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Influence of cutting size and packaging materials on the quality of fresh-cut winter squash (var. Ajijimang)

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ABSTRACT

Winter squash (var. Ajijimang) washed in 100 mg·L^{-1} chlorine water and cut into 4 and 8 parts was packed in different packaging materials, 35 μm micro-perforated P-Plus (MPP), 50 μm polyethylene (PE), 80 μm nylon/PE (Ny/PE), and 90 μm PE films separately. Fresh-cut samples were then stored at 10˚C for up to 17 days. The 35 μm MPP having a high oxygen transmission rate (OTR) has the most stable gas exchange ratio while the 80 μm Ny/PE was the most unstable. Firmness of the mesocarp remained acceptable until the end of storage regardless of the cutting size. Soluble solids content (SSC) remained stable and even slightly increased to a certain extent within 6 days. An increase in pH after 10-day storage suggested the activity of microorganisms within the packaging films. Strong off-odor was detected in samples packaged in 80 μm Ny/PE film after 13 days of storage. Mold was observed in all 1/4 cut samples on day 13 except the sample packaged with 80 μm Ny/PE film. However, no mold was found in all 1/8 cut samples except 35 μm MPP film on day 13. Severe mold invasion was apparent on the onset of the 17-day storage in 35 μm MPP film and 50 μm PE film. Samples cut into 8 parts and packed in 80 μm Ny/PE and 90 μm PE films had less mold incidence compared with other two packaging films. Fresh-cut winter squash packaged in 90 μm PE film maintained quality with shelf-life of 10 days at 10˚C. Winter squash as fresh-cut commodity, with the right packaging material has the potential for longer period of storage in retail stores.

Keywords: Fresh-Cut; Packaging Films; Shelf-Life; Storage; Winter Squash

1. INTRODUCTION

Fresh-cut commodities are gaining popularity in Korea for the last decade in response to an increased consumer demand for convenient food. However, fresh-cut produce has limited shelf-life due to rapid quality deterioration. Quality of fresh-cut produce depends mainly on the quality of the intact product and its maintenance between harvest and preparation of the fresh-cut products, processing method, and subsequent handling conditions [1]. Korean fresh-cut processors recognize the importance of postharvest handling of raw materials. Processors are aware that raw materials affect shelf-life of fresh-cut produce [2].

In winter squash (*Cucurbita maxima* D.), it is vital to wash newly harvested fruits with 200 ppm of NaOCl to control growth of spoilage fungi before storage or processing [3]. The atmosphere surrounding fresh-cut processed vegetables likewise is extremely important to extend shelf-life. One of the most influential factors on its composition is the permeability of the film used for packaging [4] and the interaction between film oxygen transmission rates (OTR) and initial headspace O_2 [5].

Polyethylene (PE) is one of the most commonly used materials in packaging. Polypropylene (PP) either unperforated or micro-perforated is likewise gaining popularity. These films in different thickness possess a range of gas transmission rates. Fresh-cut products that normally have elevated respiration rate require films with high gas transmission capabilities. Even within the package, fresh-cut vegetables are bound to deteriorate. The main spoilage mechanisms influencing processed products include oxidation, water loss and the activity of microorganisms. Reducing the respiration rate and inhibiting agents of spoilage with the right packaging films having appropriate gas transmission rates and right temperature at storage would result in longer shelf-life of packed commodity.

Green rind winter squashes commonly known as buttercup is a popular variety that has an appealing yellow orange flesh with high soluble solids content (SSC) of 13 to 17% [6,7]. Cultivar Ajijimang is another green rind winter squash more appealing for its higher SSC of 17 to 19% [8]. Ajijimang is a potential variety as fresh-cut winter squash that may be used for ready-to-cook commodity. Oftentimes, the fruit is cut in halves or in quarter covered with a 15 μm polyvinyl chloride (PVC) wrap and displayed at 15˚C to 20˚C shelves in supermarkets in Korea. The cut squash fruits often last for 2 to 3 days. Optimum modified atmosphere (MA) packaging is effective in prolonging the shelf-life of fresh-cut produce by matching film permeability for O_2 and CO_2 to the respiration rate of the packaged commodity. The respiration rate of fresh-cut produce is influenced by storage temperature, cut size, etc. Little information exists on optimum packaging film for different sized fresh-cut winter squash. To date, vacuum packaging with Ny/PE film and PVC wrap are utilized for covering cut winter squash. In the present experiment, different films were assessed as packaging material for fresh-cut winter squash (var. Ajijimang) prepared in different cuts.

2. MATERIALS AND METHODS

2.1. Materials, Fresh-Cut Processing, and Packaging

Winter squash (*Cucurbita maxima* D., cv. Ajijimang) grown in a plastic house in Suwon was harvested 45 days after flowering. The fruits were conditioned for a month for further maturation at room temperature (25˚C ± 2˚C). The squash material was subjected to further storage of three months at 12˚C. The average weight of intact winter squash was 1.8 kg.

Three months stored Ajijimang were washed with 100 ppm of sodium hypochlorite (NaOCl) prior to cutting. The squash was cut into quarter (1/4) and eight parts (1/8) with seeds removed and washed with cold sterile water to remove cellular exudates released during cutting of winter squash. Samples were air dried for a few minutes to remove surface water. After surface drying, fresh-cut squash were packaged in 35 μm micro-perforated P-Plus (MPP), 80 μm Nylon/PE (Ny/PE), 50 μm PE, or 90 μm PE films. Fresh-cut squash samples in packages (20 × 25 cm) were then stored at 10˚C for up to 17 days.

Oxygen transmission rates (OTR) of 50 and 90 μm PE films (Samkyoung Chemistry Ltd., Korea) were 1850 $mL·m^{-2}·d^{-1}$ and <1300 $mL·m^{-2}·d^{-1}$ at 10˚C [9], respectively. 35 μm MPP film (Amcor, UK) with an OTR of 11,648 $mL·m^{-2}·d^{-1}$ at 10˚C and 80 μm NY/PE film (Dasan Polybag, Korea) with an OTR of about <100 $mL·m^{-2}·d^{-1}$ at 25˚C [10] were also used to pack different cutting sizes of winter squash.

2.2. Gas Composition Analyses

Oxygen (O_2) level and accumulation of carbon dioxide (CO_2) within the package of different films containing fresh-cut winter squash were monitored in every sampling occasion. Gases were measured using a gas monitoring devise (PBI-Dansensor CheckMate II, Denmark) by placing the needle directly into the packages.

2.3. Texture Measurements

In every period of analysis, samples of each cut in triplicate representing a treatment were sliced twice horizontally making a 5 cm-thick cut in the middle. The top slice represented the stalk side while the bottom slice represented the underside of the fruit where the calyx is located. The middle slices were analyzed for firmness while top and bottom parts were analyzed for soluble solids content and change in pH. In each sampling occasion, cut samples from the middle section of the fruit were analyzed for firmness by using a texture analyzer (Model TA-XT2-5, Stable Microsystems, UK). Two spots per replicate on flat surface of sliced samples were pricked with a cylindrical probe of 3 mm in diameter mounted on a drill stand at 3 mm per second speed and deformation distance of 8 mm.

2.4. Soluble Solids Content and pH

Juice samples used for soluble solids content (SSC) and pH measurements were obtained by grating of peeled samples and squeezing of the squash samples from each replicate with a hand juicer. Samples were then filtered through two layers of cotton gauze. Soluble solids content and pH of the juice were measured at room temperature with a digital refractometer (Model PAL-1, Atago Co., Japan) and a pH meter (Model Titro-Line Easy, Schott, UK), respectively.

2.5. Mold Infection and Off-Odor Development

Incidence of mold infection was monitored throughout the storage period. The incidence rate was calculated by the weight of all mold infected pieces in each package, divided by the total fresh weight of the sample and multiplied by 100 to obtain percentage. Off-odor was evaluated immediately after opening the packages and scored on a five-point scale where 0 = none; 1 = slight; 2 = moderate; 3 = strong; and 4 = severe [5]; a score of 3 or above was considered unacceptable.

3. RESULTS AND DISCUSSION

3.1. Gas Composition

Any vegetables when processed or cut will have increased metabolic activity as a result of an increased surface area exposed to the atmosphere. The respiration rate increases as the cutting allows oxygen to diffuse into the interior cells more rapidly [11]. Winter squash in two different cuts were packaged in four different films with different OTRs. Levels of O_2 and CO_2 within the package as the squash were stored at 10˚C are presented in **Figure 1**. Fresh-cut winter squash packaged in 35 µm MPP film has the most stable gas concentrations/exchange within the package for the entire storage period of 17 days. This type of film has a high OTR of 11,648 $mL \cdot m^{-2} \cdot d^{-1}$ at 10˚C [9] and therefore allows higher gas exchange. On the other hand, O_2 concentration in package prepared with 80 µm Ny/PE film decreased rapidly to zero from 18% while CO_2 increased tremendously within three days. This film has a very low OTR of about <100 $mL \cdot m^{-2} \cdot d^{-1}$ at 25˚C [10] and level of CO_2 keeps on accumulating as storage progressed which resulted in ballooning of the package. CO_2 levels within the package even reached 60 % in 10 days. Both 50 and 90 µm PE films exhibited better gas exchange in the presence of fresh-cut winter squash. Although O_2 levels in those films reached anaerobic conditions from 3 days until the end of the storage period, ballooning was not observed neither in the two PE films tested. However, the level of CO_2 in 50 µm PE film was lower than 90 µm PE film because CO_2 diffusion in 50 µm PE film was faster due to a higher OTR compared to 90 µm PE film [9].

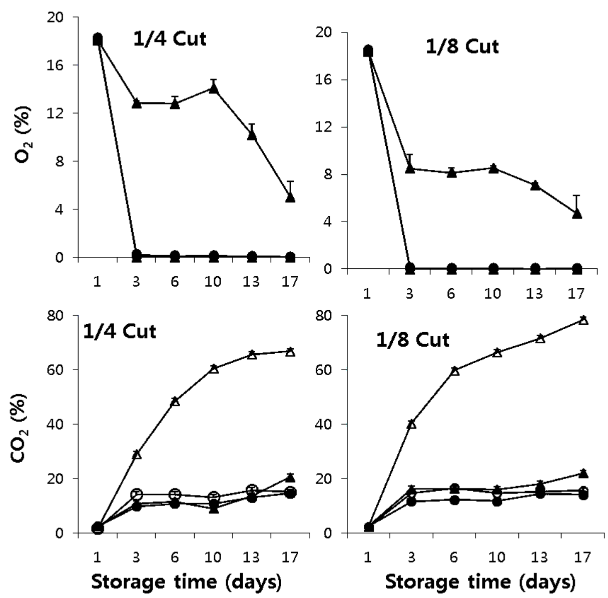

Figure 1. Levels of O_2 and CO_2 concentration in fresh-cut winter squash packaged in different films (µm) and stored at 10˚C for 17 days. Each symbol is the mean of three replicate measurements; vertical lines represent SE. (●) 50 µm PE, (○) 90 µm PE, (▲) 35 µm MPP, (Δ) 80 µm Ny/PE.

3.2. Firmness

Mesocarp of fresh-cut Ajijimang was highly firm initially at 36.9 N when preconditioned one month after harvest. Firmness of fresh-cut winter squash was generally maintained for 10 days regardless of the cut and packaging film **(Figure 2)**. Slicing plant tissues generally results in loss of firmness causing direct water loss due to cell leakage [12]. As minimally processed vegetables are stored, loss in turgor pressure and textural breakdown due to enzymatic hydrolysis of cell compounds becomes apparent [13]. The mechanism of physical spoilage in fresh-cut winter squash is unique. The breakdown of tissues may have been very slow due to its high starch content. The result only suggests that firmness is not going to be a problem in winter squash as a fresh-cut commodity. More so, with the right packaging film and storage temperature, other quality attributes will likewise be preserved.

3.3. Soluble Solid Content and pH

Winter squashes are not only known for its excellent nutritive value and eating quality, its seeds and flesh likewise contain high level of Vitamin E and carotenoids, respectively as anti-oxidants [14,15]. In the same way, winter squash which has high sugar content is attractive. It is therefore important that give attention to SSC as a quality attribute of fresh-cut winter squash. Levels of SSC in fresh-cut Ajijimang increased slightly from 17.2% to 18.6% and were maintained within 10 days of storage (**Figure 3(a)**). The same trend was true with 80 µm Ny/PE film (data is not shown). Fresh-cut winter

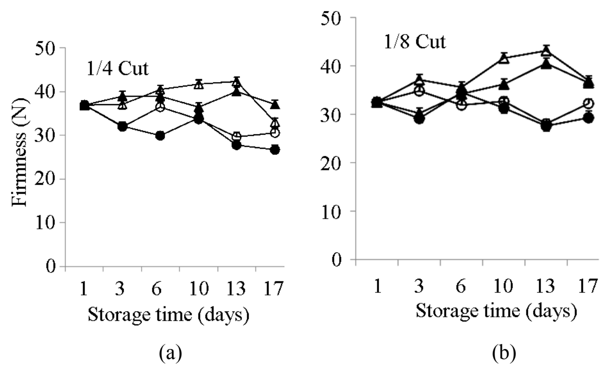

Figure 2. Firmness of fresh-cut winter squash packaged in different films (µm) and stored at 10˚C for 17 days. Each symbol is the mean of three replicate measurements; vertical lines represent SE. (●) 50 µm PE, (○) 90 µm PE, (▲) 35 µm MPP, (Δ) 80 µm Ny/PE.

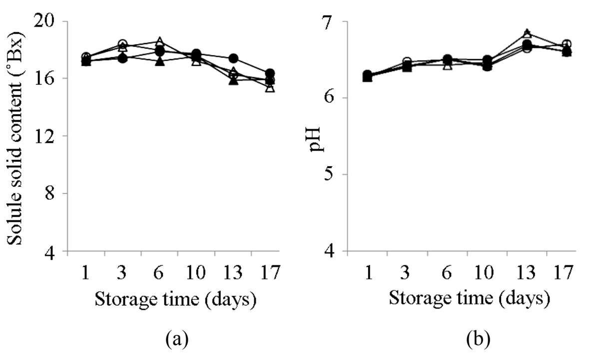

Figure 3. Levels of soluble solid content (SSC) and pH in fresh-cut winter squash packaged in two different films (µm) and stored at 10˚C for 17 days. Each symbol is the mean of three replicate measurements; vertical lines represent SE. (●) 1/4 Cut + 50 µm PE, (○) 1/4 Cut + 90 µm PE, (▲) 1/8 Cut + 50 µm PE, (Δ)1/8 Cut + 80 µm PE.

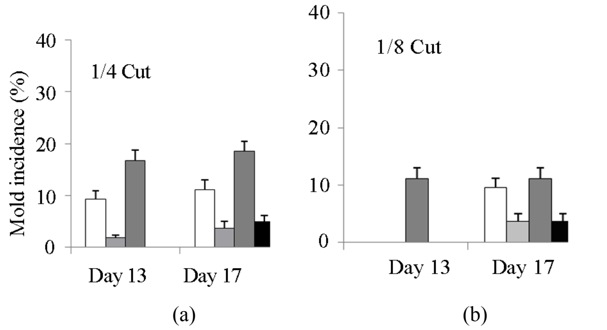

Figure 4. Decay incidence of fresh-cut winter squash packaged in different films stored at 10˚C for 13 and 17 days. Each symbol is the mean of three replicate measurements; vertical lines represent SE. (□) 50 µm PE, (■) 90 µm PE, (■) 35 µm MPP, (■) 80 µm Ny/PE.

squash from Ajijimang, in this case, continued to ripen within the specified period of time. The same findings were observed by Roura *et al.* [16] in diced squash (*C. moschata*) packed and covered with 15 µm PE wrap where SSC and sugar/titratable acidity ratios increased during storage at 10˚C ± 2˚C. Soluble solids content in fresh-cut winter squashes although initially very high were at a plateau and started to decline after 10 days. These findings suggest the importance of selecting proper maturity and preconditioning details of squash varieties as fresh-cut vegetable. It appears that packaging films used facilitated maintenance in quality in terms of increasing or maintaining SSC in storage. However, surface drying was noticeable early in storage even within 6 days in 35 µm MPP film package. The RH during storage period ranged from 45% to 60%. Increasing the RH would improve dryness of fresh-cut surface.

It is worth interesting to note that pH of fresh-cut winter squash increased slowly during storage. Increase in pH became prominent after 10 days of storage **(Figure 3(b))** signifying higher microbial activity which is consistent with the visible growth of fungi on day 13 for winter squash packed in 50 µm PE film **(Figure 5)** and possible bacterial accumulation or other fermenting organisms in squash packed in 90 µm PE film.

3.4. Spoilage and Off-Odor

The main causes of deterioration mechanisms influencing processed products include oxidation, water loss and the activity of microorganisms. All three mechanisms were observed in fresh-cut winter squash depending on the films used. 35 µm MPP film is capable of exchanging more balanced gases however surface of fresh-cut winter squash dries up within the package. Appearance of mold spots in fresh-cut squash packaged in 35 µm MPP film was apparent on day 10 (data is not shown) while the activity of molds in fresh-cut squash packaged in other three films occurred later. No mold activity was recorded in fresh-cut winter squash packed with 80 µm Ny/PE film on day 13 in both 1/4 and 1/8 cut samples **(Figure 4)**. High CO_2 levels in both 90 µm PE and 80 µm Ny/PE film suppressed fungal growth for at least or over 10 days. Suppression of fungi in MPP film, on the other hand, was less than 10 days. A decrease in temperature has a tremendous effect on lowering respiretion rates, thereby lowering microbial activity. Moreover, its affects on permeability of gases through the packageing films also slow microbial growth [17]. Occurrence of mold growth was evident in either 90 µm PE or 80 µm Ny/PE film.

Off-odor development was not detected in fresh-cut squash packed in 35 µm MPP film until 6 days **(Figure 5)**. On the other hand, the absence of O_2 inside the package for other three films encouraged fermentative metabolism resulting in the development of off-odor within 3 days in squash packaged in 80 Ny/PE film **(Figure 5)**. Sour smell was produced and became stronger in 6 days as the package is opened. However, the sour smell disappears once the fresh-cut winter squash are aerated for a few minutes. It also worth noting that off-odor development was much intense in fresh-cut winter squash cut into 8 parts than 4 parts in 50 µm PE, 90 µm PE, and 35 µm MPP film. Higher number of cuts probably increased respiration which can cause more off-odor development of samples packaged in only 80 µm Ny/PE film. Both 80 µm Ny/PE and 90 µm PE films was best in suppressing respiration by reducing O_2 levels to almost zero and similarly increasing CO_2 levels within three days **(Figure 1)**. This condition suppressed sensitivity of fresh-cut winter squash of further ripening and the growth of microorganisms [11]. The CO_2 levels on day 3 were 12 to 14% in 90 µm PE film and 30 to 40% in 80 µm Ny/PE film that was more than enough to cause such suppression. In these conditions, off-odor development in winter

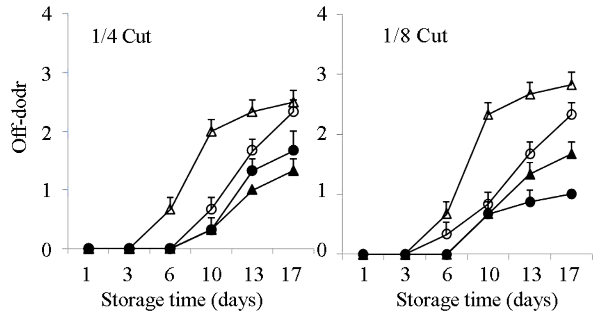

Figure 5. Off-odor development in fresh-cut winter squash packaged in four different films (µm) and stored at 10˚C for 17 days. Off-odor was scored using a 0 to 4 hedonic scale where 0 = no off odor; 1 = slight; 2 = moderate; 3 = strong and 4 = severe. Each symbol is the mean of three replicate measurements. (●) 50 µm PE, (○) 90 µm PE, (▲) 35 µm MPP, (Δ) 80 µm Ny/PE.

squash in the early days of storage may not be a product of microbial action since no signs of physical deterioration are apparent.

The shelf-life of fresh-cut winter squash packaged in 35 µm MPP was 6 days at 10˚C regardless of cutting size. However, both 1/4 and 1/8 cut samples packaged with 90 µm PE films had longer than 10 days of shelf-life though off-odor development was detected in the samples. The samples had less mold incidence and the off-odor was acceptable until 10 to 13 days in 1/4 and 1/8 cut treatments, respectively.

4. CONCLUSION

Packaging film affected package atmosphere, mold incidence, and off-odor development of fresh-cut winter squash during the 10˚C storage. Firmness, SSC, and PH of fresh-cut winter squash remained acceptable for at least 10 days regardless of the cutting size. Mold was detected in all packaging films after 17 days of storage. However, less mold incidence was found in samples cut into 8 parts and packed with 80 µm Ny/PE and 90 µm PE films compared with 35 µm MPP film and 50 µm PE film. Strong off-odor was detected in samples packaged in 80 µm Ny/PE film after 13 days of storage. Therefore, fresh-cut winter squash packaged with 90 µm PE film maintained better quality with 10 to 13 days of shelf-life in 1/4 and 1/8 cut, respectively at 10˚C.

5. ACKNOWLEDGEMENTS

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