Compositional and Marketable Quality of Fresh-Cut Florets of Four Specialty Brassicas in Relation to Controlled Atmosphere Storage

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Abstract

***Brassica* vegetables are consumed year-round as raw salad or cooked ingredients. Four *Brassica* species were selected for this study, broccoli (*Brassica oleracea* var. *italica*), broccoli raab (*Brassica rapa* L.), choisum (*Brassica rapa* var. *parachinensis*), and gailan (*Brassica oleracea* var. *alboglabra*). While there is abundant information about broccoli, research on gailan, choisum and broccoli raab is very limited. The effect of CA (3% O_2 alone or in combination with 7 or 15% CO_2, 1% O_2 alone or combined with 15% CO_2) and air on marketable quality (overall visual, yellowing, discoloration, decay) and chemical parameters (antioxidant activity, chlorophyll, sugar, fermentative volatiles, and ammonia content) during storage at 5°C was evaluated. Products were obtained from a wholesaler, washed in chlorinated water, trimmed into florets and placed in unsealed polyethylene bags that were held in polycarbonate chambers through which humidified air or the controlled atmospheres flowed. Visual quality was evaluated after 0, 8, 12, 16 and 20 days, while chemical parameters were measured after 0, 8, 16 days. Generally, CA treatments did not affect the antioxidant activity, chlorophyll or sugar concentrations in any of the specialty brassicas studied. On the other hand, both ammonia content and visual quality evaluations were affected by atmosphere composition. Florets stored in low oxygen (3% O_2) often had the best visual quality but generally all atmospheres maintained better marketable quality than air storage. The 3% oxygen CA improved marketability to about 16 days. Low oxygen delayed postharvest and post-cutting deterioration of florets from all *Brassica* species, and based on changes in ammonia concentrations, was considered beneficial to maintain quality of fresh-cut brassicas stored at 5°C.**

INTRODUCTION

Brassica vegetables are perishable commodities and postharvest quality loss is mainly due to dehydration and floret yellowing (Page et al., 2001). *Brassica* vegetables are rich in health-promoting compounds, such as glucosinolates, flavonoids and vitamins A, C, and E and these have high antioxidant and free-radical scavenging properties (Posedek et al., 2007). These compounds have gained much attention in recent years because of their purported role in the prevention of cardiovascular disease and cancer. However, reduction of these compounds has been reported during postharvest handling, processing and storage of broccoli (Rangkadilok et al., 2002; Vallejo et al., 2003).

Broccoli can deteriorate rapidly after harvest, and low temperatures (0 to 4°C) are essential to maintain quality (Cantwell and Suslow, 1997). CA storage is very effective in maintaining *Brassica* quality, and can double postharvest life (Izumi et al., 1996; Toivonen and Forney, 2004). Ideal atmospheres to maintain quality were 1-2% O_2 with 5-10% CO_2 at 0 to 5°C (Cantwell and Suslow, 1997), but if O_2 drops below 1%, off-odors develop (Forney and Rij, 1991). Low O_2 atmospheres were useful in maintaining Vitamin C and chlorophyll contents (Barth et al., 1993). In general the recommended postharvest conditions for maintaining broccoli quality also maintain the important phytonutrients (Jones et al., 2006; Serrano et al., 2006).

While there is substantial research on broccoli, there is relatively little on other specialty brassicas. Zong et al. (1998) reported on some of the basic physiology and temperature responses of choisum and gailan. As expected, low temperature was critical to maintaining quality. O'Hare et al. (2000) studied the response of several Asian brassicas to CA and found that pakchoy, tatsoi and choisum responded well to high CO_2 atmospheres while mizuna and mibuna did not. Cefola et al. (2010) reported that 3% O_2 was more beneficial to maintaining quality of broccoli raab than air or 3% O_2 in combination with 10% CO_2.

Brassica vegetables are consumed cooked or raw and some are prepared as fresh-cut products. This study was conducted to compare the performance of florets of three specialty brassicas to those of broccoli when stored in a range of controlled atmospheres.

MATERIALS AND METHODS

Four *Brassica* species were selected for this study, including broccoli (*Brassica oleracea* var. *italica*), broccoli raab (*Brassica rapa* L.), choisum (*Brassica rapa* var. *parachinensis*), and gailan (*Brassica oleracea* var. *alboglabra*). All products were obtained through a wholesaler from product grown in California (broccoli, broccoli raab) and in Mexico (choisum, gailan). Products had been liquid iced and transported in refrigerated trucks. Products were 2 to 4 days from harvest when the experiments were conducted. Two experiments were carried out to compare the visual and compositional changes of the florets in a range of controlled atmosphere (CA) conditions. Products were held at 0°C room overnight, after removing ice from the boxes and trimming into florets. All florets contained leaves except broccoli (Fig. 1). To minimize weight loss, florets were placed in small unsealed LDPE bags (6 florets per bag) in large polycarbonate containers at 5°C, through which a humidified air or CA flowed. Flow rate was based on respiration rates in air. Five CA conditions were compared with air: 1 or 3% O_2, 3% O_2 +7 or 15% CO_2, and 1% O_2 +15% CO_2. Visual quality was evaluated after 0, 8, 12, 16, and 20 days; composition was determined on days 0, 8, and 16.

Visual quality was scored on a 9 to 1 scale, where 9=excellent, fresh appearance, 7=good, 5=fair, 3=fair (usable but not salable), 1=unusable. Intermediate numbers were assigned where appropriate. A score of 6 was considered the limit of marketability. One visual quality score was given to an entire sample. Decay was scored 1 to 5 scale where 1=no decay, 2=slight decay, but product salable, <2% affected; 3=moderate decay, product useable but not salable, <5% affected, 4=moderately severe, <15% affected and 5=severe, unusable. Discoloration on the cut ends was scored on a 1 to 5 scale, where 1=none, 2=slight (not reduce salability), 3=moderate (limit of salability), 4=moderately severe, and 5=severe. Yellow of beads or leaves was scored on a 1 to 5 scale where 1=green, 2=slight yellowing (1-2 beads per floret), 3=moderate yellowing (3-5 beads per floret), 4=moderately severe and 5=severe.

Total sugars were analyzed on ethanol extracts by a phenol-sulfuric colorimetric method (Buysse and Merckx, 1993) with color development at 490 nm and glucose as a standard. Ammonia concentrations were determined from water extracted tissue by reaction with a phenol nitroprusside reagent and alkaline hypochlorite (Beecher and Whitten, 1970) using ammonium sulfate to construct a standard curve. The antioxidant assay was performed on 5 g frozen tissue based on the procedure described by Brand-Williams et al. (1995). Tissue was homogenized in methanol:water solution (80:20) 2 mM in sodium fluoride for 1 min, and centrifuged at 5°C and 12000 ×g for 5 min. The diluted sample (50 µl) was pipetted into 0.950 ml of DPPH solution to initiate the reaction. The absorbance was read after 20 min at 515 nm. Trolox was used as a standard and antioxidant activity reported in mg of Trolox equivalents per 100 g fresh weight. Total ascorbic acid (vitamin C) was determined on 5 g tissue extracted in 15 ml 2% oxalic acid, centrifuged and supernatant held at -80°C until determination of ascorbic acid and dehydroascorbic acid by HPLC (Tausz et al., 1996).

Chlorophyll was analyzed on 5 g samples placed in capped 50 ml tubes and frozen at -80°C until extracted in 80% acetone containing a few mg of magnesium carbonate with an Ultra-Turrex homogenizer. Tissue was extracted twice and extracts combined. Samples were centrifuged, and chl a and b were determined at 663.2 and 646.8 nm and carotenoids at 470 nm (Wellburn, 1994). For fermentative volatiles, 5 g chopped tissue was placed in 22 ml glass test tube, sealed with rubber stopper and stored at -20°C until analyzed. After 1 h incubation in 65°C water bath, a 1 ml headspace gas sample was taken and injected into a FID GC (Shimadzu GC-14A); FID temp. 150°C, injector temp. 130°C, oven temp. 80°C. 5% CBWX 20M on Carbograph 1AW20 80/120, 6'×1/8"×0.085" AT STEEL column (Alltech). Ethanol and acetaldehyde were identified by co-chromatography with standards and quantified by a range of concentrations of standards in 5 ml of water.

For statistical analysis, four replicates of all treatments were used. Data were analyzed by ANOVA and means separated by LDS.05. 1 replication = 6 florets.

RESULTS AND DISCUSSION

The visual quality of the four brassicas is generally maintained better under CA conditions than in air at 5°C (Fig. 2). Changes in visual quality were associated with yellowing, decay, discoloration and other defects (data not shown). Broccoli raab quality, in particular, was clearly benefited by CA conditions. Initial chlorophyll concentrations were lowest in broccoli florets without leaves (16.4 mg/100 g) and similar among the other 3 brassicas (26.3, 27.3, 26.5 mg/100 g for broccoli raab, choisum and gailan, respectively). Storage changes were small and not affected by CA, with average decrease in chlorophyll of 8.5, 5.3, 7.7 and 6.0% over 16 days for broccoli, broccoli raab, choisum and gailan, respectively.

Ammonia can be used as an indicator of stress during controlled atmosphere storage and it has been shown that broccoli is very tolerant of CA conditions (Cantwell et al., 2010). In this study, the increase in ammonia concentrations was higher in broccoli raab and choisum than in broccoli or gailan (Fig. 3). The 15% CO_2 atmospheres resulted in the greatest increases in ammonia in all four brassicas. Ethanol concentrations were low in all four of the brassicas under all storage conditions on day 12 and 16 (data not shown). Higher concentrations of ethanol were measured in air-stored broccoli raab, choisum and gailan (average on day 16 of 61, 83 and 104 µmol/100 g, respectively) and in gailan stored in the 1% O_2 + 15% CO_2 atmosphere (173 µmol/100 g) than in broccoli florets (average 12 µmol/100 g on day 16). Broccoli florets had the lowest ethanol but the highest acetaldehyde concentrations (average 80 µmol/100 g on day 16). However, all fermentative volatile concentrations remained relatively low up to 16 days independent of the storage atmosphere.

Sugars are important to the flavor of the brassicas and they differed in their sugar content with initial values of 15, 8, 3 and 13 mg/g for broccoli, broccoli raab, choisum and gailan, respectively (Fig. 4). Sugar content of choisum florets did not change due to time or storage atmosphere. Over 16 days storage, average sugar concentrations declined 33, 31 and 18% in florets of broccoli, broccoli raab and gailan, respectively. The 15% CO_2 atmospheres generally resulted in higher sugar retention, while sugar content was similar in the other storage conditions for a given *Brassica*.

Vitamin C content is very high in these brassicas, with initial concentrations of 273 and 280 mg/100 g in broccoli and broccoli raab florets (Table 1). Vitamin C declined during storage with an average 17 and 37% loss after 8 and 16 days in broccoli; corresponding values for broccoli raab were a 42 and 46% decrease after 8 and 16 days. The low O_2 atmospheres helped retain higher vitamin C content during storage in some cases, but the differences, although significant, are not very important. Antioxidant activity remained stable or increased during storage (Table 1). The data for all 4 brassicas indicate that the antioxidant activity is very stable even under conditions where the product is clearly past marketable quality (i.e., broccoli raab in air at 16 days).

CONCLUSIONS

At a storage temperature of 5°C, CA can be useful to retard yellowing, discoloration and other defects in green tissues. The 4 brassicas in this study were generally very tolerant of both low O_2 and high CO_2 conditions**.** The CA treatments did not affect the antioxidant activity, chlorophyll or sugar concentrations in any of the specialty brassicas studied. Ammonia concentrations and visual quality evaluations were affected by atmosphere composition. Florets stored in low oxygen (3% O_2) often had the best visual quality but generally all atmospheres maintained better marketable quality than air storage. The 15% CO_2 atmospheres resulted in the greatest changes in the stress indicator ammonia.

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Tables

Table 1. Vitamin C concentrations and antioxidant activities of florets of broccoli, broccoli raab, choisum and gailan stored at 5°C in air or controlled atmospheres. Data are averages from 4 replicates with mean separation for a constituent and *Brassica* type by LSD.05.

Product/CA	Vitamin C (mg/100 g)			Antioxidant activity (mg Trolox/100 g)		
	Day 0	Day 8	Day 16	Day 0	Day 8	Day 16
Broccoli						
Air	267	194	170	58	73	78
3% O_2	245	264	187	69	71	82
1% O_2	276	272	186	71	73	68
3% O_2 + 7% CO_2	268	140	150	71	75	67
3% O_2 + 15% CO_2	300	226	169	67	70	67
1% O_2 + 15% CO_2	280	262	176	63	69	67
Average	273	226	173	67	72	72
LSD.05	27			10		
Broccoli raab						
Air	286	163	126	71	114	111
3% O_2	271	182	156	81	124	111
1% O_2	277	164	171	88	118	104
3% O_2 + 7% CO_2	284	141	128	87	112	85
3% O_2 + 15% CO_2	270	159	164	85	107	86
1% O_2 + 15% CO_2	289	172	160	84	75	86
Average	280	163	151	83	112	97
LSD.05	22			20		
Choisum						
Air	--	58	63	77	77	111
3% O_2	--	89	74	70	105	116
1% O_2	--	104	65	67	104	96
3% O_2 + 7% CO_2	--	94	58	67	92	99
3% O_2 + 15% CO_2	--	90	55	75	91	52
1% O_2 + 15% CO_2	--	93	67	72	99	59
Average		88	64	72	95	89
LSD.05		12		12		
Gailan						
Air	--	213	180	128	152	142
3% O_2	--	215	220	102	167	154
1% O_2	--	203	208	115	163	150
3% O_2 + 7% CO_2	--	183	111	119	156	160
3% O_2 + 15% CO_2	--	182	149	114	165	167
1% O_2 + 15% CO_2	--	188	164	118	161	174
Average		197	172	116	161	158
LSD.05		20		19		

Figures

Fig. 1. Appearance of broccoli (upper left), broccoli raab (upper right), choisum (lower left) and gailan (lower right) florets on day 0.

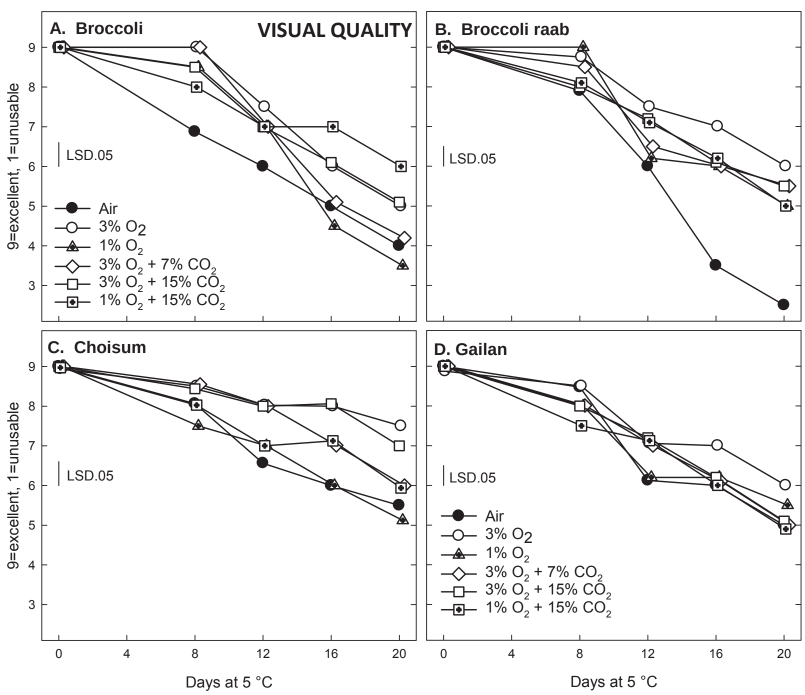

Fig. 2. Changes in visual quality of florets of four brassicas stored in air or controlled atmospheres at 5°C. A score of 6 is the limit for marketable quality. Data are averages of 4 replicates of 6 florets.

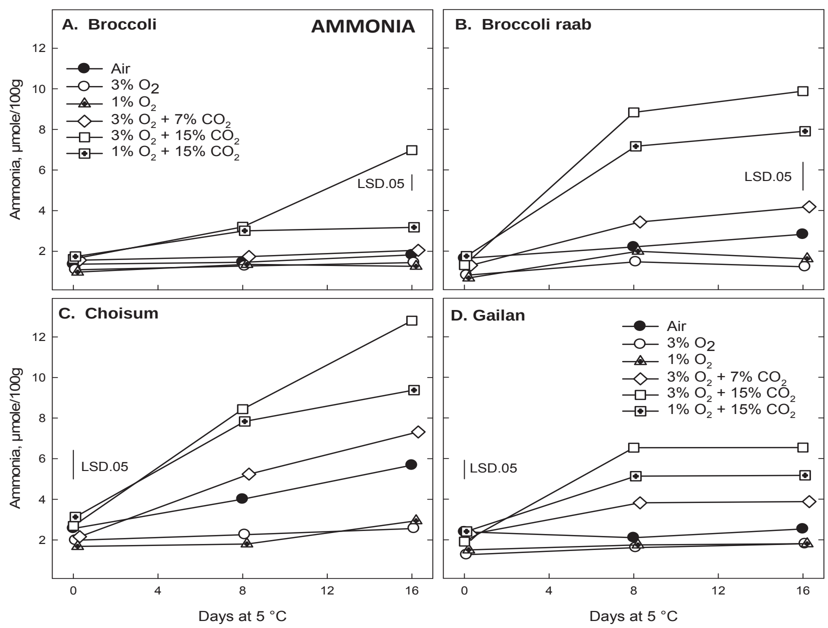

Fig. 3. Changes in ammonia concentrations of florets of four brassicas stored in air or controlled atmospheres at 5°C. Data are averages of 4 replicates of 6 florets.

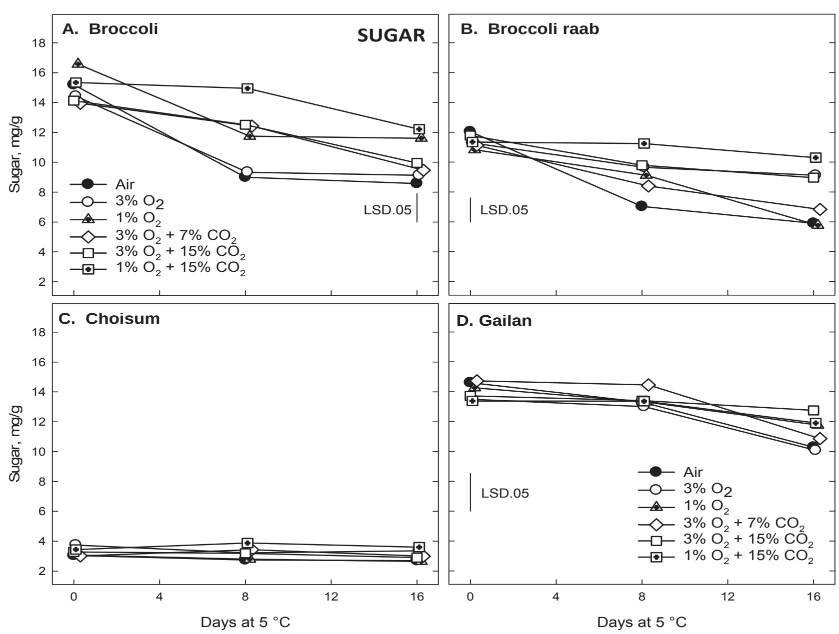

Fig. 4. Changes in sugar concentrations of florets of four brassicas stored in air or controlled atmospheres at 5°C. Data are averages of 4 replicates of 6 florets.