different bags for each treatment.

Color and Firmness Determinations

The surface color of the sweet potato shreds was determined with a Minolta Chromameter (model CR 300; Minolta Co., Ramsey, NJ) calibrated with a standard white plate provided by the instrument manufacturer. The surface color was determined after removing sweet potato shreds from the bags and directly placing the head of the instrument on the sweet potato shreds. Ten determinations were observed for shredded sweet potatoes in each bag. Only the brightness value (L^*) was used to evaluate sweet potato color. The smaller the L^* values reported, the greater the degree of darkness (browning).

Changes in firmness of the shredded sweet potatoes during storage were determined with an Instron Universal Testing Machine (model 5500; Satec System, Grove City, PA) equipped with a model 4801 Kramer shear cell. The crosshead speed was 60 mm/min, and the compression load cell was 500 kg. Twenty-five grams of sweet potato shreds was placed in the Kramer shear cell and sheared with a compressive force by the Kramer shear cell blades (Truong and Daubert 2003). The peak compressive force was expressed in newtons. The greater the peak force required to compress and shear the shredded sweet potatoes, the firmer the shredded sweet potatoes. The firmness reported was the means of 10 randomly selected 25-g aliquots of shredded sweet potatoes from each bag.

Chemical Analyses

The shredded sweet potatoes were removed at selected time intervals and analyzed for dry matter, glucose, sucrose, fructose (Walter and Schwartz 1993), alcohol-insoluble solids (AIS) and starch (Walter *et al.* 1993). Ascorbic

acid was determined using the 2,6-dichloroindophenol titrimetric method from the AOAC (1990). The beta-carotene content was determined as described by Dignos *et al.* (1992). The analysis of chlorogenic acid (Walter and Purcell 1980) was conducted to determine the level of secondary metabolites formed throughout the storage of the shredded sweet potatoes.

The ethanol production in the sweet potato tissue was determined by headspace gas analysis. A gas-tight syringe (Hamilton Co., Reno, NV) was used to remove 50- μ L volumes of headspace gas from each bag. Each 50- μ L volume was then injected into a model 5980 gas chromatograph with a mass spectrophotometer detector (model 5972; Hewlett Packard, Palo Alto, CA). The oven temperature was held constant at 100C. The carrier gas was He₂ and the run time was 4 min. External standards were prepared by adding 25, 50, 100, 250, 500 or 1000 μ L of pure ethanol to 200-mL distilled water in a 0.946-L closed jar, and allowed to equilibrate overnight. The concentrations of ethanol were expressed as microliters per milliliter.

Microbiological Analysis

A standard plate count assay was used to enumerate the total aerobic bacteria on the shredded sweet potatoes. Fifty grams of shredded sweet potatoes from each treatment was aseptically transferred to sterile filter bags (Spiral Biotech, Bethesda, MD) containing 50 mL of sterile 0.85% NaCl solution. The sterile filter bags contained polyester filters that allowed the diffusion of microorganisms through the filters while filtering out particles large enough to clog the delivery needle of the spiral plater. The shredded sweet potatoes in the filter bags were macerated with a Tekmar Stomacher (Model TR5T, Tekmar Co., Cincinnati, OH) on the high setting for 160 s. Appropriate dilutions of the stomacher filtrate were made using sterile, physiological saline solution, and spread onto duplicate Plate Count Agar (PCA) plates using the Autoplate 4000 spiral plater (Spiral Biotech, Bethesda, MD). The PCA plates were incubated at 25C for 24 h, and the total aerobic bacterial counts were observed using the Synoptics Proto Plus plate counter (Spiral Biotech, Bethesda, MD). Appropriate dilutions of the stomacher filtrate were also spread onto plates of Violet Red Bile Agar plus glucose, Yeast/Mold agar and de Man, Rogosa and Sharpe plates containing 0.02% sodium azide for enumeration of enteric bacteria, yeast/molds and lactic acid bacteria, respectively (DIFCO 1998).

Statistical Analysis

Data were analyzed using statistical analysis software (SAS 1994). Statistically significant differences ($P \leq 0.05$) among treatments were deter-

mined using analysis of variance. The analytical error for each variable was calculated as the root mean square error for three replicated experiments for both cultivars divided by the mean multiplied by 100.

RESULTS AND DISCUSSION

Because similar trends were observed in the quality parameters of cvs. Beauregard and Hernandez, the results presented were primarily determined with cv. Beauregard.

Gas Composition and Shredded Sweet Potatoes

When minimally processed shredded sweet potatoes were packaged in four selected packaging films and stored for up to 14 days, different equilibrium gas compositions were observed. The changes in the O₂ and CO₂ concentrations are presented for shredded sweet potatoes, cv. Beauregard, in Fig. 1. There was a significant difference between the treatments within each cultivar ($P \leq 0.05$). As expected, the highest O₂ and lowest CO₂ concentrations were observed in the headspaces over shredded sweet potatoes in packages with the greatest film permeabilities, and packages exposed to air every day during storage.

The headspace over shredded sweet potatoes stored in low permeability PD 900 bags maintained a gas composition of about 5% O₂ and 4% CO₂ throughout the 14-day storage period. The headspace over shredded sweet potatoes stored in the medium permeability PD 961 bags did not maintain the initial headspace gas concentration of 5% O₂ and 4% CO₂. Instead, the gas concentrations of the headspace reached an equilibrium of about 8% O₂ and 3% CO₂ prior to the 3-day analysis, and remained at this concentration for the remainder of the storage period. The headspace over the shredded sweet potatoes stored in the high permeability PD 941 film essentially equilibrated with the gas composition of air, 21% O₂ and negligible CO₂. The O₂ level of the headspace over the shredded sweet potatoes stored in the high-permeability PD 941 film did not fall below 18%, while the CO₂ level remained constant at <0.7% throughout the 14 days of storage. The headspace over the shredded sweet potatoes stored in the LDP bags exposed to air each day maintained atmospheric conditions of 21% O₂ and negligible CO₂ throughout the storage.

The use of MAP extends the shelf life of many types of produce when compared to air storage (O'Brien and Ballantyne 1987; Huxsoll and Bolin 1991; Solomos 1995). The shelf life of shredded lettuce stored in polyethylene packs filled with 5% O₂ and 5% CO₂ was nearly doubled from 8 to 14 days when compared with the shredded lettuce stored in air (Ballantyne *et al.* 1988).

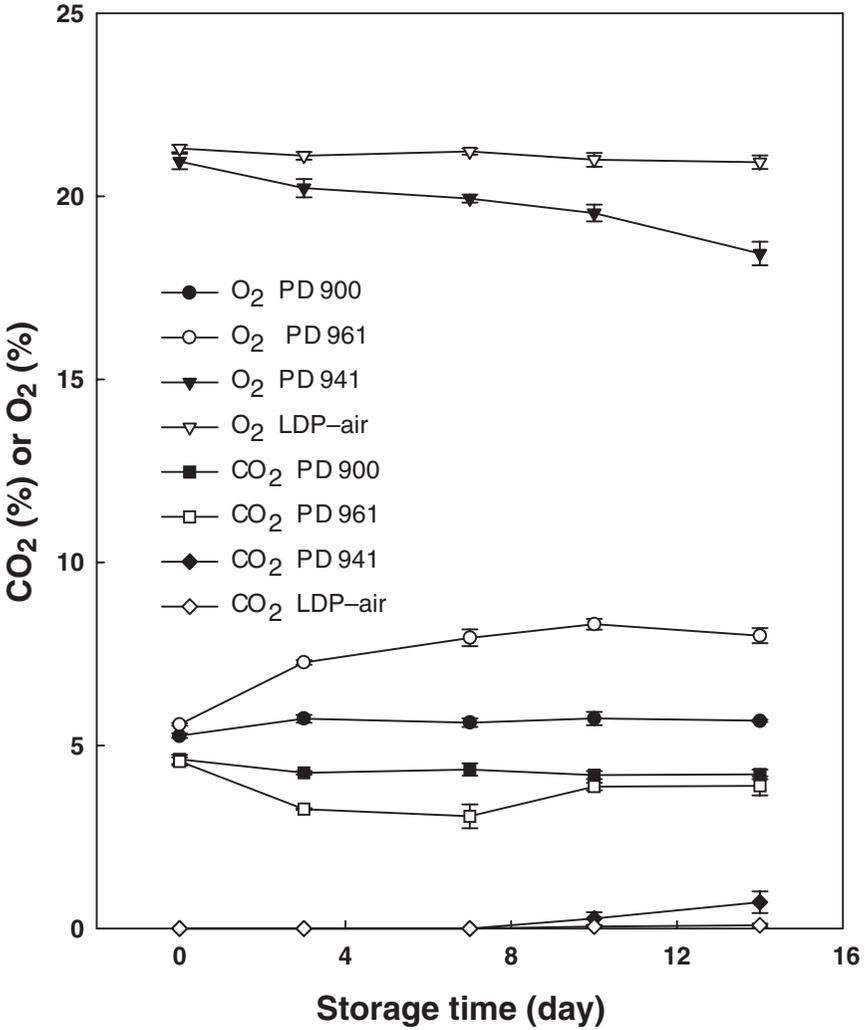


FIG. 1. O₂ AND CO₂ IN SHREDDED SWEET POTATO (CV. BEAUREGARD) PACKAGES STORED AT 4C
 MAP-stored atmospheres: low- (PD 900) and medium- (PD 961) O₂ permeability films. Air-stored atmospheres: high- (PD 941 and LDP) O₂ permeability films. PD, Packaging Digest; LDP, low-density polyethylene.

Carlin *et al.* (1990) reported that high-O₂ permeability films (between 10,000 and 20,000 cm³/m²/day/atm) provided a greater shelf-life extension to grated carrots than low-O₂ permeability films. A modified atmosphere containing 6% O₂ and 21% CO₂ was responsible for extending the shelf life of carrots from 7 to 12 days. Because the carrot is a moderately high-respiring root crop, packaging carrots in low-permeability films results in anaerobic respiration, high potassium leakage and high lactic acid bacteria counts (Carlin *et al.* 1990). Barry-Ryan *et al.* (2000) concluded that an equilibrated atmosphere containing 18% O₂ contained too much oxygen to provide a beneficial atmosphere for the storage of carrots.

Although shelf-life extension is commodity dependent, a range of 2–5% O₂ and 2–10% CO₂ (Barmore 1987; Zagory and Kader 1988) is acceptable for most produce. Delate and Brecht (1989) reported that whole sweet potatoes tolerate 8% O₂ and 92% N₂ during curing. However, an exposure to low O₂ levels of 2 or 4% with a balance of N₂, as well as an exposure to medium to high O₂ combined with high CO₂, resulted in decay that resulted in unacceptable sweet potato quality within 1 week. Erturk and Picha (2002) reported that freshly cut sweet potatoes shifted from aerobic to anaerobic respiration as indicated by an increased activity of pyruvate decarboxylase and production of ethanol when O₂ concentrations in the bags decreased to <1% after 2–3 days at 2 or 8C. Therefore, the determination of ethanol concentrations in packaged freshly cut vegetables is important because substantial ethanol concentrations indicate anaerobic respiration resulting from low O₂ concentrations and anaerobic respiration. Furthermore, high ethanol concentrations result in off-odor and off-flavor in respiring produce. In this research, we selected a gas mixture of 5% O₂, 4% CO₂ and 91% N₂ as the initial modified atmosphere to compare with air because the selected modified atmosphere was within the range of gas compositions suggested by the literature for successful extension of the shelf lives of other vegetables. Even with the selected gas composition, a slight increase in the ethanol concentrations in the headspace over shredded sweet potatoes was observed in all headspaces sampled by day 3. By day 14, the ethanol concentrations significantly increased ($P \leq 0.05$) to 20 and 24 µL/L in the headspace over shredded sweet potatoes stored in PD 900 and PD 941 bags (Fig. 2), the ethanol concentrations were much greater than those observed in the headspace over shredded sweet potatoes stored in atmospheres resembling air. Previous research on other vegetables such as carrots (Carlin *et al.* 1990; Amanatidou *et al.* 2000), lettuce (Hagenmaier and Baker 1997) and jicama (Aquino-Balanos *et al.* 2000) also demonstrated greater accumulation of ethanol in the headspaces over produce stored in MAP compared to the headspaces over produce stored in air. However, large ethanol concentrations that render carrots inedible were only reported for carrots where fermentation occurred at extremely low O₂ conditions. The development of anaerobic

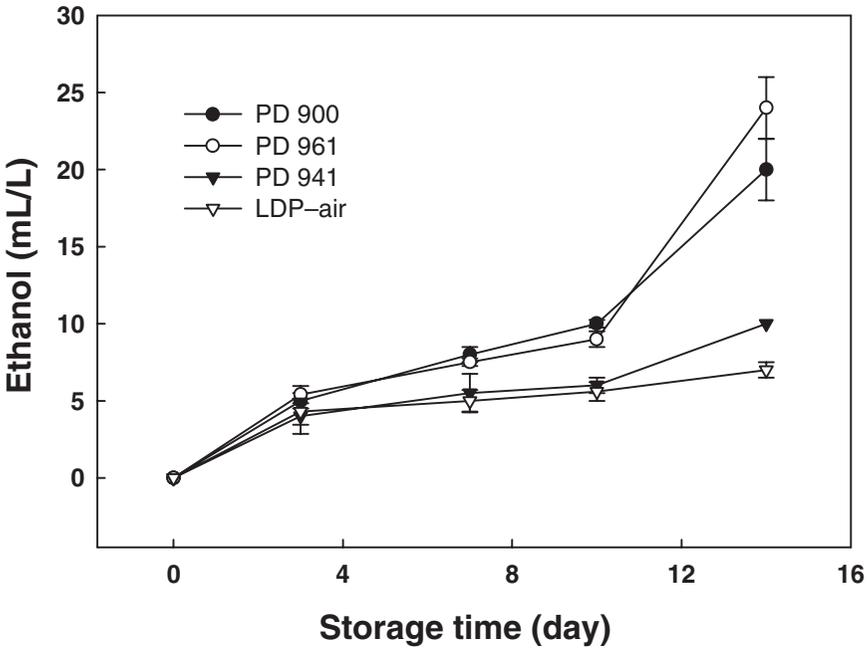


FIG. 2. ETHANOL IN THE HEADSPACE OF SHREDDED SWEET POTATO (CV. BEAUREGARD) PACKAGES STORED AT 4C MAP-stored atmospheres: low- (PD 900) and medium- (PD 961) O₂ permeability films. Air-stored atmospheres: high- (PD 941 and LDP) O₂ permeability films. PD, Packaging Digest; LDP, low-density polyethylene.

conditions in packages is potentially hazardous because anaerobic conditions may not only lead to the production of fermentation volatiles such as ethanol, but also to the germination and growth of anaerobic spore-forming pathogens (Smyth *et al.* 1999).

Color and Chlorogenic Acid

Both cvs. Beaugard and Hernandez, regardless of treatment, exhibited minimal to no color change as expressed by the L^* values over storage time. Sweet potatoes with an orange flesh do not typically discolor when cut or sliced as other vegetables or fruits like white potatoes, peaches or apples (Walter and Purcell 1980). Through visual examination, cv. Hernandez displayed a deep, rich orange hue, while cv. Beaugard displayed a brighter but fainter orange hue. The lack of color change (darkening) when the package atmosphere oxygen varied from 5 to 21% and the CO₂ varied from 0.04 to 4%

indicates that off-colors will not be a problem for cut sweet potatoes stored in MAP.

Priepke *et al.* (1976) reported better appearance scores for salad vegetables stored in MAP (2.25% O₂, 10.5% CO₂ and the balance N₂) as opposed to salad vegetables stored in air. Aquino-Balanos *et al.* (2000) observed good to excellent visual quality for jicama pieces stored in MAP by day 12, compared to jicama pieces stored in air. Brackett (1990) did not observe any significant differences in the color of shrink-wrapped, gas-packaged or air-stored bell peppers. Color changes in broccoli (Ballantyne *et al.* 1988) and asparagus (Berrang *et al.* 1990) were not significantly affected by storage atmosphere. However, cauliflower stored in air exhibited greater color changes (browning) than cauliflower stored under controlled atmosphere storage (Berrang *et al.* 1990). Amanatidou *et al.* (2000) reported surface browning of carrots stored in air because of the oxidation of phenols, but observed only occasional surface browning of carrots stored in MAP (1% O₂ and 10% CO₂). Heimdal *et al.* (1995) reported more browning in lettuce packaged in air, as opposed to lettuce packaged in selected MAP.

The chlorogenic acid content increased in all shredded sweet potatoes by day 10 of storage (Fig. 3). However, the shredded sweet potatoes stored under greater O₂ concentrations (PD 941 and LDP) exhibited greater accumulations of chlorogenic acid than shredded sweet potatoes stored under smaller O₂ concentrations (PD 900 and PD 961) ($P \leq 0.05$). Imaseki *et al.* (1968) also reported an increase in chlorogenic acid in sliced sweet potatoes stored in air. Higher concentrations of total soluble phenols were observed in other vegetables such as carrots (Amanatidou *et al.* 2000) stored in air when compared to vegetables stored in selected MAP (1% O₂ and 10% CO₂). Phenolic compounds such as chlorogenic acid often accumulate in vegetables in response to infections or structural damage. Phenolic compounds can be oxidized by polyphenoloxidases resulting in tissue discoloration (Ferrerres *et al.* 1997). The most common natural substrates for the polyphenoloxidase activity are chlorogenic acid and its isomers, catechin and epicatechin (Dorantes-Alvarez and Chiralt 2000). However, the concentrations of chlorogenic acid present in shredded sweet potatoes were too small to negatively impact the overall color of shredded sweet potatoes.

Storage and Firmness of Shredded Sweet Potatoes

A significant decline in firmness was observed in both cultivars ($P \leq 0.05$) of shredded sweet potatoes stored in air compared to the firmness of shredded sweet potatoes stored in MAP. The firmness of the shredded sweet potatoes in the MAP packages did not decrease to <1793 N (5% decrease) in the PD 900 packaging film, or <1749 N (8% decrease) in the PD 961 pack-

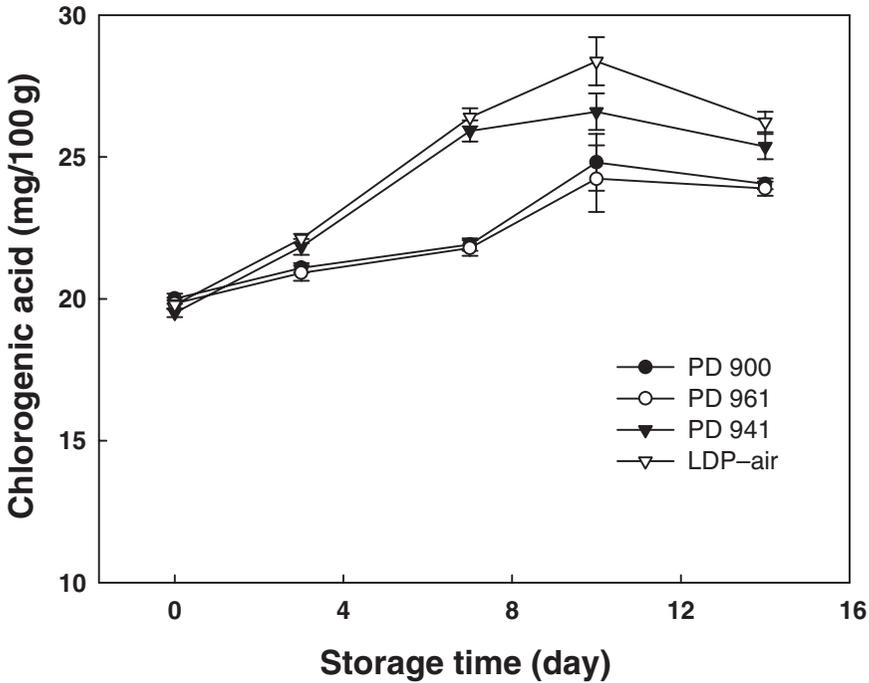


FIG. 3. CHLOROGENIC ACID IN SHREDDED SWEET POTATOES (CV. BEAUREGARD) STORED IN MAP AND IN AIR AT 4°C
 MAP-stored atmospheres: low- (PD 900) and medium- (PD 961) O₂ permeability films. Air-stored atmospheres: high- (PD 941 and LDP) O₂ permeability films. PD, Packaging Digest; LDP, low-density polyethylene.

aging film throughout the 14-day storage period. The initial firmness of cv. Beauregard (Fig. 4) decreased 25% by day 14 when stored in PD 941 packaging films, and 30% by day 14 when stored in LPD packaging films (air). Tissue damage because of shredding together with water evaporation during storage results in loss of turgor pressure and softening of selected freshly cut vegetables (Varoquaux and Wiley 1994). Amanatidou *et al.* (2000) observed poor-quality, softened carrots after 12 days of storage in air compared to acceptable-quality carrots after 12 days of storage in MAP (1% O₂ and 10% CO₂). On the other hand, O'Brien and Ballantyne (1987) reported that MAP (1–2% O₂ and 3–4% CO₂) or vacuum packaging exhibited little effect on the firmness of raw potato strips. The firmness of broccoli and cauliflower also remained relatively stable when stored in air or under a controlled atmosphere (Berrang *et al.* 1990).

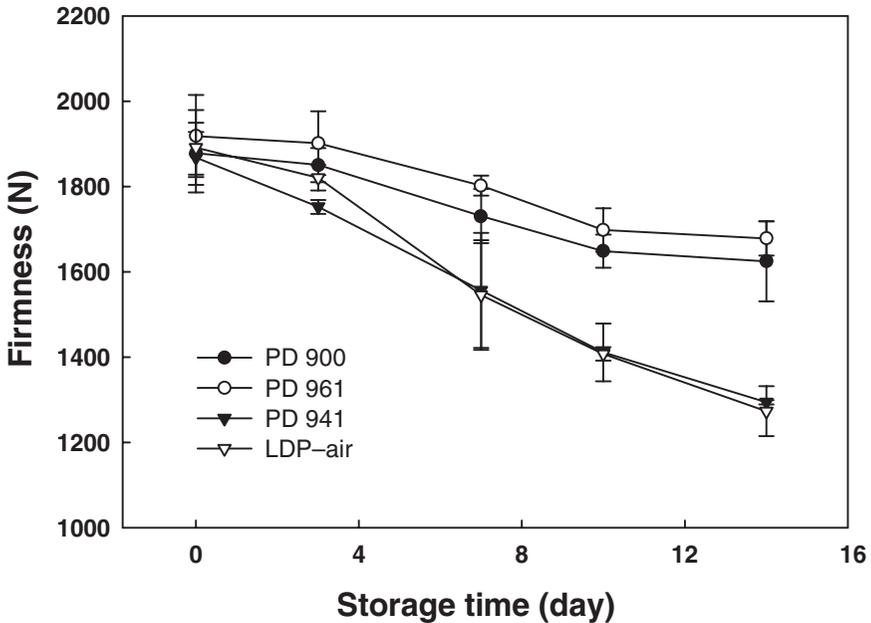


FIG. 4. FIRMNESS OF SHREDDED SWEET POTATOES (CV. BEAUREGARD) STORED IN MAP AND IN AIR AT 4C

MAP-stored atmospheres: low- (PD 900) and medium- (PD 961) O₂ permeability films. Air-stored atmospheres: high- (PD 941 and LDP) O₂ permeability films. PD, Packaging Digest; LDP, low-density polyethylene.

Dry Matter, Starch and Sugars

The initial dry matter content of the sweet potato shreds for both cultivars was about 16%, which gradually declined to 14.0–15.3% during the 2-week storage period. The results were inconsistent with dry matter loss during storage of whole sweet potatoes (Kushman and Pope 1972; Purcell *et al.* 1989). Dry matter loss is attributable to tissue respiration and carbohydrate metabolism. Starch breakdown and sugar metabolism result in decreased concentrations of starch in AIS and total sugars in the stored shredded sweet potatoes (Fig. 5). The decrease in dry matter, starch and sugars was significant ($P \leq 0.05$) in MAP (PD 900 and PD 961 packaging films). Limiting O₂ reduces respiration rate and depletion of carbohydrates. Janardhana *et al.* (1998) observed that dry matter loss in maize was significantly reduced in low O₂ and high CO₂ atmospheres.

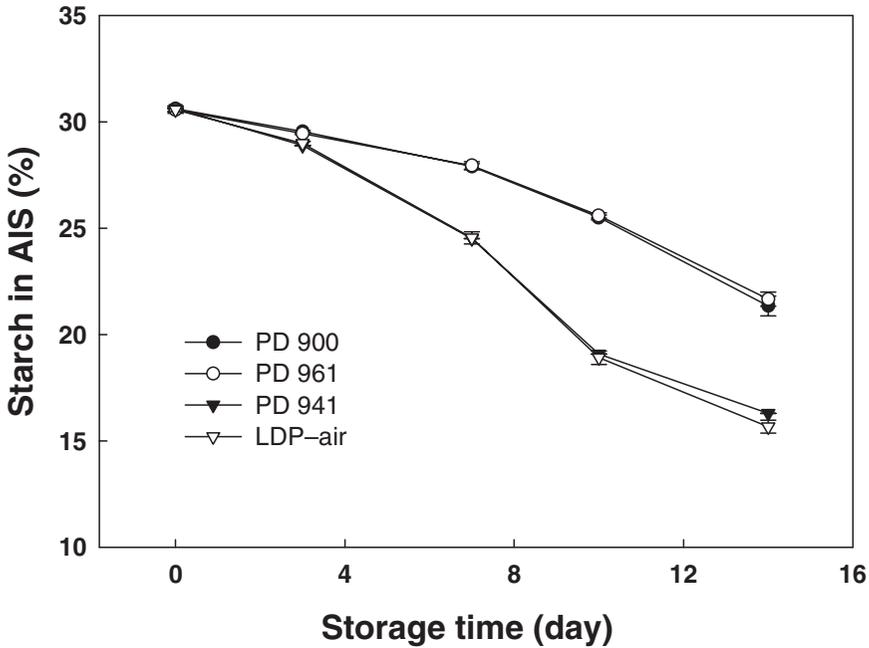


FIG. 5. STARCH CONTENT OF SHREDDED SWEET POTATOES (CV. BEAUREGARD) STORED IN MAP AND IN AIR AT 4°C

MAP-stored atmospheres: low- (PD 900) and medium- (PD 961) O₂ permeability films. Air-stored atmospheres: high (PD 941 and LDP) O₂ permeability films. PD, Packaging Digest; LDP, low-density polyethylene.

Beta-carotene and Ascorbic Acid

Regardless of treatment, the beta-carotene concentrations remained stable at 6.7 and 7.4 mg/100 g for cvs. Beauregard and Hernandez, respectively. The observed beta-carotene concentrations are in the upper range of beta-carotene of sweet potatoes with an orange flesh as reported by Kays (1992). The carotenoid concentrations in whole sweet potato roots are stable during storage and may even increase (Wolfe 1992). An increase in total carotene content was reported for freshly cut sweet potatoes (Erturk and Picha 2002). However, apparent increases in carotene may be a result of water loss from the tissues. Slight decreases in carotene content were observed in other vegetables. Hernandez-Brenes (1997) observed 90% retention of beta-carotene in jalapeño pepper rings in MAP (5% O₂, 4% CO₂) and 80% retention in jalapeño pepper rings stored in air. Carlin *et al.* (1990) reported 85% retention of carotene in carrots regardless of storage atmosphere.

The initial ascorbic acid contents of cvs. Beauregard and Hernandez were 15.4 and 14.7 mg/100 g, respectively. These values remained relatively stable for the shredded sweet potatoes stored in modified atmospheres (PD 900 and PD 961 packaging films) up to 14 days. Cultivar Beauregard retained about 85% of the initial ascorbic acid content when stored in air (PD 941 and LPD packaging films) for 14 days, while cv. Hernandez retained about 89% of the initial ascorbic acid content when stored in air (PD 941 and LPD packaging films) for 14 days. Significant decreases in the ascorbic acid content of sweet potato roots during curing and storage are reported (Wolfe 1992). Greater losses of ascorbic acid were observed in other minimally processed vegetables, and MAP improves ascorbic acid retention during storage. Hernandez-Brenes (1997) reported that the total ascorbic acid retention in jalapeño pepper rings after 15 days was 94% in MAP (5% O₂ and 4% CO₂) and 69% in air. Similar results were also reported for spinach stored in MAP or in air (Gil *et al.* 1999).

Microbial Growth

The total aerobic plate count was significantly greater ($P \leq 0.05$) in shredded sweet potatoes stored in air (PD 941 and LDP packaging films) than in shredded sweet potatoes stored in MAP (PD 900 and PD 961 packaging films). Growth of aerobic bacteria was observed in each of the three experiments with both sweet potato cultivars from two different harvest years (Fig. 6). The aerobic bacteria in control shredded sweet potatoes from bags repeatedly flushed with air increased to 2.7×10^8 and 3.6×10^8 cfu/g for cvs. Beauregard and Hernandez, respectively, after 2 weeks of storage. The large permeability MAP bags that maintained the atmospheric composition near that of air exhibited a similar increase in total aerobic counts of 1.5×10^8 and 2.9×10^8 cfu/g for cvs. Beauregard and Hernandez, respectively. The total aerobic counts of shredded sweet potatoes from medium- and low-permeability bags (PD 900 and PD 961 packaging films), where O₂ was substantially decreased and CO₂ increased to a moderate level, exhibited about one log smaller total aerobic counts of 10^7 cfu/g for both cultivars. After 2 weeks, the shredded sweet potatoes stored under high O₂ levels displayed obvious soft spots. The presence of soft spots on shredded sweet potatoes was not observed on shredded sweet potatoes stored under small O₂ concentrations. Informal sensory evaluations did not identify off-odors developed in any shredded sweet potatoes stored for 14 days. There were no significant differences in the total aerobic bacteria counts between cvs. Beauregard and Hernandez.

Microorganisms may respond to MAP differently, depending on microbial tolerance for O₂ and CO₂. The MAP can affect the growth and inhibition of obligate aerobic microorganisms by reducing the level of the needed O₂

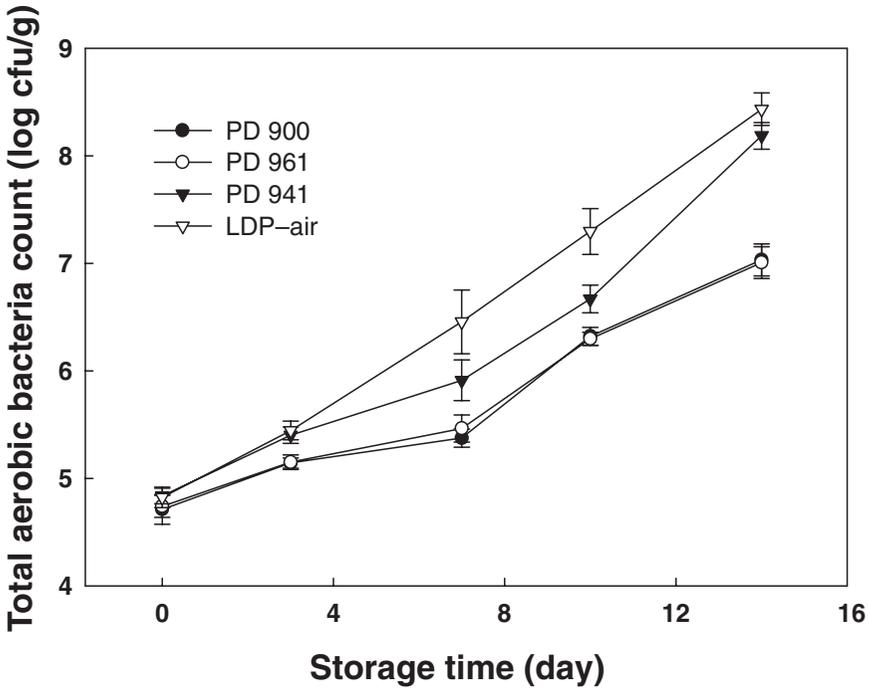


FIG. 6. TOTAL AEROBIC BACTERIA COUNT OF SHREDDED SWEET POTATOES (CV. BEAUREGARD) STORED IN MAP AND IN AIR AT 4°C
 MAP-stored atmospheres: low- (PD 900) and medium- (PD 961) O₂ permeability films. Air-stored atmospheres: high- (PD 941 and LDP) O₂ permeability films. PD, Packaging Digest; LDP, low-density polyethylene.

(Brackett 1987). CO₂ may exhibit an inhibitory effect on many common spoilage organisms by increasing the lag phase of the growth curve (Farber 1991; Nguyen-the and Carlin 1994). In general, aerobic Gram-negative bacteria are more sensitive to CO₂ than obligate or facultative anaerobic bacteria. The effects of MAP on microorganisms are dependent on the concentration of CO₂, the microbial flora and the specific produce (Gunes *et al.* 1997). A MAP system of 2.25% O₂ and 10.5% CO₂ results in a one-log reduction in microbial counts on salad vegetables (lettuce, carrots, celery, radishes, broccoli and green onion) stored in air (Mohd-Som *et al.* 1994; Amanatidou *et al.* 2000).

The trends for *Enterobacteria* counts are similar to the observed total aerobic counts. Shredded sweet potatoes stored in MAP consistently exhibited less microbial growth than shredded sweet potatoes stored in air. From an initial population of about 3.8×10^4 and 5.1×10^4 cfu/g for cvs. Beauregard and Hernandez, respectively, the *Enterobacteria* counts on shredded sweet

potatoes stored under large O_2 concentrations increased to 7.8×10^7 and 1.5×10^8 cfu/g, respectively. Shredded sweet potatoes stored in the high-permeability MAP film increased to 4.5×10^7 and 1.3×10^7 cfu/g for cvs. Beauregard and Hernandez, respectively. The shredded sweet potatoes stored under the medium- and low-permeability films exhibited *Enterobacteria* counts of about one log smaller at 4.7×10^6 and 8.6×10^6 cfu/g for cvs. Beauregard and Hernandez, respectively. The one-log difference represents a significant difference ($P \leq 0.05$) between the shredded sweet potatoes stored in the two high-permeability packaging films and the shredded sweet potatoes stored in the low- and medium-permeability packaging films, but no significant difference between cvs. Beauregard and Hernandez. Different effects of MAP on the growth of enteric bacteria were observed with other vegetables. Mohd-Som *et al.* (1994) reported that a MAP system (5% O_2 and 8% CO_2) reduced the enteric bacteria population on broccoli florets stored in MAP by nearly one log when compared to the enteric bacteria population on broccoli florets stored in air. However, experiments with tomatoes (Brackett 1987) and bell peppers (Brackett 1990) resulted in no significant differences in the growth of enteric bacteria between tomatoes or bell peppers stored in MAP or in air. O'Brien and Ballantyne (1987) reported a 10^5 cfu/g population of enteric bacteria in potato strips stored in MAP (1–2% O_2 and 3–4% CO_2) by day 7, and a 10^7 cfu/g population of enteric bacteria in potato strips stored in vacuum packaging by day 14.

The number of lactic acid bacteria remained small ($<10^3$ cfu/g) on all stored shredded sweet potatoes. However, the lactic acid bacteria counts on the shredded sweet potatoes stored under the two high- O_2 atmospheres were significantly higher than the lactic acid bacteria counts on the shredded sweet potatoes stored under the two low- O_2 atmospheres ($P \leq 0.05$). From an initial 10^2 cfu/g population, the lactic acid bacteria counts on the shredded sweet potatoes stored under the two high- O_2 atmospheres (PD 941 and LDP packaging films) increased to 10^4 cfu/g, while the lactic acid bacteria counts on the shredded sweet potatoes stored under the two low- O_2 atmospheres increased to 10^3 cfu/g for both cultivars. The lactic acid bacteria only represent about 0.1% of the total microbial count. No significant differences in lactic acid bacteria counts on shredded sweet potatoes were observed between the two cultivars. The lactic acid bacteria counts on the stored shredded sweet potatoes are not in agreement with previous experiments with other vegetables. Brackett (1990) observed a decrease in the populations of lactic acid bacteria on shrink-wrapped, gas-packaged and air-stored bell peppers. However, larger populations of lactic acid bacteria observed on shredded carrots stored in MAP compared to shredded carrots stored in air (Carlin *et al.* 1990; Amanatidou *et al.* 2000; Barry-Ryan *et al.* 2000) may be attributed to the accumulation of phenols with antimicrobial properties in carrots and peppers under aerobic conditions.

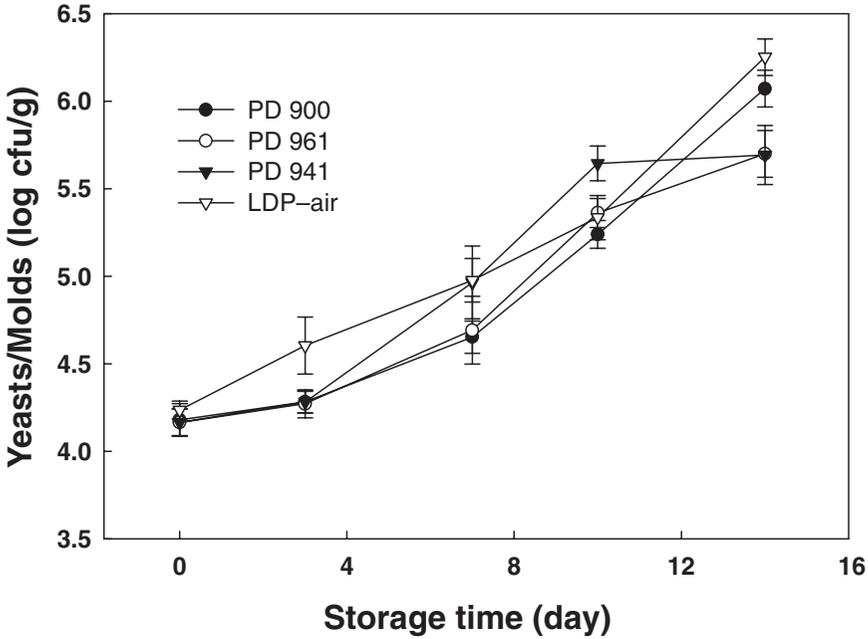


FIG. 7. YEAST AND MOLD COUNTS OF SHREDDED SWEET POTATOES (CV. BEAUREGARD) STORED IN MAP AND IN AIR AT 4C
 MAP-stored atmospheres: low- (PD 900) and medium- (PD 961) O₂ permeability films. Air-stored atmospheres: high- (PD 941 and LDP) O₂ permeability films. PD, Packaging Digest; LDP, low-density polyethylene.

The yeast and mold counts were smaller than the *Enterobacteria* counts and different from the other types of microbial counts because there were no significant differences among the shredded sweet potatoes stored under low- (PD 900 and PD 961 packaging films) or high-O₂ atmospheres (PD 941 and LPD packaging films) for cv. Beauregard (Fig. 7). The yeast and mold counts of the shredded sweet potatoes increased from 10⁴ cfu/g to nearly 10⁶ cfu/g during storage. Cultivar Hernandez stored under the two high-O₂ atmospheres significantly exhibited larger counts ($P \leq 0.05$) than the shredded sweet potatoes stored under low-O₂ atmospheres. Thus, cvs. Beauregard and Hernandez significantly exhibited different ($P \leq 0.05$) growth of yeasts and molds. The MAP reduced the yeast and mold counts on broccoli when compared to broccoli (Mohd-Som *et al.* 1994) or potato strips (O'Brien and Ballantyne 1987) in air, but MAP exhibited little effect on lettuce (King *et al.* 1991) or shredded carrots (Barry-Ryan *et al.* 2000).

CONCLUSIONS

The quality of shredded sweet potatoes from commercial cvs. Beauregard and Hernandez was maintained for 7 days at 4C in air. The quality of shredded sweet potatoes was extended up to 14 days with MAP. Considering the parameters determined in this research (firmness, ascorbic acid, beta-carotene, color, chlorogenic acid, starch, sugars, ethanol and selected microbial counts), the best results were obtained with packaging film PD 961 reflected in a modified atmosphere of 5% O₂, 4% CO₂ and 91% N₂, combined with refrigeration at 4C. Shredded sweet potatoes stored in MAP exhibited smaller changes in tissue firmness, dry matter, ascorbic acid and starch than shredded sweet potatoes stored in air. The shredded sweet potatoes stored in MAP consistently exhibited smaller populations of total aerobic bacteria and enteric bacteria when compared to shredded sweet potatoes stored in air. Yeasts, molds, lactic acid bacteria, color, beta-carotene and sugars of stored shredded sweet potatoes did not change significantly regardless of package atmospheres. Greater ethanol concentrations were generated in the shredded sweet potatoes stored in MAP after 10 days, but off-odors were not detected in any of the shredded sweet potatoes during 14 days of storage.

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