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Quality of fresh-cut produce

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Abstract

Fresh-cut fruits and vegetables are highly perishable due to damaged and exposed tissues and lack of protective skin. Disorders arising from processing can be minimized by the use of sharp cutting tools, enzymatic browning inhibitors, modified atmospheres and low temperatures. High quality can be maintained by selecting produce at proper maturity and controlling deterioration with low temperatures and modified atmospheres. By recognizing and controlling factors that have a deteriorative effect on quality, good quality fresh-cut product with sufficient shelf-life can be attained. © 1999 Published by Elsevier Science B.V. All rights reserved.

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Fresh-cut fruits and vegetables are products that are partially prepared so that no additional preparation is necessary for their use. They are prepared for restaurants, dining commons, fast food outlets and retail markets. The fresh-cut products are packaged in film packages or containers over-wrapped with film with the weight ranging from 0.5 to 4 kg. The projected shelf-life differs among the fresh-cut products and ranges from 7 to 20 days when held at the recommended temperature.

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Consumers expect fresh-cut product to be without defects, of optimum maturity and in fresh condition. Condition covers general appearance, sensory quality (texture/firmness and taste) and nutrient quality.

Fresh-cut products are vulnerable to discoloration because of damaged cells and tissues, and lack of protective skin. These exposed tissues have the potential of becoming dehydrated and/or discolored. Carrot slices, when handled improperly, become white, which makes them appear aged and undesirable. Scanning electron microscopy of the cut surface shows that the white discoloration is due to dehydration of damaged cells (Tatsumi et al., 1991). Cutting and slicing carrots with a

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very sharp blade reduces the amount of damaged cells and dehydration when compared with those sliced with a regular culinary knife. Dehydration is also minimized by treating the cut carrots with calcium and placing them in very high relative humidity atmosphere (Cisneros-Zevallos et al., 1997).

Browning of cut surface is a problem with several products such as cabbage (Yano and Saijo, 1987), lettuce (Bolin and Huxsoll, 1991), potato (Sapers et al., 1990), apple (Sapers et al., 1990) and peach (Gorny, 1997). Oxidation of phenols catalyzed by polyphenol oxidase results in the browning complex. The phenols are a product of a reaction catalyzed by phenylalanine ammonia-lyase (PAL), and the activity of PAL is used as an index for potential browning (Mateos et al., 1993).

Enzymatic browning of apples slices can be reduced by treating slices with 4.5% sodium erythorbate and 0.2% $CaCl_2$ (Sapers et al., 1990). The inhibitory effect is diminished with storage duration and differs with apple cultivars. Controlled atmosphere/modified atmosphere (CA/MA) is effective in delaying browning and/or PAL activity. Shredded lettuce becomes brown in 8 days when held in air at 5°C, whereas an induced MA of 1% O_2 + 12% CO_2 delays browning by 2 weeks (Ballantyne et al., 1988). A 20% CO_2 atmosphere reduces PAL activity and phenol content of cut lettuce midribs held at 2.5°C, which was thought to be due to reduction of tissue pH by the high CO_2 level (Mateos et al., 1993). The maximum PAL activity occurred earlier at 15°C than at 5°C (Lopez-Galvez et al., 1996b), thus low temperature should be maintained to reduce browning.

Cultivars differ in the degree of browning. Yano and Saijo (1987) examined 25 cultivars of shredded cabbage and found eight cultivars to brown slightly and two cultivars to brown minimally after 24 h at 20°C. Kim et al. (1993) found that, among 12 apple cultivars, slices of ‘Cortland’, ‘Empire’, ‘Golden Delicious’, ‘New York 674’ and ‘Delicious’ showed the least browning after 3 days at 2°C. Thus, selection of proper cultivar is important to control browning of sliced products.

Maturity is an important quality attribute of fresh-cut fruit because immature fruit lack good sensory quality and over-mature fruit has limited shelf-life. We noted that the quality of young honeydew melon cubes with 8.8% soluble solids was lower than that of more mature fruits with 13% soluble solids after a few days’ storage. Young honeydew melon cubes at the immature to mature threshold level (8.8% soluble solids) had an average quality score of ‘3’ (poor) after 3 days at 10°C and a score of ‘4’ (fair to poor) after 7 days at 5°C (data not presented). The very mature melon cubes (13% soluble solids) had an average quality score of ‘5’ (fair) after 3 days at 10°C and a score of ‘6’ (good to fair) after 7 days at 5°C. The quality scores were derived from scores for general appearance, shear force values and taste scores. Those with 8.8% soluble solids failed to retain honeydew taste/aroma and deteriorated more rapidly than those with 13% soluble solids. Honeydew cubes with 13% soluble solids had good taste/aroma, but deteriorated more rapidly than those with 11% soluble solids at 10°C. Thus, with the limited shelf-life of the fresh-cut fruits, it is essential to use mature fruit with acceptable eating quality for processing, but not overmature fruit, which will deteriorate rapidly.

The general quality condition, which includes appearance, firmness/texture and vitamin content, is affected by various factors. The most important factor is temperature. When temperature increases from 0 to 10°C, respiration rate increases substantially, with the Q_{10} ranging from 3.4 to 8.3 among various fresh-cut products (Watada et al., 1996). Zucchini, tomato and kiwi had a Q_{10} of about 3.5 while bell pepper, muskmelon and crenshaw had values of about 8.3. With increased respiration rate, deterioration increases at a comparable rate; thus, low temperature is essential for maintaining good quality.

About 40% of fresh produce in the market is chilling sensitive, thus chilling injury is a concern with fresh-cut products held at chilling temperatures. Since fresh-cut products are held only for a short period and are highly perishable when compared with the whole product, a temperature which causes a slight amount of chilling injury is preferred over a temperature which causes rapid natural deterioration. In our study with zucchini slices, all of the slices of triplicate samples held at 0°C had severe to extreme chilling injury after 17 days of storage; about 50% of the slices of triplicate samples held at 5°C had slight to moderate amount of lesions and decay due to chilling injury and natural deterioration after 16 days of storage; and about 90% of the slices of triplicate samples held at 10°C had moderate to severe amount of browning and decay due to natural deterioration by the twelfth day (Izumi and Watada, 1995). With the lesions and decay being greatest from chilling injury at 0°C and from natural deterioration at 10°C, 5°C was the best holding temperature even though it caused some chilling injury. O'Connor-Shaw et al. (1994) also reported that fresh-cut honeydew melons and muskmelons should be held at the chilling temperature of 4°C, because the amount of chilling injury at this temperature was much less than the amount of natural deterioration that occurred at higher temperatures. The optimum temperature differs with duration of holding and product, because produce types and cultivars differ in chilling sensitivity (Hardenburg et al., 1986).

Modified atmospheres within fresh-cut containers or bags can be beneficial in maintaining quality of the fresh-cut product (Gorny, 1997). The suitable gas mixture for modified atmosphere has been based on that recommended for the whole commodity (Saltveit, 1997). Fresh-cut products probably can tolerate more extreme levels of O_2 and CO_2, because they do not have as much cuticle or skin to restrict gas diffusion, and the distance of gas diffusion from the center to outside of the product is much less than that for the whole commodity. However, threshold levels that might cause injury should be avoided because gas mixture of modified atmosphere packages cannot be regulated closely.

Controlled atmosphere system is used to simulate modified atmosphere with similar gas composition for assessing quality. A 10% O_2 + 10% CO_2 CA has been shown to retard chlorophyll degradation in parsley (Yamauchi and Watada, 1993). A CA of 5–10% O_2 + 5–15% CO_2 retarded browning and disorders of shredded cabbage (Kaji et al., 1993). An atmosphere of 3% O_2 + 10% CO_2 was beneficial for fresh-cut iceberg lettuce, slightly beneficial for romaine lettuce, and not beneficial for butterhead lettuce (Lopez-Galvez et al., 1996a). A CA of 2% O_2 + 6% CO_2 delayed yellowing and mold development on broccoli florets by 2 weeks at 4°C (Bastrash et al., 1993). The O_2 level for broccoli florets can be allowed to drop down to 0.5% at 0 and 5°C and 1.0% at 10°C and still obtain beneficial results (Izumi et al., 1996b). The O_2 level can be allowed to drop to near or at the respiratory quotient breakpoint (RQB) without injury with some the fresh-cut products. The O_2 level could be dropped to 0.25% for zucchini slices (Izumi et al., 1996a), 0.5% for Pak choi (O'Hare et al., 1995) and carrots (Izumi et al., 1996c), 0.8% for spinach (Ko et al., 1996), 1% for butterhead lettuce (Varoquaux et al., 1996) and romaine lettuce (Hamza et al., 1996) and 2% for diced onions (Blanchard et al., 1996). These low O_2 levels were beneficial in retaining quality of the product.

At slightly below the RQB, carrot shreds alter their respiratory pathway to continually produce chemical energy (Kato-Noguchi and Watada, 1996a,b). Fructose 2,6-bisphosphate is synthesized at the low O_2 level, which enhances enzyme activity of pyrophosphate dependent phosphofructokinase activity. With the increased enzyme activity, more fructose 1,6-bisphosphate is produced, which hastens glycolysis with a concomitant inefficient production of ATP as well as ethanol (Kato-Noguchi and Watada, 1997). Under this condition, the Krebs cycle is functioning minimally if any at all, and the tissue becomes dependent on glycolysis for ATP to maintain minimum metabolism.

Ethylene production is stimulated when plant tissues are injured and it can accumulate in packages of fresh-cut product, which can lead to undesirable effects. A concentration of 2 $\mu l\ l^{-1}$ ethylene hastened softening of kiwifruit and banana slices held at 20°C and softening was retarded when an ethylene absorbant (charcoal with palladium chloride) was used to reduce the ethylene levels (Abe and Watada, 1991). The accelerated softening was noted after 1 day of storage, so it is essential to control ethylene production to maintain quality.

Fresh-cut products are highly susceptible to weight loss because internal tissues are exposed and lack skin or cuticle. However, relative humidity generally is very high in film bags or containers overwrapped with film, so dehydration typically is not a problem. Edible coatings can also be used to retain high relative humidity (Baldwin et al., 1995). Although films or coatings provide high relative humidity, two potential problems exist. Moisture condenses on the inner surface of the packaging films which detracts in viewing the material and the droplets can become a site for possible breakdown and microbial growth. The second problem is that, if the film or coating does not allow sufficient transmission of O_2 or CO_2, over-modification of atmosphere can cause injury to the product. Thus, films and coatings need to be selected not only for maintaining high relative humidity, but also for allowing proper transmission of gases.

In summary, although fresh-cut products are highly perishable, high quality products can be assured by selecting the proper maturity for processing, controlling defects and disorders, and maintaining temperature, atmosphere and relative humidity.

References

Abe, K., Watada, A.E., 1991. Ethylene absorbent to maintain quality of lightly processed fruits and vegetables. J. Food Sci. 56, 1493–1496.

Baldwin, E.A., Nisperos-Carriedo, M.O., Baker, R.A., 1995. Edible coatings for lightly processed fruits and vegetables. HortScience 30 (1), 35–38.

Ballantyne, A., Stark, R., Selman, L.D., 1988. Modified atmosphere packaging of shredded lettuce. Int. J. Food Sci. Technol. 23, 267–274.

Bastrash, S., Makhlouf, J., Castaigne, F., Willemot, C., 1993. Optimal controlled atmosphere conditions for storage of broccoli florets. J. Food Sci. 58, 338–341, 360.

Blanchard, M., Cataigne, F., Willemot, C., Makhlouf, J., 1996. Modified atmosphere preservation of freshly prepared diced yellow onion. Postharvest Biol. Technol. 9, 173–185.

Bolin, H.R., Huxsoll, C.C., 1991. Control of minimally processed carrot (*Daucus carota*) surface discoloration caused by abrasion peeling. J. Food Sci. 56, 416–418.

Cisneros-Zevallos, L., Saltveit, M.E., Krochta, J.M., 1997. Hygroscopic coatings control surface white discoloration of peeled (minimally processed) carrots during storage. J. Food Sci. 62, 363–366.

Gorny, J.R., 1997. Summary of CA and MA requirements and recommendations for fresh-cut (minimally processed) fruits and vegetables. In: Gorny, J.R. (Ed.), Proceedings of Seventh International Controlled Atmosphere Conference, vol. 5. Postharvest Outreach Program, University of California, Davis, CA, pp. 30–66.

Hamza, F., Castaigne, F., Willemot, C., Doyon, G., Makhlouf, J., 1996. Storage of minimally processed romaine lettuce under controlled atmosphere. J. Food Qual. 19, 177–188.

Hardenburg, R.E., Watada, A.E. and Wang, C.Y. 1986. The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. USDA Agricultural Handbook No. 66, 130 pp.

Izumi, H., Watada, A.E., 1995. Calcium treatment to maintain quality of zucchini squash slices. J. Food Sci. 60, 789–793.

Izumi, H., Watada, A.E., Douglas, W., 1996. Low O_2 atmospheres affect storage quality of zucchini squash slices treated with calcium. J. Food Sci. 41, 317–321.

Izumi, H., Watada, A.E., Douglas, W., 1996. Optimum O_2 or CO_2 atmosphere for storing broccoli florets at various temperatures. J. Am. Soc. Hortic. Sci. 12, 127–131.

Izumi, H., Watada, A.E., Ko, N.P., Douglas, W., 1996. Controlled atmosphere storage of carrot slices, sticks, and shreds. Postharvest Biol. Technol. 9, 165–172.

Kaji, H., Ueno, M., Osajima, Y., 1993. Storage of shredded cabbage under a dynamically controlled atmosphere of high oxygen and high carbon dioxide. Biosci. Biotechnol. Biochem. 57, 1049–1052.

Kato-Noguchi, H., Watada, A.E., 1996. Low oxygen atmosphere-induced increase in fructose 2,6-bisphosphate in fresh-cut carrots. J. Am. Soc. Hortic. Sci. 121, 307–309.

Kato-Noguchi, H., Watada, A.E., 1996. Regulation of glycolytic metabolism in fresh-cut carrots under low oxygen atmosphere. J. Am. Soc. Hortic. Sci. 121, 123–126.

Kato-Noguchi, H., Watada, A.E., 1997. Effects of low-oxygen atmosphere on ethanolic fermentation in fresh-cut carrots. J. Am. Soc. Hortic. Sci. 122, 107–111.

Kim, D.M., Smith, N.L., Lee, C.Y., 1993. Quality of minimally processed apple slices from selected cultivars. J. Food Sci. 58, 1115–1117.

Ko, N.P., Watada, A.E., Schlimme, D.V., Bouwkamp, J.C., 1996. Storage of spinach under low oxygen atmosphere above the extinction point. J. Food Sci. 61, 398–400, 406.

Lopez-Galvez, G., Saltveit, M., Cantwell, M., 1996. The visual quality of minimally processed lettuces stored in air or controlled atmosphere with emphasis on romaine and iceberg types. Postharvest Biol. Technol. 8, 179–190.

Lopez-Galvez, G., Saltveit, M., Cantwell, M., 1996. Wound-induced phenylalanine ammonia lyase activity: factors affecting its induction and correlation with the quality of minimally processed lettuces. Postharvest Biol. Technol. 9, 223–233.

Mateos, M., Ke, D., Cantwell, M., Kader, A.A., 1993. Phenolic metabolism and ethanolic fermentation of intact and cut lettuce exposed to CO_2-enriched atmospheres. Postharvest Biol. Technol. 3, 225–233.

O'Connor-Shaw, R.E., Roberts, R.A., Ford, L., Nottingham, S.M., 1994. Shelf life of minimally processed honeydew, kiwifruit, papaya, pineapple, and cantaloupe. J. Food Sci. 59, 1202–1206.

O'Hare, T.J., Smith, L.G., Wong, L.S., Meiburg, G.F., 1995. Low-oxygen storage of whole and minimally-processed pak choi. Proceedings of Australasian Postharvest Horticulture Conference, pp. 459–462.

Saltveit, M.E. Jr., 1997. A summary of CA and MA requirements and recommendations for harvested vegetables. In: Saltveit, M.E. (Ed.), Proceedings of Seventh International Controlled Atmosphere Conference, vol. 4. Postharvest Outreach Program, University of California, Davis, CA, pp. 98–117.

Sapers, G.M., Garzarella, L., Pilizota, V., 1990. Application of browning inhibitors to cut apple and potato by vacuum and pressure infiltration. J. Food Sci. 55, 1049–1053.

Tatsumi, Y., Watada, A.E., Wergin, W.P., 1991. Scanning electron microscopy of carrot stick surface to determine cause of white translucent appearance. J. Food Sci. 56, 1357–1359.

Varoquaux, P., Maxollier, J., Albagnac, G., 1996. The influence of raw material characteristics on the storage life of fresh-cut butterhead lettuce. Postharvest Biol. Technol. 9, 127–139.

Watada, A.E., Ko, N.P., Minott, D.A., 1996. Factors affecting quality of fresh-cut horticultural products. Postharvest Biol. Technol. 9, 115–125.

Yamauchi, N., Watada, A.E., 1993. Pigment changes in parsley leaves during storage in controlled or ethylene containing atmosphere. J. Food Sci. 616-618, 637.

Yano, M., Saijo, R., 1987. New preservation method for shredded cabbage with special reference to non-browning cultivar. J. Jpn. Soc. Cold Preserv. Food 13, 11–15.