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Base-Mediated Firmness Retention of Sweetpotato Products

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ABSTRACT

Sweetpotato strips vacuum-infiltrated with 0.01–0.15M solutions of Na_3PO_4, Na_2CO_3, NH_4OH, or NaOH prior to heat processing were firmer than untreated, heat-processed strips. Among the bases Na_3PO_4 and Na_2CO_3 were most effective. When base-treated, cooked tissue was adjusted to its normal pH range (5.9–6.2) and reheated, the retention of firmness did not decrease. Using calcium chloride solution in conjunction with base treatment further increased firmness retention. This process was applied on strips but could readily be adapted to other types of sweetpotato products ranging from dice to chunks.

Key Words: sweet potato, firmness, pectic, pectin methylesterase

INTRODUCTION

DIFFICULTY in controlling textural properties of processed sweetpotato products is a major reason for the small number of such products available in retail markets. Control of textural properties is essential. A successful commercial operation must produce consistent high-quality products from raw materials, ranging from freshly harvested roots to those which have been stored up to 10 mo.

Many published reports have described pureed sweetpotato products (Collins and Walter, 1992). However, there are few accounts of restructured products (Walter and Hoover, 1984; Hoover et al., 1983). For pureed/restructured products, texture control depends on change in the starch since cell to cell junctions and, consequently, product cohesiveness have been destroyed by maceration. Binders/thickeners can be added during processing to adjust texture for desired characteristics.

Control of firmness of intact sweetpotato tissue by vacuum-infiltration with acidulants prior to heat processing has been reported (Walter et al., 1992). However, this technique has limited usefulness because of changes in flavor due to acidulants. Also, when the tissue was readjusted to its normal pH (ca. 6) firmness retention was lost. Van Buren and Pitifer (1992) reported that snap beans, carrots, potatoes, cauliflower, and apples de-esterified with NaOH solution softened much more slowly when cooked at neutral or slightly basic pH than did untreated vegetables. The process they used included blanched tissue soaked for 3 days in dilute NaOH solution at pH 12.5. The process we independently developed explored the effects of several bases on raw sweetpotato tissue exposed for 20 min to an alkaline environment before exposure to heat and how each base affected firmness retention of the fully cooked material. Our objective was to develop a process to increase firmness retention of cooked sweetpotato tissue and avoid the disadvantages of the acid treatments.

MATERIALS & METHODS

JEWEL CULTIVAR sweetpotatoes harvested in 1989 and 1990 were utilized. The roots were cured and stored prior to use. The sweetpotatoes were hand-peeled, rinsed, and sliced into strips 0.9 cm thick × 0.9 cm wide, or 0.95 cm thick by 0.95 cm wide. Lengths were not controlled. For vacuum infiltration, strips were held beneath the liquid surface and the pressure reduced to 0.1 atm. After 10 min, the vacuum was released and the strips held for an additional 10 min. The solution was removed, and the strips were rinsed with water and blanched 2 min in water (100°C). For some experiments strips were frozen and, at a later date, fried in soybean oil for 3 min at 158–167°C (Fig. 1). They were then cooled and the shear force measured using a Kramer shear compression cell coupled to an Instron Universal Testing Machine (Walter et al., 1992). The crosshead speed was 200 mm/min. The shear force for each treatment was determined in triplicate. In other experiments, the shear force of blanched strips was measured in triplicate. Experimental details are outlined in Table 1.

Effect of processing steps on firmness retention (Experiment 1)

Two groups of strips were prepared. One group was VI with water and served as the control for single, VI samples. The other group was VI with 0.05M Na_2CO_3. Both groups were blanched in water at 100°C for 3 min. A part of each group was then frozen. The remainder were fried in soybean oil for 3 min at 155–168°C and cooled. After 24 hr, the frozen samples were fried as described for nonfrozen samples. The force to shear samples was measured on raw, VI, blanched, fried, and frozen-fried strips for both groups.

Effect of bases on firmness retention (Experiment 2)

Depending upon the experiment, 0.01–0.15M solutions of Na_3PO_4, Na_2CO_3, NH_4OH, and/or NaOH were vacuum infiltrated (VI).

Effect of increasing pH of base-treated tissue on firmness (Experiment 3)

Five 300-g batches of sweetpotato strips were treated as follows: (1) VI with water, blanched 2 min at 100°C, VI with water, blanched 2 min at 100°C (control); (2) VI with 0.03M Na_2CO_3, blanched, VI with water, blanched (base control); (3) VI with 0.03M Na_2CO_3, blanched, VI with 0.1M acetate buffer (pH 6.1), blanched; (4) VI with 0.03M Na_2CO_3, blanched, VI with 0.1M acetate buffer (pH 5.1),

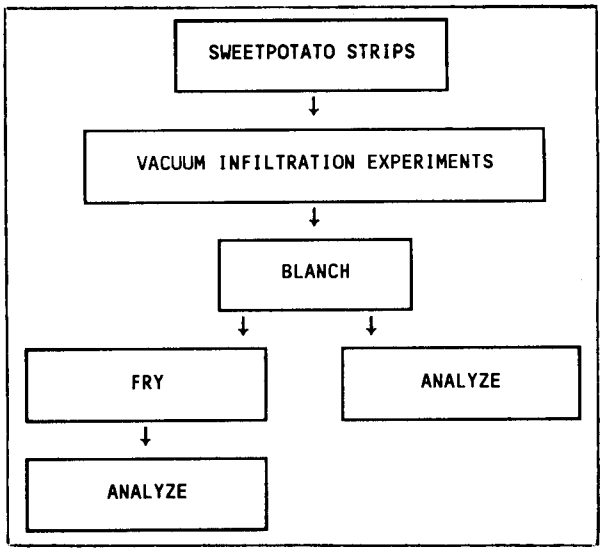

Fig. 1—Flow sheet for base treatment of sweetpotato strips.

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Table 1—Details of experiments.

Experiment no.	Purpose	Concentration of base(s)	Analyses
1	Effect of processing steps on firmness	0.05M Na_2CO_3	Shear force; tissue pH
2	Effect of bases on firmness	0.01–0.015M Na_3PO_4, Na_2CO_3, NH_4OH, NaOH	Shear force; tissue pH; peptic substances; galacturonic acid; degree of esterification
3	Effect of firmness when tissue returned to original pH values	0.03M Na_2CO_3 and acetate buffers	Shear force; tissue pH
4	Effect of Ca^{+2} on firmness of base-treated tissue	0.3M Na_2CO_3 and $CaCl_2$ solutions	Shear force; tissue pH
5	Mechanism of base-mediated firmness retention	0.05M Na_2CO_3	Shear force; tissue pH; galacturonic acid; degree of esterification

blanched; (5) VI with 0.03M Na_2CO_3, blanched, VI with 0.1M acetate buffer (pH 4.1), blanched. The treated samples were held overnight in the refrigerator and the shear force and tissue pH measured.

Effect of calcium chloride on firmness of base-treated tissue (Experiment 4)

Seven 300-g batches of sweetpotato strips were treated as follows: (1) VI with water, blanched 2 min at 100°C, VI with water, blanched (control); (2) VI with water, blanched 2 min at 100°C, VI with 0.2% $CaCl_2 \cdot 2\ H_2O$, blanched; (3) VI with water, blanched 2 min at 100°C, VI with 0.6% $CaCl_2 \cdot 2\ H_2O$, blanched; (4) VI with 0.03M Na_2CO_3, blanched, VI with water, blanched (base control); (5) VI with 0.03M Na_2CO_3, blanched, VI with 0.1M acetate buffer (pH 5.3), blanched; (6) VI with 0.03M Na_2CO_3, blanched, VI with 0.2% $CaCl_2 \cdot 2\ H_2O$ in pH 5.3 buffer, blanched; (7) VI with 0.03M Na_2CO_3, blanched, VI with 0.6% $CaCl_2 \cdot 2\ H_2O$ in pH 5.3 buffer, blanched. The treated samples were held overnight in the refrigerator and the shear force and tissue pH measured.

De-esterification mechanism study (Experiment 5)

This study was performed to determine whether de-esterification caused by base treatment of sweetpotato strips prior to heating was enzymatic, nonenzymatic, or a combination. Four 300-g batches of sweetpotatoes were treated as follows: (1) VI with water, blanched and cooled, blanched (control); (2) VI with 0.05M Na_2CO_3, blanched and cooled, blanched (base control); (3) blanched and cooled, VI with water, blanched; (4) blanched and cooled, VI with 0.05M Na_2CO_3, blanched. Strip shear force and tissue pH were measured.

Tissue analysis

Dry matter was measured and alcohol-insoluble solids (AIS) were prepared as described by Walter et al. (1992). Using separate portions of AIS, water- and chelator-soluble pectins and total pectin were measured. Water- and chelator-soluble pectins were prepared and the anhydrogalacturonic acid content measured as described earlier (Walter et al., 1992). Total pectin content (as anhydrogalacturonic acid) was measured by a modification of the method described by Scott (1979). Duplicate 0.1-g samples of AIS were wet with 0.2 mL ethanol, placed in an ice bath for 15 min, 2 mL of cold, concentrated sulfuric acid were added and the mixture vortexed. An additional 2 mL of cold acid were added and the solution vortexed and then sonicated in an ice bath for 5 min. Samples were held at 4–5°C overnight. The viscous mixture was diluted to 50 mL with water and mixed. Aliquots were centrifuged 5 min in a tabletop centrifuge to remove particulate matter. For analysis, 0.125 mL of supernatant was mixed with 0.25 mL of 2% NaCl and 0.125 mL water in 16 × 120 mm test tubes. Then 2 mL of cold, concentrated sulfuric acid were added, and the tubes were heated at 70°C for 10 min and cooled in tap water. Next, 0.1 mL of a solution containing 0.1 g of 3,5-dimethyl phenol in 100 mL glacial acetic acid was added and the tubes held 15 min at room temperature (≈23°C). The absorbance at 400 mμ was subtracted from the absorbance at 450 mμ. This value was used to calculate the amount of galacturonic acid in the sample from a standard curve prepared with varying concentrations of galacturonic acid from 0.02 to 0.125 μM.

Pectin esterification was measured by a modification of the method of Wood and Siddiqui (1971). Alcohol-insoluble solids samples (<0.0800 g) were weighed into tubes, 2 mL of 4.0M NaOH were added, and 2 mL of water were added. The tubes were sonicated for 20 min in an ice water slurry, held at 5°C for 4.5 hr, 5.5 mL of cold, 6N H_2SO_4 added, and the mixture quantitatively transferred to a 25 mL volumetric flask and diluted to volume with water. Aliquots were centrifuged and 1.0 mL was put into 16 × 33 mm test tubes. The tubes were held in an ice water bath for ≥ 5 min, 0.2 mL of a 2% solution of $KMnO_4$ added, mixed, and, after 15 min, 0.2 mL of 0.5M sodium arsenite (in 0.12N H_2SO_4) and 0.6 mL water were added and mixed. After 1 hr, 2 mL of 0.02M pentane-2,4-dione (in a 50:50 mixture of 4.0M ammonium acetate and 0.1M acetic acid) were added, mixed, and held at room temperature for 1 hr. The absorbance at 420 nm was measured and the concentration of methanol calculated from a standard curve prepared with concentrations of methanol, ranging from 0.164 to 1.28 μM. To calculate the % methyl ester content, the molar concentration of galacturonic acid/g AIS was divided into the molar concentration of methanol/g AIS and the result multiplied by 100. Tissue pH was measured by blending duplicate 5-g samples of diced, blanched strips with 10 mL water and measuring the pH with an Orion model 701A meter.

Table 2—Effect of vacuum-infiltration of sweetpotato strips with basic substances on tissue shear force and pH prior to heat processing

Vacuum-infiltration solution	Shear force (kg)	Tissue pH
None	34.9 ± 6.1	6.07
Water	31.6 ± 2.7	6.05
0.01M Na_3PO_4	46.3 ± 2.0	6.25
0.05M Na_3PO_4	105.0 ± 9.9	6.94
0.1M Na_3PO_4	120.3 ± 11.3	7.39
0.15M Na_3PO_4	96.4 ± 7.2	7.95
0.01M Na_2CO_3	42.7 ± 5.5	6.13
0.05M Na_2CO_3	78.3 ± 7.6	6.52
0.1M Na_2CO_3	78.5 ± 1.1	6.93
0.15M Na_2CO_3	41.5 ± 3.5	8.00
0.01M NH_4OH	31.5 ± 0.7	6.26
0.05M NH_4OH	57.4 ± 7.5	6.69
0.1M NH_4OH	54.2 ± 5.5	7.7
0.15M NH_4OH	56.0 ± 4.4	8.07
0.01M NaOH	40.2 ± 3.7	6.2
0.05M NaOH	36.9 ± 1.3	6.94
0.1M NaOH	50.1 ± 2.2	8.11
0.15M NaOH	41.2	8.5

RESULTS & DISCUSSION

VACUUM INFILTRATION of sweetpotato strips with solutions of Na_3PO_4, Na_2CO_3, NH_4OH, or NaOH ranging from 0.01 to 0.15M prior to blanching and frying caused increased firmness retention when compared to untreated strips and strips VI with water (Table 2). Degree of firmness retention varied with both the base and its concentration. Firmness retention decreased in the order: Na_3PO_4 > Na_2CO_3 > NH_4OH > NaOH. Firmness retention increased as the concentration of base increased from 0.01 to 0.05M, or 0.10M. With the exception of NH_4OH, firmness retention decreased when base concentration increased from 0.10 to 0.15M, possibly reflecting basic hydrolysis of cell wall polymers. After blanching, surface erosion was observed when the base concentration was > 0.05M. However, sodium hydroxide solutions > 0.01M eroded the blanched tissue surface.

The force required to shear strips decreased as the degree of processing increased. Raw strips were slightly firmer than the VI strips (Fig. 2). After blanching, base-treated strips had lost about 49% of their firmness, while control strips had lost 83% of their firmness. Fried base-treated strips lost 52% of their firmness, while the fried control strips had lost 86% of

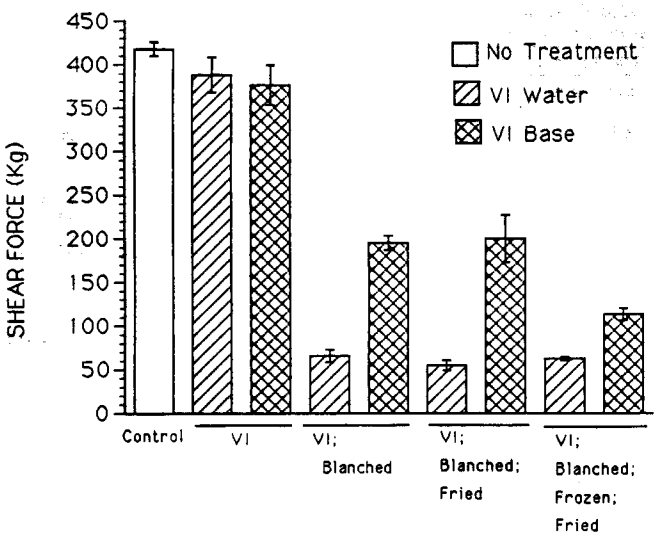

Fig. 2—Shear force of sweetpotato strips at various steps in the base treatment (0.05M Na_2CO_3) process. (VI = vacuum infiltrated).

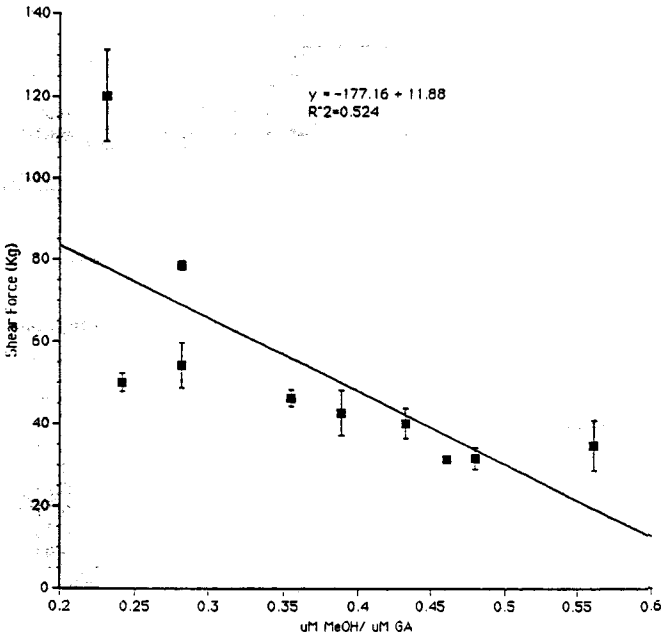

Fig. 3—Linear regression of shear force on μM methanol/μM galacturonic acid in base-treated sweetpotato strips.

Table 3—Galacturonic acid content, methanol content, and methanol/galacturonic ratio of AIS from sweetpotatoes vacuum-infiltrated with bases

Vacuum-infiltration solution	Galacturonic acid (μM/g AIS)	Methanol (μM/g AIS)	μM Methanol/μM galacturonic acid[a]
None	223.1	113.1	0.5609A
Water	238.7	114.5	0.4798B
0.01M Na_3PO_4	211.7	75.1	0.3548D
0.10M Na_3PO_4	186.7	43.2	0.2314E
0.01M Na_2CO_3	237.8	92.3	0.3884CD
0.10M Na_2CO_3	230.3	50.6	0.2816E
0.01M NH_4OH	237.4	109.4	0.4608B
0.10M NH_4OH	231.0	65.0	0.2816E
0.01M NaOH	236.1	104.2	0.4325BC
0.10M NaOH	182.3	44.1	0.2413E
MSD	16.5	15.2	0.0641

[a] Values within the same letter are not significantly different ($P < 0.05$).

their original firmness. When the frozen strips were fried, the base-treated strips lost 71%, and the control lost 84% of original firmness. Freezing prior to frying caused a greater decline in firmness of acid-treated strips than that of control strips. These data showed that treating tissue with base prior to heating decreased heat-mediated softening.

Current theory is that softening occurs during cooking because pectic substances, responsible for holding plant cells together and for plasticizing cell walls, are cleaved causing cell separation and cell wall expansion (Doesburg, 1965; Van Buren, 1986). The mechanism postulated for pectin cleavage in the pH range (5.0-6.5) common to most processed vegetables is beta-elimination. This mechanism, in which an activated proton at C-5 is removed and the glycosidic linkage alpha to the carboxyl group is cleaved, was proven to be operative at relatively high pH values (Bemiller and Kumari, 1972), but direct experimental data for vegetable tissues is not available. At neutral pH, it is postulated that there are sufficient hydroxide ions present to promote beta-elimination at cooking temperatures. However, if the pH is lowered, the concentration of hydroxide ions decreases, the rate of reaction decreases, and subsequent softening typical of cooked vegetables decreases. A characteristic of decreased softening caused by tissue acidification is that it can be reversed if tissue pH is readjusted to 6 and it is reheated (Walter et al., 1992).

Other workers have reported that, for chelator-soluble carrot pectin, the higher the methyl ester content, the greater the rate of pectin chain degradation during heating at pH 6.1 (Sajjaanantakul et al., 1989). In an extreme case, boiling totally deesterified citrus pectin for long periods at pH > 6 pH did not cause pectin degradation (Van Buren, 1979). The rationale for this result was that the negative charge associated with the deesterified carboxylic acid strongly inhibited beta-elimination by destabilizing any developing negative charge at C-5 caused by hydroxide ion-mediated removal of protons.

Our results tend to support the theory that increased demethoxylation inhibits beta-elimination and, thus, decreases heat-mediated softening. Regardless of base, strips VI with 0.1M concentrations and blanched were firmer (Table 2) and more demethoxylated than untreated samples of those treated with 0.01M base solutions (Table 3) and blanched. However, strip firmness (measured by shear force) varied by base type. Maximum shear force declined in the order: Na_3PO_4 > > Na_2CO_3 > NH_4OH and NaOH. The fact that linear regression of shear force on μM methanol/μM galacturonic acid could explain only 52% (Fig. 3) of the variability in the model indicated that other factors were involved.

A characteristic of beta-elimination inhibition due to pectin demethoxylation would be that readjusting demethoxylated tissue to its normal pH (≈6) and reheating it should not result in increased softening. In contrast to the results of Van Buren and Pitifer (1992), we found this to be true. However, Van Buren and Pitifer (1992) lowered the tissue pH to ca. 3.5 before reheating, and this could have caused increased softening. In our study, tissue treated with 0.03M Na_2CO_3, blanched, then VI with water, and again blanched was firmer than the control and was slightly less firm than base-treated, blanched tissue VI with either pH 6.1 or pH 5.1 acetate buffers and then blanched (Table 4). When base-treated, blanched tissue was VI with pH 4.1 buffer and again blanched, it was significantly firmer than the other treatments. This firmness increase was greater than that resulting from treatments in which the final tissue pH was near that of the original tissue (i.e., either of the other buffers). This was probably due to tissue acidification (Walter et al., 1992) since its pH was 5.19, while the normal pH was 6.23.

Since base-treated tissue had an increased number of carboxylate groups, we wanted to ascertain whether incorporation of calcium ions into the second infiltration medium could increase firmness. Calcium has been shown to increase firmness in many processed vegetables (Van Buren, 1979; 1986). This effect, described by the "egg-box model," is ascribed to a mechanism in which divalent calcium crosslinks adjacent pec-

Table 4—Effect on shear force and tissue pH of readjusting base-treated sweetpotato tissue to original pH

Treatment[a]	Shear force (kg)	Tissue pH
Water (control) → water	50.0 + 10	6.23
0.03M Na_2CO_3 → water	85.3 + 12	6.56
0.03M Na_2CO_3 → pH 6.1 buffer	100.3 + 11.9	6.41
0.03M Na_2CO_3 → pH 5.1 buffer	104.0 + 9.5	5.87
0.03M Na_2CO_3 → pH 4.1 buffer	131.8 + 12.6	5.19

[a] Tissue was vacuum-infiltrated with the solution of the arrow and blanched. After cooling, the blanched strips were vacuum-infiltrated with the solutions to the right of the arrow, blanched, and the shear force and pH measured.

Table 5—Effect of $CaCl_2$ on shear force of Na_2CO_3-treated sweetpotato strips

Treatment[a]	Shear force (kg)	Tissue pH
Water (control) → water	69.3 ± 5.1	6.25
Water → 0.2% $CaCl_2$	65.3 ± 10.8	6.14
Water → 0.6% $CaCl_2$	83.0 ± 9.3	6.11
0.03M Na_2CO_3 → water	121.3 ± 7.5	6.77
0.03M Na_2CO_3 → pH 5.3 buffer	140.6 ± 6.1	6.11
0.03M Na_2CO_3 → 0.2% $CaCl_2$ in pH 5.3 buffer	162.5 ± 15.3	6.15
0.03M Na_2CO_3 → 0.6% $CaCl_2$ in pH 5.3 buffer	196.3 ± 14.9	6.09

[a] Tissue was vacuum infiltrated with the solution to the left of the arrow and blanched. After cooling, the blanched strips were vacuum infiltrated with the solutions to the right of the arrow, blanched, and the shear force and pH measured.

tin molecules via formation of ionic bonds with free carboxyl groups. The resultant three-dimensional network confers increased resistance to shearing forces. We found that treatment of sweetpotato strips with 0.03M Na_2CO_3, blanching the strips, and then VI with 0.6% calcium chloride solution in acetate (buffer (pH 5.3) resulted in almost a three-fold increase in shear force over control strips (Table 5). The buffer alone increased firmness by about 16% over Na_2CO_3 treated strips, and 0.2% calcium chloride increased firmness by another 16%. These results suggested that firming could be enhanced and tissue pH readjusted to the normal value by vacuum-infiltrating a second solution composed of acetate buffer (pH 5.3) and calcium chloride.

Vacuum infiltration with bases could have removed some of the pectic materials from the strips compared with VI with water. Thus, we measured the galacturonic acid content of water- and chelator-soluble pectin fractions and the galacturonic acid content of the total dry matter. We observed no consistent loss of pectic material (Table 6). For both water- and NaOH-treated samples, blanched pectic substances apparently increased over raw pectic substances, possibly due to extraction of endogenous sugars by blanch water. Some differences were observed between relative amounts of water-soluble pectins and chelator-soluble pectins. For raw tissue, vacuum infiltration with either base caused chelator-soluble pectins to be more abundant than water-soluble pectins. For blanched tissue, this was reversed, but in base treated, blanched tissue the amount of chelator-soluble pectin was still twice that in the blanched control strips. Thus, base treatment apparently converted some of the pectic materials from water-soluble to chelator-soluble.

The mechanism by which bases de-esterified methyl esters of polygalacturonic acid-containing polymers in sweetpotatoes could be either enzymatic or nonenzymatic. Research has demonstrated that sweetpotatoes have an active pectin methylesterase system (Baumgardner and Scott, 1965). Van buren and Pitifer (1992) held plant material in NaOH solution for 3 days to ensure that de-esterification was a non-biological process. To study this, we conducted an experiment in which we VI strips with 0.05M Na_2CO_3 either before or after blanching the tissue and measured the degree of esterification. Two sets of samples in which water was the infiltrating solution before and after blanching were also analyzed. We found that tissue treated with base prior to blanching was significantly less esterified than that which was blanched prior to treatment with 0.05M Na_2CO_3

Table 6—Galacturonic acid[a] content of raw and blanched sweetpotato strips vacuum-infiltrated with either water, 0.1M NaOH, or 0.1M Na_2CO_3

Galacturonic acid	Water	0.1M NaOH	0.1M Na_2CO_3
Raw tissue			
Water-soluble	115.7	65.0	72.6
Chelator-soluble	44.8	76.8	96.7
Total	229.5	214.6	238.4
Blanched tissue			
Water-soluble	155.6	99.8	88.9
Chelator-soluble	21.8	58.6	63.7
Total	258.2	228.5	219.7

[a] μMoles galacturonic acid/g dry matter.

Table 7—Effect of blanching on % methyl ester content of sweetpotato strips treated with 0.05M Na_2CO_3 solution

Treatment[a]	% Esterification[b]	Tissue pH
VI water → blanch → blanch	71.49A	5.83
VI Na_2CO_3 → blanch → blanch	52.08B	6.12
Blanch → VI water → blanch	74.75A	5.90
Blanch → VI Na_2CO_3 → blanch	64.21A	6.97

[a] Tissue was vacuum-infiltrated either before or after an initial blanch treatment.
[b] Values with the same letter are not significantly different ($P < 0.05$).

(Table 7). On that basis, we concluded that most of the de-esterification resulting from base treatment was enzymatic.

CONCLUSIONS

TREATMENT of sweetpotato tissue with either Na_2CO_3 or Na_3PO_4 prior to heat processing increased firmness retention. When base-treated tissue was VI with calcium chloride, tissue firmness was enhanced. Base-mediated firmness retention was effective on strips and could easily be adapted to many types of products ranging from dice to chunks.

REFERENCES

Baumgardner, R.A. and Scott, L.E. 1965. The relation of pectic substances to firmness of processed sweet potatoes. J. Amer. Soc. Hort. Sci. 83: 629–640.

Bemiller, R.W. and Kumari, G.V. 1972. Beta-elimination in uronic acids; evidence for an ElcB mechanism. Carbohy. Res. 25: 419–426.

Collins, J.L. and Walter, W.M. Jr. 1992. Processing and processed products. In *Fifty Years of Cooperative Sweetpotato Research. 1939–1989.* p. 71–87. Louisiana Agric. Expt. Sta. Southern Cooperative Bulletin No. 369, Baton Rouge, LA.

Doesburg, J.J. 1965. *Pectic Substances in Fresh and Prepared Fruits and Vegatables*, I.B.V.T., Wageningen, The Netherlands.

Hoover, M.W., Walter, W.M. Jr., and Giesbrecht, F.G. 1983. Method of preparation and sensory evaluation of sweet potato patties. J. Food Sci. 48: 1568–1569.

McFeeters, R.F. and Lovdal, J.A. 1987. Sugar composition of cucumber cell walls during fruit development. J. Food Sci. 52: 996–1001.

Sajjaanantakul, T., Van Buren, J.P., and Downing, D.L. 1989. Effect of methyl ester content on heat degradation of chelator-soluble carrot pectin. J. Food Sci. 54: 1272–1277.

Scott, R.W. 1979. Colorimetric determination of hexuronic acids in plant material. Anal. Chem. 51: 936–941.

Van Buren, J.P. 1979. The chemistry of texture in fruits and vegetables. J. Text. Stud. 10: 1–23.

Van Buren, J.P. 1986. Softening of cooked snap beans and other vegetables in relation to pectins and salts. In *Chemistry and Functions of Pectin*, M.L. Fishman and J.J. Jen (Ed.), p. 190–199. American Chemical Society, Washington, DC.

Van Buren, J.P. and Pitifer, L.A. 1992. Retarding vegetable softening by cold alkaline pectin de-esterification before cooking. J. Food Sci. 57: 1022–1023.

Walter, W. M. Jr. and Hoover, M.W. 1984. Effect of pre-processing storage conditions on the composition, microstructure, and acceptance of sweet potato patties. J. Food Sci. 49: 1258–1261.

Walter, W.M. Jr., Fleming, H.P., and McFeeters, R.F. 1992. Firmness control of sweetpotato French fry-type product by tissue acidification. J. Food Sci. 57: 138–142.

Wood, P.J. and Siddiqui, I.R. 1971. Determination of methanol and its application to measurement of pectin ester content and pectin methyl esterase activity. Anal. Biochem. 39: 418–428.

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