ABSTRACT: Three corn and 2 broccoli cultivars were steam blanched for various times and evaluated for residual enzyme activity. Lipoxygenase was inactivated in 4 min in supersweet corn, while sweet corn required a 6-min blanch; peroxidase was inactivated in 8 min. Inactivation of broccoli lipoxygenase, peroxidase, and cystine lyase was achieved in 90 s. Blanched samples were stored 9 mo at −18 °C, then analyzed for color, texture, hexanal, free fatty acids, and sugars. Firmness increased significantly with blanching in both commodities, then declined. Short blanch treatments targeting lipoxygenase inactivation positively affected color and texture of both corn and broccoli. Changes in current industry practices are recommended.

Key words: corn, broccoli, enzymes, blanching, frozen storage

Introduction

BLANCHING VEGETABLES TO INACTIVATE ENDOGENOUS ENZYMES is a critical step prior to freezing. However, the severity of the process should be limited in order to maintain color, texture, flavor, and nutritional quality. Peroxidase (POD) is used commercially as an index of blanching adequacy; however, recent work (Theerakulkait and others 1995; Lim and others 1989; Williams and others 1986) has shown that other enzymes, such as lipoxygenase (LPO), may be better correlated to quality changes. Theerakulkait and others (1995) found that LPO in sweet corn catalyzed off-odor formation, and blanch treatments targeting inactivation of this enzyme enhanced desirable characteristics, such as sweetness and corn flavor. Addition of POD extracts to corn homogenates did not result in a significant difference in sensory quality. Lim and others (1989) found that cystine lyase (CL) is the principal enzyme responsible for off-odor production in broccoli, and Ramirez and Whitaker (1998) determined that cystine lyase is more thermolabile than POD. There is little published evidence of correlation between residual POD activity and undesirable quality in frozen vegetables.

The choice of LPO as a blanching indicator in many vegetables would result in significantly shorter blanch times, therefore improving nutritional and sensory quality, decreasing energy and water use, and allowing for more efficient processing production rates. Barrett and Theerakulkait (1995) found that LPO inactivation in supersweet corn at 93 °C was accomplished in 6 to 9 min while POD inactivation under the same conditions required 18 to 20 min. Inactivation of POD and LPO at 93 °C in green beans required times of 2.0 and 0.5 min, respectively.

Cultivars may vary widely in initial enzyme activity and quality. Barrett and Theerakulkait (1995) noted that 2 cultivars of green beans had significantly different initial enzyme activities. Therefore, target blanch times varied by cultivar. Azanza and others (1994) found significant differences between inbred supersweet lines and commercial supersweet and sweet corn cultivars for sweet corn aroma, texture, and flavor. These authors determined that sweetness was strongly correlated with sweet corn flavor, sugar, and sucrose content, while grassy flavor and aroma were logarithmically correlated with dimethyl sulfide (DMS) concentration. DMS is a product of the thermal degradation of S-methylmethionine (Bills and Keenan 1968), produced during the cooking process and associated with overall “corn-like” aroma (Flora and Wiley 1974).

Results

Enzyme activity

Enzyme activity decreased with longer blanching time in both corn-on-the-cob and broccoli, regardless of cultivar (Tables 1 and 3). Analysis of variance (ANOVA) revealed significant differences among corn cultivars (Table 2) for LPO (p < 0.01) and POD (p < 0.001), as well as among blanching times (Table 1) for both LPO and POD (p < 0.001) activity.

In a comparison of mean activity levels for the 3 corn cultivars (Table 1), LPO activities in corn that was blanched for 4, 6, and 8 min were not significantly different. Therefore, it might be concluded that the 4 min blanch was sufficient to inactivate LPO. Corn POD was more heat resistant than LPO, and complete POD
inactivation required an 8 min blanch. Therefore, use of POD as the target enzyme for blanching adequacy of corn would result in a requirement for twice the process time (8 min in contrast to 4 min) than if LPO were the target enzyme.

Cultivar played an important role in enzyme activity. The sweet corn cultivars A and B had significantly higher activity of both LPO and POD than the supersweet cultivar C (Table 2). A comparison of mean blanch times showed that there was no significant difference in LPO activity of cultivars A and B. However, cultivar B, followed by A and C, demonstrated significantly higher POD activity.

LPO activity, which declines with increasing blanch time, may result in the formation of short chain alcohols (for example, hexanal) that confer grassy flavor and aroma (Azanza and others 1994). Earlier work by our group (Theerakulikait and Barrett 1995) illustrated that LPO activity relates more to corn quality changes during frozen storage and is inactivated in shorter times than POD.

Broccoli blanch times showed significant differences for the following enzyme activities (Table 3): floret LPO (p < 0.001), floret POD (p < 0.01), and floret CL (p < 0.01), stalk LPO (p < 0.001), stalk POD (p < 0.001), and stalk CL (p < 0.01). Broccoli cultivar was a significant factor only in the activity of stalk LPO (p < 0.05), and the other enzymes showed no significant cultivar effect (Table 4).

Activity of POD, LPO, and CL in broccoli florets declined significantly between the 0- and 45-s blanch (Table 3). Residual activity of all 3 enzymes was detectable in samples of both florets and stalks exposed to 45 s blanching. However, comparing means of both cultivars showed the only significant activity was that of floret LPO in the 90 s blanch treatment (Table 3). Trends for enzyme inactivation in floret in contrast to stalk material were similar; LPO activity was essentially the same in florets and stalks following a 45-s blanch. CL activity was initially higher in the floret material than stalk material of unblanched samples. The 45-s blanch, however, resulted in a significant reduction in both floret and stalk, with slightly higher residual activity in the stalk. CL activity in the stalks was significantly lower following the 90-s blanch than after the 45-s treatment. Ramirez and Whitaker (1998) blanched broccoli for 2 min at 90, 80, and 63 °C and found total inactivation of CL after 30 s at either 80 or 90 °C and after 3 min at 63 °C.

POD activity was initially similar in both stalk and florets; however, the 45-s blanch left more residual activity in the stalks than the florets. It may be that slower heat penetration into stalk material in contrast to florets is responsible for the presence of residual activity. Again, comparing means of all blanch times (Table 4) demonstrated LPO activity in cultivar A broccoli stalks was significantly higher than that in cultivar B.

The broccoli results are interesting because in this case, LPO inactivation in the floret material actually required a longer blanch than POD inactivation. Wu and Whitaker (1986) found that broccoli did not have significant amounts of LPO, but they did not evaluate time required for inactivation. These authors found that CL was less stable than POD and lipoase at 70 and 80 °C. However, the presence of more than 1 isozyme of CL may have allowed for residual activity. Lim and others (1989) found that CL was the enzyme most responsible for off-aroma formation in blanched broccoli homogenates. Results of the present study indicate that both CL and POD became inactive in a relatively short time. Further investigation is warranted to determine whether broccoli LPO activity is a catalyst for off-aroma development in broccoli. If LPO is the enzyme most responsible for frozen storage quality changes, a blanch targeting POD inactivation may not be adequate to inactivate LPO.

### Hexanal and dimethyl sulfide

None of the blanched corn samples contained detectable amounts of dimethyl sulfide (DMS). However, hexanal was present. Hexanal content (p < 0.05) was significantly different among corn cultivars, and a comparison of mean blanch times (Table 2) shows that cultivar C was significantly higher in hexanal concentration than A or B. The unblanched sample was significantly higher in hexanal content (Table 1) than those blanched 2 or 4 min. However, the hexanal content increases again in the 6 and 8 min blanched samples.

Other investigators have found that blanching vegetables results in a rapid loss of volatiles and a detectable change in aroma. Azanza and others (1994) reported low levels of both DMS and hexanal in commercial corn samples and attributed results to volatile loss during thermal processing. Shamaila and others (1996) determined that water blanching carrots for 60 s resulted in at least a 50% loss in most volatiles.

There was no detectable DMS in either unblanched broccoli florets or those blanched for 45 s; however, it was detectable at longer blanch times (Table 3). The effect of cultivar was not found to be significant in production of DMS. Usually considered a defect, the presence of sulfur compounds is often responsible for “off-aromas” in foods and beverages (Goniak and Noble 1987). Published thresholds for DMS in beer include ranges from 21 to 68 μg/L, while 25 μg/L is the established threshold in wine, both of which are much higher than the amount detected in this study.

There was a significant difference between broccoli blanch times in terms of hexanal content (p < 0.01). Comparison of means of the 2 cultivars (Table 3) indicates that hexanal concentration decreased significantly when blanching broccoli for as little as 45 s and remained constant up to 180 s of blanching.
Quality Evaluation of Corn and Broccoli

Sensory and Nutritive Qualities of Food

Statistical analysis of data for sugar and free fatty acid content is limited, because evaluations of only 1 of the 2 process replicates occurred. Of the fatty acid and sugar moieties evaluated in blanched and frozen sweet corn, only sucrose content varied significantly (p < 0.05) with blanch time. It is noteworthy that when comparing means of the 3 cultivars, sucrose content increased from 1.08% in the unblanched cobs to 5.90% in the 4 min blanched cobs; there was no difference between sucrose content in samples blanched for 4, 6, or 8 min (data not shown). There was no significant difference between corn cultivars for free fatty acids or sucrose. The total mono- and disaccharide content of the blanched samples of the cultivar C (supersweet) ranged from 7% to 9%, while B (sweet) averaged 2.7% to 3.7% and A (sweet) ranged from 4% to 8.8%. Evaluations of one process replicate of the broccoli samples found that there were significant differences between cultivars in dextrose content (p < 0.01) and blanch times produced significant differences in linoleic acid (C18:2) concentration (p < 0.01). None of the other free fatty acids or sugars analyzed showed differences as an effect of either cultivar or blanch time (data not shown). Cultivar A had significantly higher concentrations of the monosaccharides fructose and dextrose, and of total mono- and disaccharides, which may contribute to observed differences in sensory flavor. A 45-s blanch treatment significantly reduced both linoleic acid and dextrose concentration to a level that remained constant with additional blanching.

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Blanched samples of cultivar C were clustered in the center of the diagram. Corn blanched for 4 min were significantly firmer than those blanched for 2, 6 and 8 min. Cultivar C samples blanched for 8 min (C8) were higher in chroma and hue (saturated orange color) than those of the shorter blanch treatments and had the least enzyme activity. Cultivar B still had high POD activity following the 2-min blanch (B2). The top left side of Fig. 1 contains a cluster of the cultivar B, the firmest of the 3 cultivars. This cultivar had a very low L* lightness value, indicating that it is quite dark in color.

**Broccoli.** Broccoli enzyme activities were all related (Fig. 2) and the correlation between them was r > 0.87. In addition, activity of all the enzymes except CLs correlated with hexanal concentration (r > 0.87). The 1st factor in the PCA diagram relates to enzyme activity, which explains 78.6% of the variance; the 2nd factor relates to firmness and color (chroma and L* lightness value), which explain 12.4% of the variance.

Unblanched samples of both cultivars (A0 and B0) appear opposite all the blanched samples on the right-hand side, near the vectors corresponding to floret and stalk enzyme activity. Unblanched cultivar A broccoli was higher in PODf, CLf, and hexanal and lowest in chroma and firmness than B0. Unblanched cultivar B had higher LPOf, LPOs, PODs, and CLs activity and had the highest L* lightness value (lightness). Firmness (Factor 2) was highest at the top of the PC and decreased towards the bottom; therefore, unblanched cultivar B was a bit firmer than A.

Figure 2 illustrates that the primary effect of blanching time was on broccoli firmness and chroma (saturation or vividness). The relationship between enzyme activity and blanch time is obvious in this PCA. Both cultivars of broccoli blanched for 45 s still retained some residual enzyme activity, while samples blanched longer had none. After 90 s of blanching, enzyme activity was undetectable and firmness and chroma changes predominated.

Broccoli firmness increased with blanch time to 90 or 135 s, depending on the cultivar, and then decreased. Chroma or saturation generally increased with blanch time. There is a clear separation of all the blanched cultivar A and B samples.

**Conclusions**

There were significant differences among the 3 corn cultivars evaluated. These cultivars also behaved differently as a function of blanching time. Corn POD inactivation in all 3 cultivars required an 8-min blanch, while LPO inactivation required a 6-min blanch in cultivars A and B and a 4-min blanch in C. Reducing blanch time is desirable from a sensory standpoint, because longer blanch treatments generally reduce firmness and fresh corn attributes and increase cooked flavors. Sucrose content increased with blanch times up to 4 min and, then, was relatively constant. After 9 mo of storage at 0°F (−18°C), cultivar C required the shortest blanch, was the firmest, and showed the least number of undesirable attributes. Instrumental texture analysis of the means of the 3 cultivars found that firmness increased with blanching up to 6 min and then declined.

The 2 broccoli cultivars responded to blanching time increases in a similar fashion, which resulted primarily in textural changes. Broccoli firmness increased with blanching up to 90 to 135 s and then decreased. Complete inactivation of broccoli enzymes required a 90-s blanch. Dimethyl sulfide concentration increased significantly between 90 and 135 s, which presents an argument for maintaining broccoli blanch times at 90 s to avoid off-flavor production.

Overall, short blanch treatments positively affected both broccoli and corn color, and longer blanch times resulted in undesirable effects on color. Blanch times for both corn and broccoli may be significantly reduced from current industry practices. Reduced blanch times would benefit the industry by decreasing energy costs, water use, and clean-up cost and would result in a more desirable product.
Materials and Methods

Materials

Three cultivars of sweet corn-on-the-cob (Zea mays), designated A (sugary or su), B (sugary or su) and C (supersweet or su sh2) were harvested at 77%, 76%, and 78% moisture, respectively, in Darien, Wis. (U.S.A.), water-cooled, and shipped on ice overnight to the University of California (Davis, Calif., U.S.A.). Two cultivars of broccoli (Brassica oleracea), designated A and B, were harvested in Watsonville, Calif. (U.S.A.), and shipped on ice the same day to the University of California (Davis). Samples were sorted, cleaned, and washed in the Pilot Plant of the Dept. of Food Science and Technology. Two 2-in segments were obtained from the central portion of each corn ear using an electric saw before processing. Broccoli samples consisted of both floret material and approximately 1 in (2.54 cm) of stalk just below the floret. Some enzyme analyses were carried out on the floret and stalk material separately, and all other analyses were conducted on the floret with 1 in of stalk.

Corn-on-the-cob blanching was carried out in a pilot steam blancher (Key Technology, Walla Walla, Wash., U.S.A.) at 100 °C for 0, 2, 4, 6, and 8 min, while times for blanching broccoli samples were 0, 45, 90, 135, and 180 s. Two process replicates were run for each blanch time treatment for both commodities and results were averaged. Fatty acid and sugar analysis were carried out on one process replicate, other analyses were done on both replicates. Following blanching, all samples were cooled in ice-water for 3 min, drained, and frozen on metal trays in a blast freezer (−44 °C) until internal temperature reached 0 °C (−18 °C). Samples were stored in sealed polyethylene freezer bags at 0 °C (−18 °C). A subsample was analyzed immediately for enzyme activity and the remainder stored for 9 mo before quality evaluation.

Sigma Chemical Company (St. Louis, Mo., U.S.A.) provided linoleic acid, Tween-20, polyvinyl-polypyrrolidone (PVPP), guaiacol, H₂O₂, CuSO₄·5H₂O, and crystallized bovine serum albumin. All experiments used deionized, distilled water, and chemicals of reagent grade.

Enzymes

Immediately after blanching and cooling, corn and broccoli samples were analyzed for residual enzyme activity. Frozen, stored samples were not evaluated for enzyme activity. LPO and POD activity were determined in corn-on-the-cob kernels and LPO, POD, and CL were evaluated in broccoli florets and stalk.

Corn lipoygenase

Extraction of corn LPO was carried out according to the method of Theerakulkait and Barrett (1995), with slight modifications. Acetone powder (2 g) was homogenized in a ratio of 1:10 (w/v) with 0.2 M Tris-HCl (pH 8, 4 °C) for 3 min using a Polytron homogenizer at 15,000 rpm. The extract was centrifuged for 1 h at 34,540 × g (4 °C), and the supernatant was kept on ice until analyzed.

LPO activity was assayed using the method of Chen and Whitaker (1986), with modifications as described in Theerakulkait and Barrett (1995). The initial rate of conjugated diene formation was measured from the linear change in absorbance at 234 nm. Equipment used for the assay was a double beam UV-VIS scanning spectrophotometer (Model UV-2102 PC, Shimadzu, Japan) and a 1-cm path length quartz cuvette. The amount of enzyme producing a change in absorbance of 1.0/ min/g of acetone powder at 234 nm, under the assay conditions, defined one unit of enzyme activity.

Broccoli lipoygenase

Extraction of LPO from broccoli does not require acetone powder preparation because of the relatively low content of lipid and starch. The extraction buffer consisted of 1L of phosphate (0.05 M K2HPO4)-citric acid (0.05 M)-NaCl buffer (0.86 M) adjusted to pH 6.4 with 2.5 M KOH. Twenty grams of broccoli florets and 2 g of PVPP were homogenized with 40 mL of cold (4 °C) extraction buffer in a ratio of 1:0.1:2 w/w/v. After blending for 40 s, the homogenate was filtered through 2 layers of cheesecloth; the volume was measured, and then the homogenate was centrifuged (4 °C) at 27,000 × g for 30 min. The supernatant was filtered through Whatman #1 paper and kept on ice until analyzed. Broccoli LPO was assayed using the method of Chen and Whitaker (1986) as described above.

Corncysteine lyase

CL in broccoli was extracted and assayed according to the method of Ramirez and Whitaker (1998). Twenty g of broccoli (either florets or stalks) were homogenized for 1 min at maximum speed in 40 mL of cold extraction buffer containing 0.86 M NaCl and 2 g PVPP. The homogenate was strained through 2 layers of cheesecloth; the volume was measured and then the solution was centrifuged (4 °C) at 27,000 × g for 30 min. The supernatant was filtered through Whatman #1 paper and kept on ice until analyzed. The substrate solution was prepared in the same way as described above and the POD assay was conducted in the same manner as corn. The definition used for 1 unit of enzyme activity was the amount of enzyme that produced a change in absorbance of 1.0/min/g of acetone powder at 420 nm, under the assay conditions.

Broccoli peroxidase

The same POD extraction buffer utilized for corn was used for broccoli. Twenty g of broccoli florets and 2 g of PVPP (polyvinylpyrrolidone) were homogenized with 40 mL of cold (4 °C) extraction buffer in a ratio of 1:0.1:2 w/w/v. After blending for 1 min, the homogenate was filtered through 2 layers of cheesecloth; the volume was measured and then the solution was centrifuged (4 °C) at 27,000 × g for 30 min. The supernatant was filtered through Whatman #1 paper and kept on ice until analyzed. The substrate solution was prepared in the same way as described above and the POD assay was conducted in the same manner as corn. The definition used for 1 unit of enzyme activity was the amount of enzyme that produced a change in absorbance of 1.0/min/g at 420 nm, under the assay conditions.

Broccoli cystine lyase

CL in broccoli was extracted and assayed according to the method of Ramirez and Whitaker (1998). Twenty g of broccoli (either florets or stalks) were homogenized for 1 min at maximum speed in 40 mL of cold extraction buffer containing 0.86 M NaCl and 2 g PVPP. The homogenate was strained through 2 layers of cheesecloth, centrifuged at 27,000 × g and filtered. All operations were carried out at 4 °C. The standard reaction mixture contained the following constituents in a volume of 1 mL: 150 μmol Bicine (pH 8.4), 0.025 μmol PALP, 12 μmol L-cystine and 10–100 μg enzyme extract. After incubating the mixture at 30 °C for 10 min, the addition of 1 mL 10% TCA terminated the reaction. After centrifugation to remove precipitated protein, an aliquot of the supernatant was assayed for pyruvate colorimetrically by the formation of dinitrophenylhydrazone (Friedemann and Haugen 1943). Activity was expressed in terms of μmol of pyruvate per minute.
Hexanal and dimethyl sulfide

Flavor volatiles were determined in frozen, stored corn and broccoli samples according to the method of Suan and Russell (1997). A 5-g portion of broccoli or corn was placed into a 20 mL headspace vial (Alltech, Deerfield, Ill., U.S.A.). The vial was sealed with a 19-mm Teflon-faced septum (Alltech, Deerfield, Ill., U.S.A.) and a 20-mm aluminum seal (Alltech, Deerfield, Ill., U.S.A.). The sample equilibrated in a temperature controlled water bath at 35 °C for 20 min. The samples were oscillating at 150 rotations per minute during equilibration. A 2-mL portion of the headspace was drawn into a 5-mL gas tight syringe (Hamilton Co., Reno, Nev., U.S.A.) for gas chromatographic analysis. Before injection, the sample was cryofocused by placing a portion of the column in liquid nitrogen. The 2-mL headspace sample was inserted through the injector septum and injected at a rate of 1 mL/min. After the injection, the sample was cryofocused for an additional 3 min.

Samples were analyzed using a gas chromatograph (GC) (Hewlett Packard HP 5890, Avondale, Pa., U.S.A.) equipped with a flame ionization detector (FID). The injector temperature was consistent at 200 °C and that of the detector at 300 °C. The GC oven temperature was held at 40 °C for 5 min, increased to 170 °C at a rate of 7 °C/min, and then held at 170 °C for 3 min. Hydrogen was the carrier gas for the FID. Equipment used to perform separation was a DB-WAX open tubular fused silica column, 30 m × 0.25 mm inside dia, 0.25-mm film thickness (J&W Scientific, Folsom, Calif., U.S.A.). A Hewlett Packard HP 3392A integrator accomplished peak integration.

Hexanal and dimethyl sulfide reference standards (Aldrich, Milwaukee, Wis., U.S.A.) were diluted in appropriate solvents of water and carbon tetrachloride, respectively. Serial dilutions were made and subjected to GC analysis. Hexanal standards were analyzed as described above and DMS standards were subjected to direct injections. Standard curves for detector and integrator responses were then used to normalize the integrator responses to DMS and hexanal peaks in the chromatograms to the standard curve concentrations.

Free fatty acids

Only 1 of the 2 process replicates of each treatment was analyzed for fatty acid content. Free fatty acids were analyzed according to the method of Deeth and others (1983). One to 2 grams of sample were weighed and combined with 5-mL internal standard (C17), 0.2 mL H2SO4, and 2.5-g anhydrous sodium sulfate and then capped and mixed for 30 min using a vortex mixer and a sonic bath. Five mL of hexane was added, and the mixture was shaken and then centrifuged if necessary to separate aqueous and organic components. One g of activated carbon was added to an extraction column (Alltech, Deerfield, Ill., U.S.A.), and the organic layer was added and pulled through with gentle vacuum. The column was washed with 2.5 mL portions of hexane/ethyl ether, and the eluent was discarded. The alumina was dried by drawing a gentle vacuum for a few minutes and then placed into a gas chromatography vial. One mL of 6% formic acid in diisopropyl ether was added; the cap was crimped and swirled then allowed to settle. Two microfilters were injected into a gas chromatograph (Hewlett Packard Model 5890 Series II, Avondale, Pa., U.S.A.), which increased from 60 °C to 149 °C at a rate of 9 °C/min. Injector temperature was held at 121 °C and detector temperature at 138 °C. Free fatty acid (FFA) standards were prepared for C4-C18, C18:1, C18:2 and C18:3 by mixing 50 to 70 mg of the fatty acid with 95 mg C17 (internal standard or IS) and 4 g of formic acid, then diluting to 100 mL with diisopropyl ether. Calculation of free fatty acid concentration were as follows:

\[
\text{ppm FFA} = \frac{\text{mg/ml FFA (std) \times Area IS (std) \times Area FFA (sample)}}{\text{sample wt (g) \times Area FFA (std) \times Area IS (sample)}} \times 1000
\]

Sugars

Only 1 of the 2 process replicates of each treatment was analyzed for content of fructose, dextrose, sucrose, maltose, and lactose. Seven grams of sample were mixed with 10 mL of isopropyl alcohol, stirred for 5 min, diluted to 100 mL with deionized water, filtered, and injected into a high performance liquid chromatograph (HPLC, Varian Instruments, Palo Alto, Calif., U.S.A.). A Rainin (Woburn, Mass., U.S.A.) Dynamax NH2 (8 μm) column was used with a 70% acetonitrile/30% water mobile phase and a flow rate of 1.5 mL/min. Standard solutions of varying saccharide levels were prepared and used for the standard curve. Peak heights were evaluated and used for determination of sugars.

Color

Instrumental color measurements were made on samples frozen and stored at 0 °F (−18 °C) for 9 mo. Hue angle (tan−1b/a), chroma (light to gray), and L* lightness value (white to black or light to dark) measurements were taken with a Minolta CR-20 Chroma Meter, calibrated with the white plate and either the green standard tile (broccoli) or orange standard tile (corn). Frozen samples were thawed before measurement and evaluated at 23 °C. From each cob segment 3 readings were taken, and 3 cob segments were evaluated per sample. All treatments took place in duplicate; therefore, average corn hue values represent 18 readings. Five readings were obtained from broccoli florets, and treatments were duplicated therefore average hue values represent 10 readings.

Texture

Firmness of frozen, stored samples was evaluated after 9 mo using a Texture Technologies TA.XT2 (Menlo Park, Calif., U.S.A.) instrument equipped with a Kramer shear cell. Two hundred gram representative samples were thawed and drained for 1 min and then weighed. The sample was loaded into a metal shear cell with plexiglass walls and leveled, and a 5-blade probe was attached to the press ram. The probe was placed near the surface of the sample before beginning each test to avoid false triggers. The test was run a 1 mm/sec and 90% strain. Both peak force and area under the curve were recorded. Three or more replicate samples were evaluated and averages were calculated.

Data analysis

Two-way analysis of variance (ANOVA) were carried out with blanch times, cultivars and replications and their 2-way interactions as sources of variation. Because cultivars behaved differently as a function of blanch time, they were evaluated independently by ANOVA. Principal Component Analysis (PCA) of the mean quality attributes across samples were calculated to determine the relationship between quality attributes, cultivars and blanch times.
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MS 19990224 received 2/10/99; revised 10/1/99; accepted 12/28/99.

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