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# Quality and Shelf-life of Fresh Cut Crrot Slices as Affected by Slicing Method

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# Quality and shelf-life of fresh cut carrot slices as affected by slicing method. Journal of Food Science, 63, 851-856.

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## ABSTRACT

**The effects of slicing method on the quality and storage-life of modified atmosphere packaged carrot slices were determined using microscopy, sensory evaluation, microbial counts and a range of physical and chemical tests. Slicing caused physical damage, physiological stress and enhanced microbial growth. The severity of these effects were in the order of blunt machine blade > sharp machine blade > razor blade. These findings provide insights into the magnitude and basis of slicing effects and also confirm the importance of gentle processing and the use of a sharp blade.**

**Key Words: carrots, slicing, modified atmosphere, minimal processing**

## INTRODUCTION

READY-TO-USE (RTU) ROOT VEGETABLES are typically peeled, sliced, diced or shredded prior to packaging. Slicing cuts through cells, leaving large areas of internal tissue exposed. It also disrupts some sub-cellular compartmentalization, bringing previously separated enzymes and substrates together. Such physical damage also leads to leakage of cell contents during subsequent storage.

By exposing large areas of inner tissue, slicing facilitates contamination by epithelial microflora (Brackett, 1987), and leaked nutrients provide richer substrates than available in intact tissue. Thus, microbial loads and growth rates maybe increased by steps such as slicing (Carlin et al., 1989). Surface dehydration and total moisture loss may also be increased by the nature and extent of tissue exposure. Stress response reactions lead to increased respiration rates and to the synthesis of lignin. Slicing increased the respiration rate of carrots two or three fold over that of the intact roots (Watada, 1994, Kahl and Laties, 1989 and Priepke et al., 1976). Increased respiration rates may increase the rate of physiological ageing. Both dehydration (Cisneros-Zevallos et al., 1995) and lignin synthesis (Bolin and Huxsoll, 1991) have been implicated in the surface whitening of cut carrot tissue.

The extent of injury to the product caused by slicing may depend on factors such as final piece size, sharpness of slicing surfaces, mechanical aspects of the slicing action, and mechanical properties of the product (Abe et al., 1993, Zhou et al., 1992, Tatsumiet al., 1991 and Bolin et al., 1977). These factors also affect physiological response of the product and its susceptibility to microbial spoilage (Izumi et al., 1996).

The objective of this study was to determine the effects of different slicing methods on the quality and storage life of ready-touse carrot slices. Carrots were sliced with a razor blade, a sharp machine blade or a blunt machine blade. A range of physical, biochemical and microbial changes, thought to be responsible for deterioration of carrot quality were monitored.

## MATERIALS & METHODS

### Plant material

Locally grown carrots, cultivar Nairobi, were used to produce modified atmosphere packaged carrot slices. The carrots had been washed by the producer. Medium sized roots (3–4 cm dia), free of defects were used.

### Slicing and processing

Carrots (10 Kg) were hand peeled, topped and tailed using a sharp knife and then washed for 5 min with 100ppm chlorinated water. They were left to drip-dry for 15 min in a perforated cage. Carrots were sliced into 6mm thick discs, either manually or by machine. Backed stainless steel razor blades were used for hand slicing. Mechanical slicing was carried out using a Sammic CA300 vegetable processing machine (Barcelona, Spain), equipped with either a sharp or blunt cutting disk. A pair of flat straight blades (3 x 9 cm) were mounted on the cutting disks in parallel. The sharp blades were unused before this experiment. The blunt blades were rendered blunt through use on a coleslaw production line for 1 yr. Carrot slices were then packaged in 350g lots in 35µm thick oriented polypropylene (OPP) bags (280 x 180 $mm^2$) and sealed with a Multivac A300 packaging machine. The bagged product was stored at 8°C and evaluated during storage. Although the recommended storage temperature for such products is 2–6°C, ready-to-use products are often stored at higher temperatures in normal retail distribution (Carlin et al., 1990), thus we chose a storage temperature of 8°C for this investigation.

### Sensory evaluation

Analytical sensory evaluation was used to discriminate between the appearance and aroma of the carrot slices prepared by different slicing methods. A panel of ten judges, aged 22-30 years (8 female and 2 males, all members of the UL Food Science Research Centre) with sensory evaluation experience, were trained in discriminative evaluation of carrot slices. The carrots used during the training sessions, every second day for 1 month, had been subjected to various storage treatments and times. Fresh carrots were used as the control (score = 9). The training panel were shown the effects of storage over 10 days in air versus a range of modified atmospheres (achieved using different films). The effects of storage temperature (3, 8 and 20°C) and time (10 days) on the carrot slices was also shown during the training sessions. The products were presented in groups, by sample day, to a single sensory judge at a time on a white lab bench in an odor-free fluorescent lit food laboratory. The products were scored for appearance and aroma on a scale of 1 to 9 (ranked), where 1 = very poor, 4–5 = fair and 9 = excellent. Judges relied on their training experience to score products. Sensory evaluation was used to determine the shelf-life of these products, as scores of 5 or below were taken to indicate the end of shelf-life.

### Structural changes

Carrot tissue for examination under the microscope was prepared by 'free-hand sectioning'. Using a backed razor blade, thin (~12 µm) sections of fresh tissue were sliced in water, mounted in water and examined microscopically (Arnold, 1973). Tissue samples were fixed, using formyl acetic acid. This was prepared by adding 5 mL glacial acetic acid, and 85mL 70% ethyl alcohol, to 10 mL formaldehyde (40%). Tissue ultrastructure was photographed using a compound Olympus microscope (BH2), magnification 400, with an Olympus (PM6) camera attachment.

Carrot tissue samples were examined for the presence of lignin by staining for 2 min in phloroglucinol. This stain was prepared by adding 5g of phloroglucin to 100 mL 75% ethyl alcohol. The stain was removed by washing with concentrated HCL for ~1 min or until a distinctive red color appeared. The specimen was then washed with water and examined under the microscope. Phloroglucinol stains lignified cell walls red and can be used as a positive test for lignin (Fukuda and Komamine, 1982).

Aniline sulphate was also used to detect the presence of lignin. This was prepared by adding 1g aniline sulphate and 89 mL 70% ethyl alcohol to 10mL sulphuric acid (10N). This preparation stains lignin containing structures yellow after immersion for 5 min (Nakano and Meshitsuka, 1992).

**Weight loss**

A model package containing four carrot slices lying flat was accurately weighed at regular intervals during storage to determine the rate of weight loss. Weighings were made with an accuracy of $\pm 1 \infty 10^{-5}$g.

**Exudate production**

Exudate was quantified by the method described by Carlin et al. (1990). A sample (4g) was placed between two filter papers (Whatman No. 541, 5 cm dia) and a force of 10 kg was applied for 10s. The measurement was repeated four times and mean values were expressed in g exudate/100g fresh weight.

**Cell permeability**

Cylinder plugs (4 mm dia) were sliced from the 6mm thick carrot discs using a cork borer. These were taken from the secondary vascular tissue, the outer ring of the slice. The plugs were randomized, then immersed for 15 min in deionized water on an orbital shaker (25 plugs in 10 mL). An earlier study showed that exposure to water did not increase the cell permeability of carrot tissue when compared to hypertonic solutions (Simon, 1977). Immediately following treatment, plugs were placed in a salad spinner and spun for 30s to remove residual water and then packaged in OPP bags, 12 per bag, and stored at 8°C.

Following storage, the leakage of UV-absorbing solutes was monitored using methods reported by Picchioni et al. (1991) with slight modifications. The bag contents were divided and three plugs per universal tube were incubated in 7.5 mL deionized water on an orbital shaker for 4h at 25°C. The incubation medium (4 mL) was centrifuged at 3440 rpm for 10 min. Leakage was expressed as absorbance of the clarified solution (260 nm) compared with distilled water using quartz cuvettes.

**Microbial enumeration**

Packages from each treatment were sam

pled during storage at regular intervals. The product (40g) was added to 360 mL sterile peptone water and blended (2 min) at high speed in a Waring Blendor (New Hartford, CT). Serial dilutions ($10^{-1}$ to $10^{-6}$) were carried out using 1 mL of macerated sample and 9 mL aliquots peptone water. The drop and spread technique was used whereby 0.1 mL of each dilution was spread in duplicate using a sterile glass spreader. The media used were de Man, Rogasa and Sharpe (MRS) for lactic acid bacteria, plate count agar for total counts, violet red bile agar for coliforms and malt extract agar for yeasts and molds. Media were prepared and incubated as directed by the manufacturer (Oxoid). Duplicate and control samples were prepared for each sample and only counts of 30-300 colony forming units (CFU) were considered. The entire experiment was repeated three times.

**TBARS**

Thiobarbituric acid reactive substances (TBARS) were determined using the extraction procedure described by Salih et al. (1987), with some modifications. The test sample (50g) was homogenized in 100 mL of distilled water. To 25 mL of this homogenate, 25 mL of 10% trichloroacetic acid were added, and the solution was filtered through Whatman No. 1 filter paper (7cm dia). To 4 mL of the filtrate, 1mL of 0.06M thiobarbituric acid (4,6-Dihydroypyrimidine-2-thiol) was added and the solution was heated for 10 min at 100°C. After cooling, absorbance was read at 532 nm. The highest absorbance obtained was given the value of 100% TBARS and all other values were reported as percentages of this.

**Lipoxygenase**

Lipoxygenase activity was determined using the method described by Sheu and Chen (1991). The test sample (~50g) was added to 100 mL of citrate-phosphate buffer and homogenized for 1 min. The homogenate was held at 4°C for 1h and centrifuged ($10{,}000 \infty g$) for 15 min. The reaction was initiated by adding 60 µL of this enzyme extract to 3 mL of substrate. The substrate was prepared by adding 157.2 µL linoleic acid & 157.2 µL Tween 20 (polyoxyethylensorbitan monolaurate) to 10 mL distilled water, mixing and clarifying the solution by adding 1mL of 1N NaOH. This was then diluted to 100 mL to give a linolate concentration of 0.01M (stock solution). A linolate concentration of $2 \times 10^{-3}$M was then prepared with 4 volumes sodium phosphate buffer (pH 7) and let stand in the dark for 10 min. Lipoxygenase activity was measured at 234 nm (25°C) using plastic cuvettes. One unit of enzyme activity was defined as 1.00 unit of absorbance increase at 234 nm/mL of enzyme extract/min.

**Measurement of pH**

Product (100g) was blended for 2 min with 100 mL of distilled and deionized wa

ter (pH 7). The pH of the macerate was determined using a WPA CD300 digital pH meter (WPA, England).

**Respiration rate**

The effects of slicing method on respiration rate were monitored using a custom respirometer (Barry-Ryan, 1996) which consisted of a large refrigerator containing a cylinder of ethylene-free air. Air flow from the cylinder was controlled, humidified and subdivided into seperate lines serving 8 respiration chambers. The chambers consisted of 2L conical flasks each containing 350g of respiring product. The flasks had gas tight rubber bung seals and tightly fitted stainless steel tubing carried the gas through the bungs. The flow through each chamber was 12 mL/min. The outlet line from each chamber was automatically sampled hourly, for 18h. Carbon dioxide ($CO_2$) levels were quantified using a Gow-Mac (Shannon, Ireland) gas chromatograph fitted with a CTR1 column (Alltech, USA). From the changes in the level of $CO_2$ in the outlet gas compared with the inlet gas the respiration rate for the samples could be calculated using the steady-state value, generally reached 2–3h after sealing. This was done in duplicate and repeated three times.

**Gas analysis of packs**

The atmospheric gases within the stored packs were sampled throughout storage. Using an airtight syringe gas (10 mL) was drawn from the pack through the 1 mL sample loop and analyzed using the gas chromatograph and conditions as described for respiration rate. These packs were sampled in duplicate and the whole experiment repeated three times.

**Statistical analysis**

All data were subjected to analysis of variance (ANOVA) and a least significant difference multicomparison test to determine significant differences between treatments (Shamaila et al., 1992). Significance of differences was defined at $p < 0.05$.

## RESULTS & DISCUSSION

**Effects on sensory score**

Slicing method had strong effects on sensory scores for carrot slices during storage (Fig. 1). Razor slicing resulted in higher appearance scores ($p<0.05$) throughout storage than machine slicing. These high appearance scores were due mainly to the retention of a smooth cut surface on the manually cut discs as compared with the rough and cracked surfaces on machine cut products. By Day 5 scores were 2–3 units higher. In the machine sliced discs, the benefits of blade sharpness were apparent from Day 3 onwards and generally amounted to an improvement of about 1 sensory unit (Fig. 1a). The trends found in aroma scores (Fig. 1b) were similar to those

for appearance scores. In this case, however, the benefits of razor slicing were less pronounced and the damaging effects of the blunt machine blade were greater. Aroma of the carrots sliced with a razor blade retained a strong fresh carrot smell, unlike those cut by machine. Initially the drop in aroma scores for machine cut products was attributed to the loss of carrot aroma, but by Day 6 the development of off odors, was noted for the blunt blade cut slices. These off odors, due to tissue decay, were not noted in the sharp machine blade sliced carrots until Day 8. On Day 5, for example, razor sliced discs had aroma scores one unit higher than those sliced using a machine blade, which in turn had scores two units higher than those sliced using a blunt machine blade.

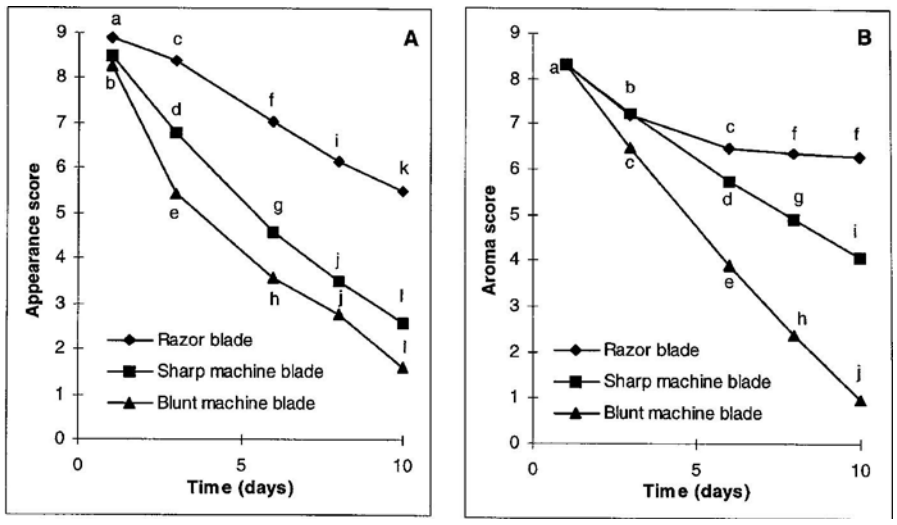


**Fig. 1—Effects of slicing method on the (A) appearance and (B) aroma scores of MA packaged carrot slices stored at 8°C. Scores were rated on a scale of 1 to 9, where 1 = very poor, 4-5 = fair and 9 = excellent. Values are means for six determinations.**

### Factors determining appearance scores

Loss of satisfactory appearance in RTU carrot products is generally attributed to factors which contribute to development of surface whitening. This phenomenon is hypothesized to result from drying out effects at the cut surface and may be followed by the synthesis of lignin. Both of these may be directly related to the extent of surface damage inflicted. Cell disruption, exudate production and lignin development were monitored in an attempt to explain the effects of slicing method and blade condition on appearance scores.

Microscopic examination showed that slicing with a razor blade had the least disruptive effect on the integrity of the tissue (Fig. 2a). After ten days all cells were plasmolyzed, with only the regular structure of the walls visible (Fig. 2b). By comparison, machine slicing inflicted greater damage and this was dependent on the condition of the blade. Carrot tissue sliced with a sharp machine blade (Fig. 3) suffered substantially less cell damage than tissue sliced with a blunt machine blade (Fig. 4a). After ten days, due to drying out effects of storage and use of a blunt blade, this tissue was extensively cracked. Cell walls had thickened due to production of lignin, confirmed by staining the tissue in phloroglunicol (Fig. 4b). Tatsumi et al. (1991), using electron micrographs, showed that cells loosened by processing became dehydrated over storage.

Bolin and Huxsoll (1991) showed that processed carrots quickly developed white lignin type material and that the degree of formation of this material was dependent on the severity of the process. Bolin et al. (1977) and Tatsumi et al. (1991) reported that the amount of white tissue development was less on carrots sliced with a razor blade than with a knife, because the blade passed cleanly through the cells and did not cause widespread damage.

Weight loss is a result of drying of the processed tissue and may have contributed to a reduction in appearance scores. The con-

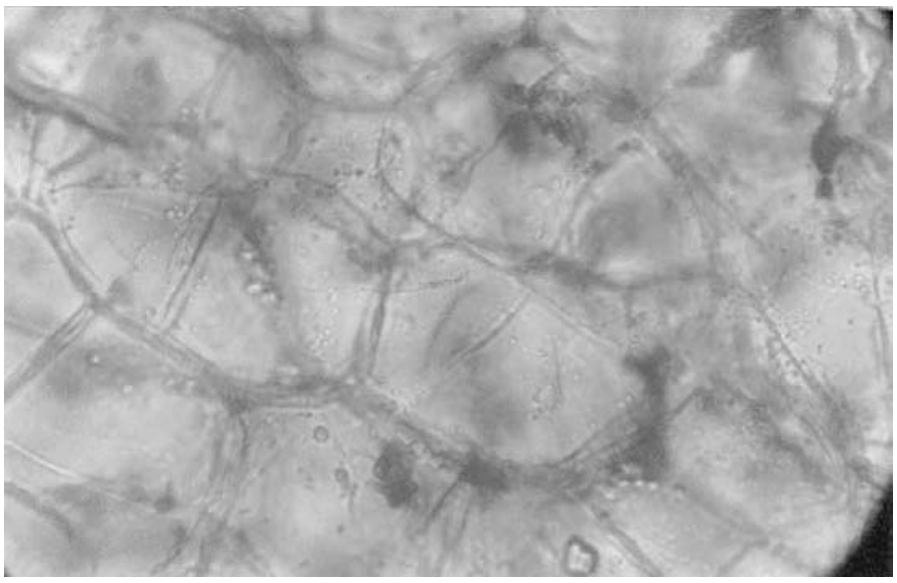

**Fig. 2a—Surface tissue of carrot slices sliced with a razor blade, transverse section, after 1 day of storage in OPP bags at 8°C (x400).**

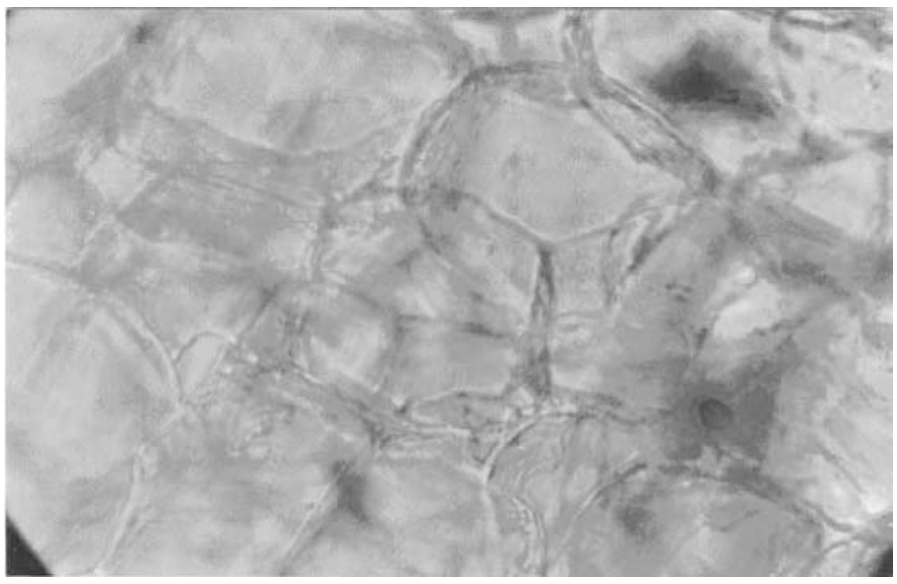

**Fig. 2b—Surface tissue of carrot slices sliced with a razor blade, transverse section, after 10 days of storage in OPP bags at 8°C (x400).**

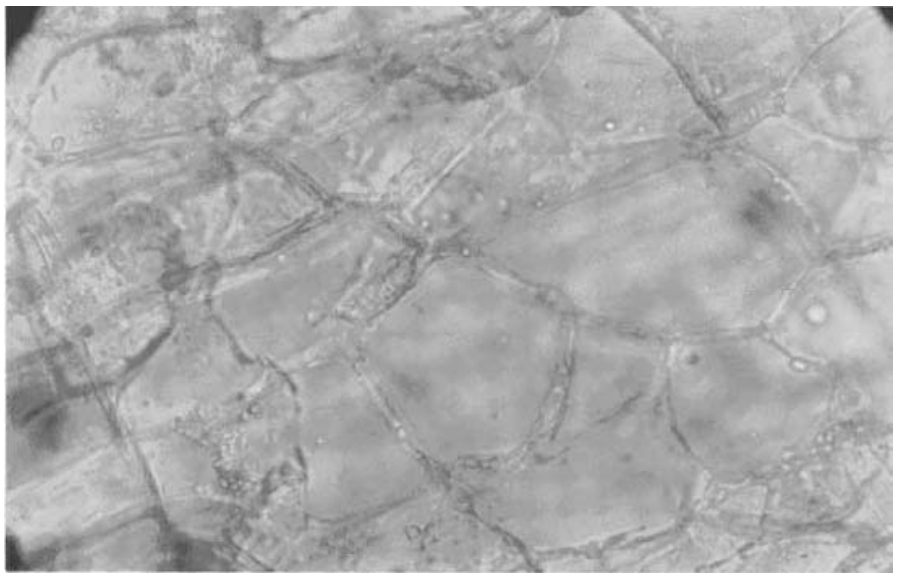

**Fig. 3—Surface tissue of carrot slices sliced with a sharp machine blade, transverse section, after 1 day of storage in OPP bags at 8°C (x400).**

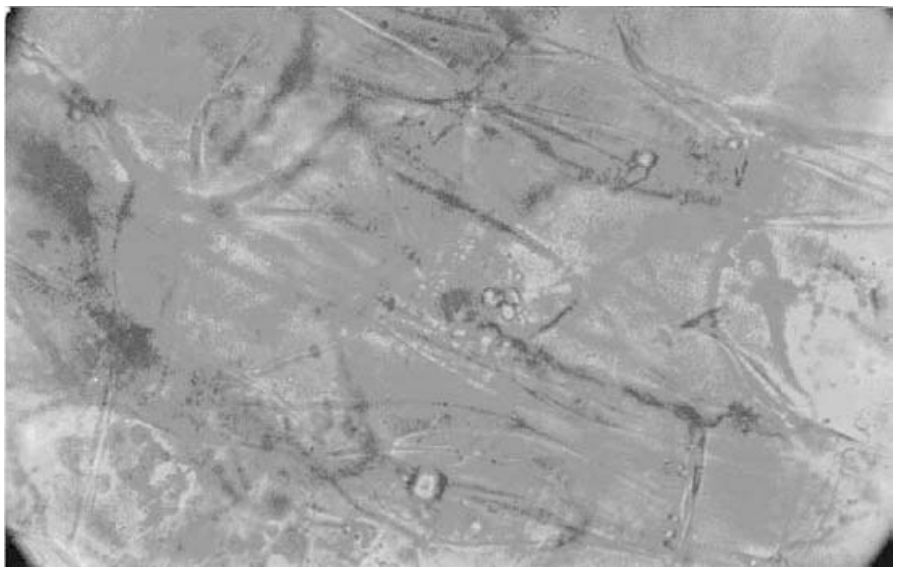

**Fig. 4a—Surface tissue of carrot slices sliced with a blunt machine blade, transverse sec-tion, after 1 day of storage in OPP bags at 8°C (∞400).**

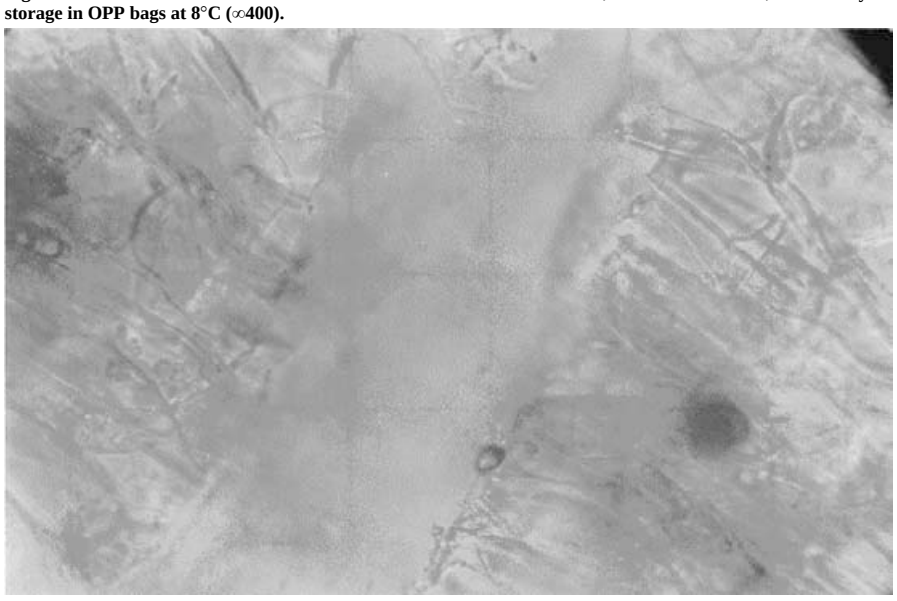

**Fig. 4b—Surface tissue of carrot slices sliced with a blunt machine blade, transverse section, after 10 days of storage in OPP bags at 8°C (x400).**

dition of the processing machine blade had no effects on weight loss, but slicing with a razor blade reduced weight loss from Day 3 onwards (Fig. 5). Tatsumi et al. (1991) had reported that weight loss in packs of carrot sticks correlated highly with loss of quality of the product which depended on slicing method. Similarly, weight loss of tomatoes was related to the degree of physical damage (Palma et al., 1995) and increased the rate of senescence.

Higher levels of exudate were recorded in samples prepared by machine than in those prepared manually (Fig. 6). Initially, discs sliced using a blunt machine blade had exudate levels almost double those of slices prepared using the sharp blade, and about triple those of discs sliced by razor blade. Exudate levels may be used as an index of quality, as spoiled packs can be characterized by having high exudate levels.

Examination of the effects of slicing method on cell permeability showed no differences between machine blades on Day 1 (Fig. 7). For the rest of storage, carrots sliced using a blunt machine blade had the highest cell permeability, and there were no differences between the other two slicing methods ($p > 0.05$).

**Microbial changes**

The development of off-odors in packs containing carrot slices coincided with increased microbial loads. In relation to the data for aroma scores, microbial loads were lowest on razor sliced carrots. The effects of blade condition were only significant for coliforms and *Pseudomonas* species.

Total aerobic counts and lactic acid bacteria loads were highest for machine sliced carrot discs irrespective of blade used, and lowest for razor sliced products (Table 1). With respect to coliform loads, highest counts were found on carrot discs sliced with the blunt machine blade, and lowest counts on razor sliced carrots. Products prepared using the sharp machine blade had a coliform population between those values. Effects of slicing method was also found on yeasts and molds. Loads were higher on the machine sliced products, with differences between the two blades obvious early in storage (~1 Log CFU/g). The lowest loads were isolated from the razor sliced carrots, generally 1–1.5 Log CFU/g lower.

higher inoculation levels. In many cases higher growth rates were evident and these were presumably related to the effects of the more severe slicing methods on exudate levels. Carlin et al. (1989) showed that cut vegetables were more susceptible to spoilage than whole vegetables, as released nutrients supported microbial growth. A survey reported by Garg *et al.* (1990) and studies by Koek et al. (1983) reported sizes and microbial population types on commercial packs of carrot sticks that are confirmed by our experiments.

**Table 1—Effects of slicing method on microbial counts of stored MA packaged carro slices (8°C)**

| Storage time (Days) | Slicing method | Log$_{10}$/g Total aerobic counts | Coliforms | Lactic acid bacteria | Yeasts & Molds |
|---|---|---|---|---|---|
| 1 | Razor sliced | 5.77a | 5.77a | 4.7a | 4.8a |
| | Sharp machine | 5.8b | 5.907a,b | 4.93b | 5.4b |
| | Blunt machine | 6.27b | 6.1b | 5.6b | 6.27c |
| 3 | Razor sliced | 6.59c | 6.17c | 6.01c | 5.53d |
| | Sharp machine | 6.91c,d | 6.48c,d | 6.36 | c6.11e |
| | Blunt machine | 7.26d | 7.03d | 6.45d | 6.87f |
| 6 | Razor sliced | 7.02e | 6.84e | 7.2e | 6.68g |
| | Sharp machine | 7.95e | 7.2f | 7.84e | 7.69g |
| | Blunt machine | 8.16f | 7.75g | 7.94f | 7.86h |
| 8 | Razor sliced | 7.2g | 7.24h | 7.42g | 7.21i |
| | Sharp machine | 8.28g | 7.54j | 8.2g | 8.23i |
| | Blunt machine | 8.46d | 7.98j | 8.46f | 8.22j |
| 10 | Razor sliced | 7.53h | 7.57k | 7.31h | 7.5i |
| | Sharp machine | 8.45h | 7.71l | 8.31g | 8.li |
| | Blunt machine | 8.65i | 8.21 | 8.73f | 8.27k |

[z]Number of viable microorganisms detected ($log_{10}$ per gram) on the carrot slices during storage. Means separated by Fisher's least significant difference ($p<0.05$). Means for individual storage times and within columns with different letters significantly different ($p<0.05$). Microbiological data are mean values for six determinations for the numbers of viable microorganisms detected ($log_{10}$ per gram).

**Table 2—Respiration rates[z] of carrots slices, measured after different slicing methods**

| | Respiration rate (µL $CO_2$/g FW/h) |
|---|---|
| Razor blade | 17.8a |
| Sharp machine blade | 19.4b |
| Blunt machine blade | 17.5a |

[z]Means separated by least significant difference ($p<0.05$). Data are means for three replications. Each product means followed by a different letter are significantly different.

Storage-life of most MA packaged prepared vegetable products are terminated by spoilage due to microbial growth (Babic et al., 1992). Bolin et al. (1977) showed that the higher the microbial load on shredded lettuce, the shorter the storage-life.

The pH values increased up to Day 8, after which they began to level off (Fig. 8). Razor sliced carrots had lower pH values than the machine sliced products throughout storage, those sliced with a blunt blade had higher values than those sliced with a sharp blade. This pH increase coincided with increased microbial loads which may have resulted in greater utilization of organic acids. King et al. (1991) reported that pH increased over 15 days storage of partially processed lettuce and that this was paralleled by increased microbial loads.

The levels of lipid oxidation, measured as %TBARS, appeared to fall during storage with no differences between treatments, suggesting that it would have little influence on aroma scores. This did not agree with findings by Bengtsson et al. (1967) for peas and Galliard et al. (1976) for cucumber, that increased injury/brusing increased lipid oxidation. However, the higher lipid content of peas and the mild native aroma of cucumber may explain such differences. The lack of evidence for involvement of lipid oxidation in the drop in aroma scores we observed, suggests that the drop was mainly due to production of off-flavor volatiles by spoilage microflora. There was also no significant difference between lipoxygenase activity of carrots sliced with either machine blade, which increased slightly over storage (Fig. 9). Lipoxygenase activity was unexpectedly highest in the razor sliced products up to Day 6 of storage, and from Day 8 there were no differences between the treatments. This initial high activity may have been due to the slower development of a modified atmosphere in these pacakges compared with the machine sliced products. Zhuang et al. (1995) showed that modified atmosphere packaging reduced lipoxygenase activity.

**Respiration rate/Gas analysis of packs**

Respiration rates were higher for sliced than for intact carrots and were affected by slicing method. Carrots sliced manually with a razor or mechanically with a blunt blade had slightly lower respiration rates than those sliced using a sharp machine blade (Table 2). Carbon dioxide levels were lowest in packs containing the razor sliced carrots (Fig. 10). Initially the levels of $CO_2$ rose faster in the packs of carrots sliced using the sharp rather than the blunt machine blade, but by the end of storage the $CO_2$ levels in packs containing discs sliced using the blunt blade were

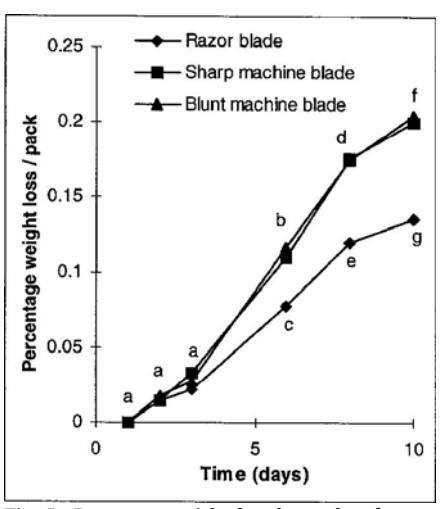


**Fig. 5—Percentage weight lost by packs of carrot slices prepared by different slicing methods, during storage at 8°C.**

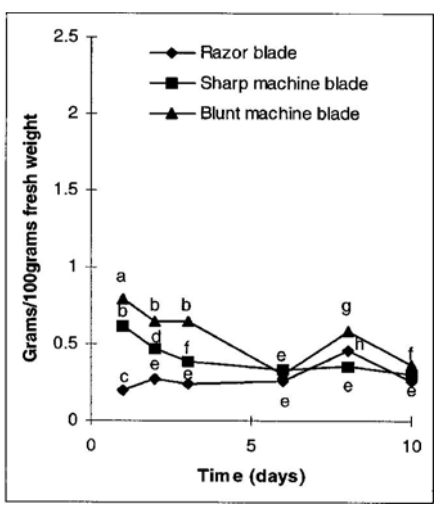


**Fig. 6—Effects of slicing method on exudate produced (g/100g fresh weight) from carrot slices during storage at 8°C.**

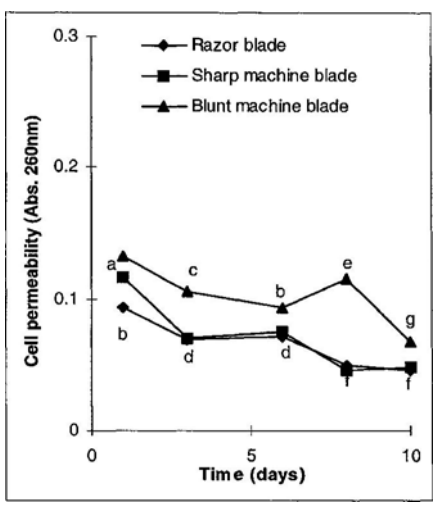


**Fig. 7—The effects of slicing method on cell permeability measured as the loss of UV absorbing solutes from the carrot tissue during storage at 8°C.**

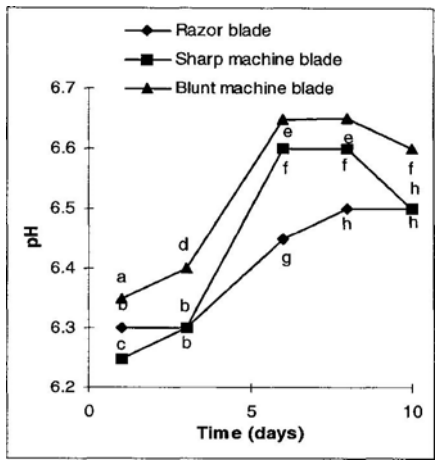


**Fig. 8—Effects of slicing method on pH of carrot slices during storage at 8°C.**

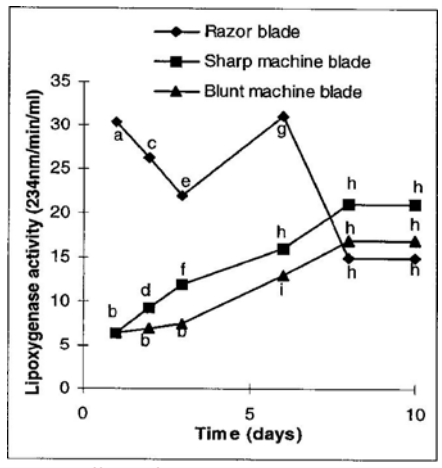


**Fig. 9—Effects of slicing method on lipoxy-genase activity in carrot slices, measured as oxidation of linoleic acid at 234 nm, over 10 days storage at 8°C.**

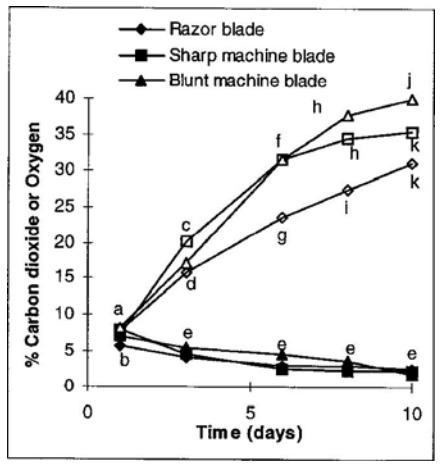


**Fig. 10—Percentage of $CO_2$ (open symbols) and $O_2$ (closed symbols) in the atmosphere of packs containing carrot slices, sliced by different methods, during storage (8°C).**

highest. Oxygen levels fell sharply in all packs, to as low as 7% by Day 1, due to the high respiration rate of these products at 8°C. By Day 3 an equilibrium modified atmosphere had developed between the product respiration rate and film permeability, therefore the oxygen level did not change over the rest of storage. Our findings broadly confirmed the work of Kader (1987), who reported an increase in respiration rates with an increase in severity of processing. However, our results suggest that slicing with a blunt blade may be initially less stressful on vegetable tissue.

## CONCLUSION

THE SLICING METHOD FOR READY-TO-USE carrots had strong effects on quality and shelf-life. Results confirmed that shelf-life may be extended by minimizing physical damage through the use of a sharp blade. Slicing caused physiological stress, physical damage and enhanced microbial growth. The milder slicing treatments led to higher appearance scores due to less cellular damage, lower cell permeability and lower levels of exudate. Most microbial loads were reduced by milder slicing treatments and this led to less off-odor development and greater retention of carrot aroma.

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