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Factors affecting quality of fresh-cut horticultural products

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Abstract

Fresh-cut products, also known as lightly or minimally processed products, are highly perishable because a large proportion of their surface area is without epidermis, the outer protective layer of tissue. Temperature, atmosphere, relative humidity and sanitation must be regulated to maintain quality of fresh-cuts. In the 0–10°C range, Q_{10} of respiration rates ranged from 2.0 to 8.6 among various fresh-cut fruits and vegetables. Low O_2 and elevated CO_2 atmosphere reduced the respiration rate; however, the respiratory quotient approached 3.0 with some fresh-cuts. Film bags or coatings are necessary to maintain high relative humidity. Micro-organisms were present in chlorine-washed spinach, and populations increased during storage. Stress from the physical action of processing and low O_2 atmosphere affects physiology and biochemistry of the fresh-cuts, which can affect quality and shelf-life. Research in all of these areas is needed to ensure that wholesome, high-quality fresh-cut products are marketed to consumers.

Keywords: Fresh-cut; Minimally processed; Respiration; Controlled atmosphere; Relative humidity; Micro-organism

1. Introduction

Fresh-cut products, which previously were called lightly or minimally processed products have been available for many years, but the types and quantity have expanded tremendously in the past decade. Initially, the food service industry (e.g., institutions) was the main user of fresh-cut products, but use has expanded to restaurants, supermarkets, and warehouse stores. The food service industry and restaurants favor fresh-cuts because manpower for preparation and special systems to handle waste are not required and specific forms of fresh-cuts can be delivered on short notice. Fresh-cut products

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are thus convenience foods with the additional benefit of reduced wastage for retail consumers.

In the United States, the sales of fresh-cuts are projected to increase from $5.8 billion in 1994 to $19 billion in 1999 (Hodge, 1995). In Europe, the problem of preparing fresh-cuts for different countries with varying cultures has been resolved and the industry is growing rapidly (Bicheron, 1995). France and the United Kingdom have the leading market share of fresh-cuts in Europe, and in the latter country, 90% of the total is sold as store brand. The Netherlands also is a major consumer of fresh-cuts with 70% going through retail outlets. The industry is relatively fragile in Germany and Italy. The success and expansion of fresh-cuts will be dependent on continual marketing of a quality products.

In the United States, most of the fresh-cut products are prepared by either national or regional processors. National processors generally are located near the site of crop production, and their raw products can therefore be at peak quality. The fresh-cut products are shipped nationally to markets of up to 4000 km in distance, thus they need to have at least 14 days of shelf-life. Savings are made on the transportation cost because only the usable portion, which may be only 50% of the original raw product, is shipped. Regional and local processors prepare fresh-cuts as needed and to a written specification. Their raw product may be 4–7 days old at the time of preparation, which can limit shelf-life after preparation. However, their fresh-cut products need only 7 days of shelf-life. Regional processors need to have sufficient refrigerated storage space for an inventory of raw products. The quality of the raw product needs to be excellent to ensure excellent quality fresh-cut product. Equally important is the regulation of temperature, relative humidity, and sanitation (microbiology) of fresh-cuts. Use of film wraps or edible coatings can modify the internal atmosphere, which has been shown to be beneficial in extending the shelf-life. However, extensive modification of atmosphere can cause injury to tissue, thus further study is needed to determine the recommended atmosphere.

2. Temperature

Fresh-cuts generally are much more perishable than intact products because they have been subjected to severe physical stress, such as peeling, cutting, slicing, shredding, trimming, and/or coring, and removal of protective epidermal cells. Consequently, fresh-cuts probably should be held at a lower temperature than that recommended for intact commodities. Although 0°C generally is the desirable temperature for most fresh-cuts, many are prepared, shipped and stored at 5°C and sometimes as high as 10°C. Storage at this elevated level can hasten deterioration substantially because Q_{10} of biological reactions range from 3 to 4 and possibly as high as 7 within this temperature region (Schlimme, 1995).

We compared the respiration rates of intact and fresh-cut products of several fruits and vegetables at 0, 5, 10, and 20°C. The commodities were obtained from local distribution center or growers in Maryland, USA. The maturity of the precuts was at the 'optimum edible' stage. Each commodity was separated into 8 uniform lots, replicated 4 times. Four lots were used for fresh-cut and the other 4 were left intact. Each sample, consisting of a single fruit or representative of a single fruit, was placed in a jar. Jars with fruit were placed in one of the 4 storage temperatures and humidified air was metered through the jar at a rate so that CO_2 did not exceed 0.3%. Carbon dioxide production by each sample was measured every 4 h for 10 days or until the commodity began to deteriorate. The steady-state respiration rates are presented in Table 1. At 20°C, when the rates of some samples increased continually instead of decreasing and a steady state was not attained, the rates for the first day of storage are presented.

Respiration rates of fresh-cuts generally were higher than the intact product (Table 1). The increase in the respiration rate of fresh-cut compared with the intact product ranged from only a few percent for green beans, grape and zucchini to over 100% for kiwifruit and lettuce. The lettuce data were collected by Cantwell (1995). At 20°C, the percentage increase in respiration was substantially greater with samples that did not attain a steady respiration rate. Removal of hulls (sepals, bracteole, and stem) from strawberry fruit or stems from Thompson seedless grapes did not affect respiration, probably because the process resulted in minimal injury. Interestingly, the respiration rates of fresh-cut muskmelons (*Cucumis melo* var. reticulatus), crenshaws (*Cucumis melo* group inodorus var. crenshaw) and honeydews (*Cucumis melo* var. inodorus) were similar to or lower than that of the intact fruit at 0, 5 and 10°C, but dramatically higher at 20°C. At 20°C, the high respiration of cut tissue was probably due to physiological deterioration and microbial growth. Typically, respiration rate can be used to approximate the shelf-life of fresh produce; however, with fresh-cut products, the physiology is altered too drastically to make the prediction.

Respiration rates of fresh-cuts increased with temperature, and the degree of increase differed with the commodity (Table 1). In the 0–10°C storage temperature range, the Q_{10} of several fresh-cuts was higher, several were similar, and a few were lower than the whole product. The Q_{10} was greater in the 10–20°C temperature range than in the 0–10°C range for 11 of the 15 fresh-cut commodities. This was not expected, because Q_{10} has been reported to be greater at the lower temperature region (Platenius, 1942). The high Q_{10} of several fresh-cut products in the 10–20°C range was due to the rapid deterioration at 20°C. The high Q_{10} values between 10 and 20°C for whole unpeeled banana and whole tomato were confirmed in repeated studies, and the reason for it is unknown. The high Q_{10} values, particularly in the 10–20°C range indicates the importance of handling and storing both intact and fresh-cut products at near 0°C, if the product is not sensitive to chilling injury.

Several commodities were chilling sensitive (Hardenburg et al., 1986), so storage at 0–10°C was of concern. During the 7-day storage at the upper region of chilling temperatures, symptoms of chilling injury had not developed and the tissues appeared normal (data not shown). Samples were not transferred to 20°C to hasten the development of any chilling injury symptoms. At the non-chilling temperature, natural deterioration and infection by pathogens contributed more to deterioration of quality than any injury that may have resulted due to chilling. This relationship has also been reported with fresh-cut honeydew, papaya, and cantaloupe (O'Connor-Shaw et al., 1994). In our study of zucchini (Izumi et al., 1996), tissue slices survived better at 5°C than at 10°C because injury from chilling at 5°C was less than the natural deterioration at 10°C. These results indicate that chilling-sensitive fresh-cuts probably should be held at a chilling temper-

Table 1
Respiration rates, mg CO_2 kg^{-1} h^{-1}, of whole and fresh-cut fruits and vegetables at several temperatures

Commodity	Type	Temperature				Q_{10}	
		0°C	5°C	10°C	20°C	0–10°C	10–20°C
Green beans	Whole	13.0	29.0	52.0	131.0	4.0	2.5
	Cut	14.0	29.0	78.0	156.0	5.6	2.0
	% Change	7.7	0.0	50.0	19.1		
Zucchini	Whole	13.0	30.0	57.0	144.0	4.4	2.5
	Slices	12.0	24.0	47.0	161.0	3.9	3.4
	% Change	−7.7	−20.0	−17.5	11.8		
Cucumbers	Whole	2.7	4.3	6.6	15.0	2.4	2.3
	Slices	3.4	5.4	9.7	45.0 [a]	2.9	4.6
	% Change	25.9	25.6	47.0	200.0		
Squash (Y)	Whole	5.7	9.4	13.0	33.8	2.3	2.6
	Slices	6.5	12.3	17.7	77.2	2.7	4.4
	% Change	14.0	30.9	36.2	128.4		
Bell pepper	Whole	7.0	8.0	13.0	68.0	1.9	5.2
	Slices	7.0	6.0	14.0	105.0	2.0	7.5
	% Change	0.0	−25.0	7.7	54.4		
Tomatoes	Whole	1.6	2.3	4.7	20.2	2.9	4.3
	Slices	1.4	3.0	10.0	35.0 [a]	7.1	3.5
	% Change	−12.5	30.4	112.8	73.3		
Kiwifruit	Whole	3.2	4.6	8.6	22.0	2.7	2.6
	Slices	7.2	11.6	23.3	76.0 [a]	3.2	3.3
	% Change	125.0	152.2	170.9	245.5		
Banana w/o peel	Whole	6.9	9.0	10.9	93.7	1.6	8.6
	Slices	7.9	10.4	21.1	119.0	2.7	5.6
	% Change	14.5	15.6	93.6	27.0		
Strawberry	Whole hull [b]	7.9	10.2	23.1	101.0	2.9	4.4
	Removed	6.0	8.4	22.3	122.0	3.7	5.5
	% Change	−24.1	−17.6	−3.5	20.8		
Green seedless grapes	w/stem	2.1	3.3	5.4	19.4	2.6	3.6
	w/o stem	2.0	2.9	5.7	22.3	2.9	3.9
	% Change	−4.8	−12.1	5.6	14.9		
Peach	Whole	4.0	8.1	15.0	72.0	3.8	4.8
	Slices	6.0	10.0	18.6	120.0	3.1	6.5
	% Change	50.0	23.5	24.0	66.7		
Muskmelon (large type)	Whole	4.8	8.6	14.7	78.7	3.1	5.4
	Cubes	3.7	7.0	12.2	230.0 [a]	3.3	18.9
	% Change	−22.9	−18.6	−17.0	192.2		
Muskmelon (small type)	Whole	3.1	6.3	13.6	56.7	4.4	4.2
	Cubes	2.7	4.2	9.8	81.0	3.6	8.3
	% Change	−12.9	−33.3	−27.9	42.9		
Crenshaw	Whole	2.1	4.0	6.8	22.5	3.2	3.3
	Cubes	1.2	3.2	9.0	77.0 [a]	7.5	8.6
	% Change	−42.9	−20.0	32.4	242.2		

Table 1 (continued)

Commodity	Type	Temperature				Q_{10}	
		0°C	5°C	10°C	20°C	0–10°C	10–20°C
Honeydew	Whole	1.4	4.6	5.2	10.0	3.7	1.9
	Cubes	2.3	3.0	8.3	62.0[a]	3.6	7.5
	% Change	64.3	−34.8	59.6	520.0		
		2.5°C	5°C	7.5°C	10°C		
Lettuce[c]	Whole	2.4	2.9	5.0	7.6		
	Shredded	7.6	8.5	12.6	15.9		
	% Change	216.7	193.1	152.0	109.2		
Carrots[c]	Whole	3.7		5.2			
	Slices	6.0		10.0			
	% Change	62.2		92.3			

[a] Rate increased continually and a steady state was not attained.
[b] Hull includes sepals, bracteoles and peduncle.
[c] Cantwell, 1995.

ature where injury from chilling will be of less consequence than the deterioration that results at non-chilling temperature.

3. Controlled/modified atmosphere

Controlled atmosphere (CA) is helpful in extending the shelf-life of several whole fruits and vegetables (Kader, 1993; Saltveit, 1993), but probably will not be used with fresh-cut products because of the short handling period. However, atmospheres within film-packed fresh-cut products or fresh-cut products with edible coatings can become modified and the modified atmosphere (MA) can have similar effect as CA when the gas mixtures are similar. To better understand the response of fresh-cut products under MA, we determined the respiration rate and quality changes of several fresh-cut products held in CA at two temperatures. Samples were prepared as described above for the temperature study. The gas mixtures selected for CA had a lower level of O_2 and a higher level of CO_2 than that recommended for the whole commodity (Kader, 1993; Saltveit, 1993). Samples were monitored for 7 days and steady-state respiration rates are reported.

Carbon dioxide production of some fresh-cuts was lower in CA than in air, but with strawberry, kiwifruit, peach, and crenshaw, the CO_2 production in CA was similar or higher than those in air (Table 2). However, the O_2 uptake was lower with all samples in CA than in air and the amount of reduction ranged from 11% for strawberry to 80% for muskmelons. Based on the larger *RQ* with most samples in CA than in air, the low O_2 or high CO_2 (or a combination of both treatments) may have altered the respiratory pathway by increasing anaerobic respiration in some fresh-cuts. When the O_2 is below the extinction point, the critical O_2 level at which CO_2 production is at minimum (Blackman, 1928), anaerobic respiration becomes the dominant process. Possibly the 0.5% O_2 for peach or 1% O_2 for muskmelon was below the extinction

Table 2
Respiration rates, ml kg^{-1} h^{-1}, and respiratory quotient of fresh-cut products stored in controlled atmosphere

Commodity	°C	Atmosphere		CO_2 production	O_2 uptake	*RQ*
Spinach	5	Air		11.3	12.8	0.9
		$O_2 + CO_2$ (%)	0.80 + 10	6.8	6.8	1.0
Tomato slices	5	Air		1.6	2.1	0.7
		$O_2 + CO_2$ (%)	1.00 + 5	1.0	0.8	1.3
Strawberry hull removed	0	Air		1.9	2.9	0.7
		$O_2 + CO_2$ (%)	0.50 + 10	3.5	2.6	1.4
	5	Air		5.7	5.1	1.1
		$O_2 + CO_2$ (%)	0.50 + 10	2.5	1.9	1.3
Kiwifruit slices	0	Air		2.1	2.8	0.8
		$O_2 + CO_2$ (%)	1.00 + 5	2.3	1.8	1.3
	5	Air		2.4	2.6	0.9
		$O_2 + CO_2$ (%)	1.00 + 5	3.3	2.4	1.4
Peach slices	0	Air		3.0	3.0	1.0
		$O_2 + CO_2$ (%)	0.50 + 10	3.1	1.0	3.1
	5	Air		5.5	4.6	1.2
		$O_2 + CO_2$ (%)	0.50 + 10	3.9	1.1	3.4
Muskmelon (large type) cubes	5	Air		4.0	4.0	1.0
		$O_2 + CO_2$ (%)	1.00 + 10	2.3	0.8	3.1
	10	Air		9.6	10.6	0.9
		$O_2 + CO_2$ (%)	1.00 + 10	5.4	2.2	2.6
Crenshaw cubes	5	Air		0.8	1.8	0.5
		$O_2 + CO_2$ (%)	1.00 + 5	0.8	0.8	1.0
	10	Air		5.7	7.2	0.8
		$O_2 + CO_2$ (%)	1.00 + 5	1.7	1.6	1.1
Muskmelon (small type) cubes	5	Air		2.7	3.8	0.7
		$O_2 + CO_2$ (%)	1.00 + 10	5.5	2.1	2.7
	10	Air		5.2	7.0	0.7
		$O_2 + CO_2$ (%)	1.00 + 10	6.5	3.2	2.1
Honeydew cubes	5	Air		1.6	1.4	1.1
		$O_2 + CO_2$ (%)	1.00 + 5		0.6	
	10	Air		5.5	5.9	1.1
		$O_2 + CO_2$ (%)	1.00 + 5	2.3	2.6	1.1
Zucchini slices	10	Air		25.0	27.5	0.9
		$O_2 + CO_2$ (%)	0.25 + 0	11.4	9.22	1.2
Broccoli florets	0	Air		12.9	15.8	0.8
		$O_2 + CO_2$ (%)	0.50 + 10	6.9	8.1	0.9
	5	Air		22.6	31.0	0.7
		$O_2 + CO_2$ (%)	0.50 + 10	7.7	11.3	0.7
	10	Air		41.2	68.0	0.6
		$O_2 + CO_2$ (%)	0.50 + 10	15.3	20.5	0.7
Carrot slices	0	Air		3.0	5.1	0.6
		$O_2 + CO_2$ (%)	0.50 + 10	1.6	2.1	0.8
	5	Air		7.8	8.8	0.9
		$O_2 + CO_2$ (%)	0.50 + 10	2.8	3.7	0.8

Table 2 (continued)

Commodity	°C	Atmosphere		CO_2 production	O_2 uptake	*RQ*
Carrot slices	10	Air		12.7	31.4	0.4
		$O_2 + CO_2$ (%)	0.50 + 10	3.3	5.9	0.6
Carrot sticks	0	Air		5.9	7.0	0.8
		$O_2 + CO_2$ (%)	0.50 + 10	3.6	3.4	1.1
	10	Air		26.8	27.0	1.0
		$O_2 + CO_2$ (%)	0.50 + 10	7.3	6.9	1.1
Carrot shreds	0	Air		5.5	9.4	0.6
		$O_2 + CO_2$ (%)	0.50 + 10	2.7	2.9	0.9
	5	Air		15.3	19.6	0.8
		$O_2 + CO_2$ (%)	0.50 + 10	10.6	6.2	1.7
	10	Air		28.6	45.9	0.6
		$O_2 + CO_2$ (%)	0.50 + 10	19.1	12.4	1.5

point and anaerobic respiration became dominant. For long-term storage, induction of the anaerobic respiration is not advisable because of the potential injury to the tissue, development of off-flavors, and growth of toxic organisms. However, for a 7-day storage period, such a level of anaerobic respiration might be acceptable, but further study is needed. Peach and muskmelon appear not to be injured by the low O_2 atmosphere, as indicated by lack of deterioration, whereas 40% of those in air were deteriorated after a comparable 6-day time period (data not shown). Samples were not submitted to sensory analysis, so their sensory quality is unknown.

The benefits of modified atmosphere have been reported by other scientists. Ascorbic acid and chlorophyll contents were maintained and peroxidase activity was reduced in broccoli spears when the internal atmosphere within the film pack was ≈9% CO_2 and ≈3% O_2 (Barth et al., 1993). Quality of shredded lettuce was maintained with a 10% CO_2 and 3% O_2 controlled atmosphere (Barriga et al., 1991), and the browning of shredded cabbage was suppressed when CO_2 was increased (Kaji et al., 1993). Although benefits may occur with modified atmosphere, the extinction point of the commodity must be recognized to avoid anaerobic respiration (Joles et al., 1994; Ko et al., 1996).

Changes in atmosphere affect the physiology and biochemistry of fresh-cuts. Chlorogenic acid, which could affect flavor, had increased in fresh-cut carrots stored in oriented polypropylene film bags (Babic et al., 1993a). The increase in phenylalanine ammonia lyase activity and phenolic compounds was lower in fresh-cut carrots stored under 30% CO_2 or 0% O_2, and the increase was thought to be related to microbial spoilage (Babic et al., 1993b). Others have suggested using PAL activity to predict shelf-life of fresh-cut lettuce, because C_2H_4, which increased in fresh-cut, induced PAL (Couture et al., 1993). Low O_2 (0.5%) increased fructose 2,6-bisphosphate (F2,6-P_2) in fresh-cut carrots, and at an elevated level, F2,6-P_2 activates pyrophosphate-dependent : phosphofructokinase enzyme to catalyze the reaction from fructose 6-phosphate to fructose 1,6-bisphosphate (Kato-Noguchi and Watada, 1996). Enhancement of glycolysis by this pathway might be a mechanism for fresh-cut carrots to maintain a supply of energy, when energy from the Krebs cycle becomes limited.

Respiration rates differ widely among samples of a given commodity. Therefore, absolute respiration rates given here need to be treated with caution when calculating heat production or the requirement for gas permeability of films for a given commodity (Christie et al., 1995). The more important issue with respiration is to recognize the minimum level of O_2 that does not diminish quality or to determine at what O_2 level the anaerobic pathway becomes the dominant pathway of respiration. This becomes a concern with fresh-cuts subjected to modified atmospheres within film bags or treated with edible coatings combined with slightly elevated storage temperatures. In these circumstances, the Q_{10} may approach 3 or 4. It is certain that with the use of properly managed temperature and atmosphere regimes, respiration rates will be reduced, which will be helpful in maintaining quality.

4. Relative humidity

Since fresh-cuts have a large surface area without any skin, they have the potential for losing a substantial amount of weight, particularly at higher temperatures where a vapor pressure deficit is large. In our CA study, weight loss was minimal because the gases were humidified. In film-packed salads, the relative humidity would be expected to be high, but apparently is not sufficient because wilted leaves are often observed with these products. Edible coatings or proper packaging would be very helpful in attaining relative humidity close to 100%. A few reports have been published on films or coatings designed to reduce water-loss and also accommodate gas exchanges with the surrounding atmosphere (Banks et al., 1993; Baldwin et al., 1995; Cameron et al., 1995; Christie et al., 1995). Further research is needed to identify films or coatings that will maintain high relative humidity and also have proper gas permeability as temperature changes.

5. Micro-organisms

A number of micro-organisms have been found in fresh-cut products, including mesophilic microflora, lactic acid bacteria, coliforms, fecal coliforms, yeasts and molds, and pectinolytic microflora (Nguyen-the and Carline, 1994). The largest population is the mesophilic microflora followed by the lactic acid bacteria in processed products; however, the type and population differ with commodity, sanitation and cultural practices. Product quality is found to be acceptable even with high counts of micro-organisms, where growth is sustained by the product.

Fresh-cuts are generally rinsed in 50–200 ppm chlorine solution, but the wash does not eliminate all micro-organisms (Torriani and Massa, 1994). We found fresh-cut spinach washed with 50 ppm chlorine to contain mesophilic aerobic bacteria, psychrotrophic bacteria, *Pseudomonadaceae*, *Enterobacteriaceae*, *Vibrionaceae*, coliforms, *Micrococcaceae*, and yeasts (Babic et al., 1996). Populations of a few micro-organisms reached 10^{10} CFU g^{-1} after the spinach was held 12 days at 10°C. These micro-organisms were found inside broken cells or cells adjacent to broken tissue as noted with low temperature scanning electron micrographs. Therefore, although fresh-cuts are washed with chlorine solution, micro-organisms can survive when they are located within cells or areas not penetrated by the chemical.

Alternative treatments have been studied to control growth of micro-organisms. Gamma irradiation (2 kGy) inhibited growth of aerobic mesophilic and lactic acid microflora, but caused a loss of color of fresh-cut carrots (Chervin and Boisseau, 1994). Edible coatings containing a biocontrol agent *Candida quilliermondii* controlled *Penicillium* (McGuire, 1994), and similar coatings may be effective in controlling growth of micro-organisms on fresh-cut products. Coatings have been shown to extend the shelf-life of grapefruit, probably by keeping the fruit sanitary and maintaining high relative humidity, and such coatings have a prospective appeal for use on fresh-cuts. However, since consumers are concerned with additives, including wax, acceptability of edible coatings must be recognized.

6. Physiology and biochemistry

Fresh-cut products are subjected to stress during the physical action of processing and are marketed in a condition that can result in an undesirable product. The whitish tissue on the surface of fresh-cut carrots, termed white blush by some scientists (Avena-Bustillos et al., 1994), makes the carrot appear to be aged with an unattractive appearance. The cause of white tissue has been reported to be the formation of lignin tissue (Bolin and Huxsoll, 1991), but others have shown it to be dehydration of cells that are damaged or removed from the tissue (Tatsumi et al., 1991; Avena-Bustillos et al., 1994). Calcium treatment or modification of tissue turgidity was not helpful in reducing the white tissue (Tatsumi et al., 1993; Izumi and Watada, 1994), but sodium caseinate–stearic acid coating ameliorated the white tissue (Avena-Bustillos et al., 1994).

In fresh-cut carrots, membrane steryl lipids and phospholipids undergo changes to indicate that membrane degradation and repair processes coexist during storage (Picchioni et al., 1994). The regulation of these processes remains unknown. In fresh-cut spinach, lipid peroxidation increased, but did not affect the peroxidase–hydrogen peroxide pathway in chlorophyll degradation (Yamauchi and Watada, 1991). The peroxidase–hydrogen peroxide system was dependent on specific phenolic compounds (Yamauchi and Watada, 1994). Additional basic information is needed to complement current information in order to develop improved methods for handling and storage of fresh-cuts without loss of quality. Investigations are needed particularly at the molecular level to develop genetic lines with desirable fresh-cut product quality.

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