Firmness Control of Sweetpotato French Fry-Type Product by Tissue Acidification

W. M. WALTER JR., H. P. FLEMING, and R. F. McFEETERS

ABSTRACT

The softening of a French fry-type product prepared from 'Jewel' sweetpotatoes decreased linearly ($P \leq 0.01$) when the tissue pH was incrementally lowered from ca. 6 to 3.8 prior to blanching. Tissue pH was decreased by vacuum infiltration of a series of organic and mineral acids of 0.01 to 0.4M. Firmness retention decreased when the ionic strength of the acidulant was increased by addition of NaCl. The structures of the pectic substances were affected by the tissue pH and starch hydrolysis decreased as tissue pH decreased from its normal value of ca. 6, reflecting partial inactivation of endogenous amylolytic enzymes.

INTRODUCTION

SWEETPOTATOES are an underutilized crop in the United States primarily because it is difficult for food processors to control textural properties. In sweetpotato, starch content and cell wall architecture exert a significant influence on textural properties. All sweetpotato cultivars commercially produced in the United States have a cultivar-dependent amylolytic enzyme system which decreases starch content during storage prior to processing and during processing (Ikemiya and Deobald, 1966; Deobald et al., 1968; Walter et al., 1975). Since canned sweetpotato is the main processed product, most published information on textural properties has concerned that product. Sweetpotatoes canned shortly after harvest are firmer than those canned several weeks after harvest (Kattan and Littrell, 1963; Woodroof et al., 1955). This time-dependent effect on firmness was found to be related to pectic substances (Ahmed and Scott, 1957; Baumgardner and Scott, 1963), and to alcohol-insoluble substances (AIS) and starch (Kattan and Littrell, 1963). Firmness of canned sweet potatoes has been increased by treatment with $CaCl_2$ as a soak and by incorporation into the syrup (Scott and Twigg, 1969; Woodroof et al., 1955). Calcium chloride presumably exerted its effect by interacting with the cell wall pectic material. Post-harvest history also has been shown to impact textural properties of patties (Walter and Hoover, 1984) and French fries (Walter and Hoover, 1986).

In contrast, white potatoes have little amylolytic enzyme activity, so that during heat processing amylase-mediated starch hydrolysis is not observed. As a result, the length of storage prior to processing has little effect on the textural properties of the processed product, provided the specific gravity of the tubers does not change. It should be noted, however, that long-term storage of white potatoes at <5°C elicits formation of sugars, which causes browning of the cooked product (Feustal and Kueneman, 1967), a serious quality defect in chips and French fries.

An approach to controlling the firmness of sweetpotato products could be by lowering the tissue pH prior to heat processing. Doesburg (1961) found that plant tissues of a parenchymatous nature were firmest when cooked in boiling water acidified to pH 4.0–5.0. Sistrunk (1971) used a series of buffered citric acid solutions as precanning firming agents. Alteration of normal tissue pH with buffered citric acid was hypothesized to have resulted in retention of some of the tissue firmness by partially inhibiting enzymatic starch hydrolysis. Hughes et al. (1975) reported that white potato discs cooked in an acidic solution were firmer than discs cooked in water. Sterling (1968) and Heil and McCarthy (1989) reported similar results for carrot discs and carrot cylinders respectively cooked in acidic solutions.

The objective of our study was to determine if the firmness of a model sweetpotato food, a French fry-type product, could be controlled by modifying tissue pH prior to heat processing.

The authors are affiliated with the USDA-ARS and North Carolina Agricultural Research Service, Dept. of Food Science, North Carolina State Univ., Raleigh, NC 27695-7624.

MATERIALS & METHODS

JEWEL CULTIVAR sweetpotatoes harvested in 1988 and 1989 were utilized. The roots were used as harvested or were cured and stored prior to use. For all texture modification experiments, the sweetpotatoes were hand-peeled, rinsed, and sliced into strips 0.6 cm thick × 0.9 cm wide. The lengths were not controlled. For vacuum infiltration, the 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 several times with water, blanched 2 min in water (100°C), and frozen. Frozen strips were fried in soybean oil for 3 min at 158–167°C. They were then cooled and the shear force measured using a Kramer shear compression cell (Kramer, 1972) coupled to an Instron Universal Testing Machine. The cross head speed was 200 mm/min. The shear force for each treatment was determined in triplicate.

Acidulant penetration

Extent of acidulant penetration was determined by vacuum infiltration of strips with 0.25M acetic acid, followed by separation into two groups. One group was analyzed after infiltration, while the second group was blanched prior to analysis. For analysis, strips were separated into surface and interior sections by excising tissue from each of the 6 facets of the strip. Each section contained about half of the total weight. After separation into sections, 5g of tissue was homogenized with 10 mL water and the pH measured. Four replicate samples were tested for each treatment.

Acidulants

For part of the 1988 crop, 0.17, 0.33, and 0.67M citric acid solutions were vacuum-infiltrated into strips which had been stored for 9, 16, 17, 27, and 29 wk, and the strips processed as described. For both 1988 and 1989 crops, 2 concentrations each of four organic acids, and one concentration of hydrochloric acid, were used as acidulants. The organic acid concentrations were chosen to provide two distinctly different sets of tissue pH levels with different conjugate bases. Hydrochloric acid was included as a highly ionized mineral acid. The following acidulant solutions were used: 0.2 and 0.4M acetic, 0.15 and 0.3M lactic, 0.15 and 0.3M malic, and 0.2M hydrochloric acids. For some experiments, acidulant solutions contained sodium chloride (NaCl).

Effect of processing steps on firmness retention

Two groups of strips were prepared. One group was vacuum-infiltrated with water and served as the control for single vacuum-infiltrated samples. The other group was vacuum-infiltrated with 0.25M acetic acid. Both groups were blanched in water at 100° for 2 min. A part of each group was then frozen. The remainder was fried in soybean oil for 3 min at 155–168°C and cooled. After 24 hr, the frozen samples were fried as described for the nonfrozen samples. The force

required to shear the samples was measured on raw, vacuum-infiltrated, blanched, fried, and frozen-fried strips for both groups.

Effect of two blanch treatments on tissue firmness

This experiment was done to determine if firmness retention caused by blanching acidified tissue could be reversed if the pH of the acidified tissue was increased and the tissue blanched again. To accomplish this, acidified, vacuum-infiltrated, blanched tissue was again vacuum-infiltrated with buffers at higher pH than the original acidulant and then blanched again. The procedure was as follows: A 1000-g lot of sweetpotato strips was separated into 200-g groups. One group was vacuum-infiltrated with water, blanched in water at 100°C for 2 min, cooled to room temperature, vacuum-infiltrated with water again, blanched as before, and frozen. This treatment served as the control for double vacuum infiltration and double blanching. The other groups were vacuum-infiltrated with 0.25M acetic acid, blanched in water for 2 min at 100°C, and cooled. One of the acid-treated groups was vacuum-infiltrated with water, blanched, and frozen. This served as the control for double blanching of acidified tissue. The remaining three acid-treated groups were vacuum-infiltrated with 0.1M potassium dihydrogen phosphate buffers adjusted to either pH 6.0, 6.5, or 7.0, blanched, and frozen. The frozen strips for all five groups were fried as described and the shear force measured. In addition, four strips from each treatment were thawed, diced, and the tissue pH measured.

Tissue analysis

Dry matter, alcohol-insoluble solids (AIS), starch, and pectins were measured on blanched material. Dry matter of the blanched material was measured by weighing duplicate 10 g samples, heating them in a drying oven (100°C) to constant weight, and determining the weight difference. The AIS were obtained by blending duplicate 25g samples of diced, blanched sweetpotato with 85 mL ethanol (95%) and 11 mL water. The supernatant was removed and the residual material extracted twice with 150 mL boiling, 80% aqueous ethanol. The residue (AIS), was weighed, ground to <60 mesh, dried, and held in a desiccator until used.

Starch content was measured by weighing duplicate AIS samples ranging from 12 to 20 mg into test tubes, moistening with ethanol to prevent clumping, blending with 2 mL of 0.5N sodium hydroxide solution, and incubating at 36°C for 15 min. After incubation, the pH was adjusted to 4.5 with acetic acid, 1 mL of amyloglucosidase solution (1 mg/mL) added, and the solution incubated for 2 hr (37°C). The tubes were placed in boiling water for 10 min to inactivate enzymes, cooled, and diluted to 100 mL. The glucose content was measured using a glucose oxidase procedure (Sigma Procedure No. 510, Sigma Chemical Co.) and the starch content calculated by multiplying the glucose content by 0.9.

Water and phosphate-soluble pectins were measured by shaking duplicate, weighed 0.2 g samples of AIS with 3 × 10 mL portions of water (10 min at 300 rpm). The water extracts were combined and diluted to 50 mL. The residue from the water extraction was extracted with 4 × 10 mL portions of 0.5% sodium hexametaphosphate. The phosphate extracts were combined and diluted to 50 mL. The galacturonic acid content of both extracts was determined as described by McFeeters and Lovdal (1987). Tissue pH was measured by blending duplicate 5g samples of diced, blanched strips with 10 mL water and measuring the pH with an Orion model 701A meter.

RESULTS & DISCUSSION

VACUUM INFILTRATION (VI) with both 0.22 and 0.66M acetic acid resulted in a slight pH gradient in raw tissue of about 0.2 pH units. When the tissue was blanched, the pH gradient was eliminated. For strips treated with δ-gluconolactone (0.15 and 1.0M) and hydrochloric acid (0.06 and 0.15M), the pH gradients for raw tissues were 0.8 to 1.4 pH units, respectively. As was observed for acetic acid, blanching eliminated the pH gradients. Increased firmness retention of the sweetpotato French fry product resulted with both organic and mineral acids for both 1988 and 1989 crops (Fig. 1). There was, however, a significant difference in the degree of firmness retention between roots from the two crop years. Fries prepared from the 1988 crop had been stored for 27 wk prior

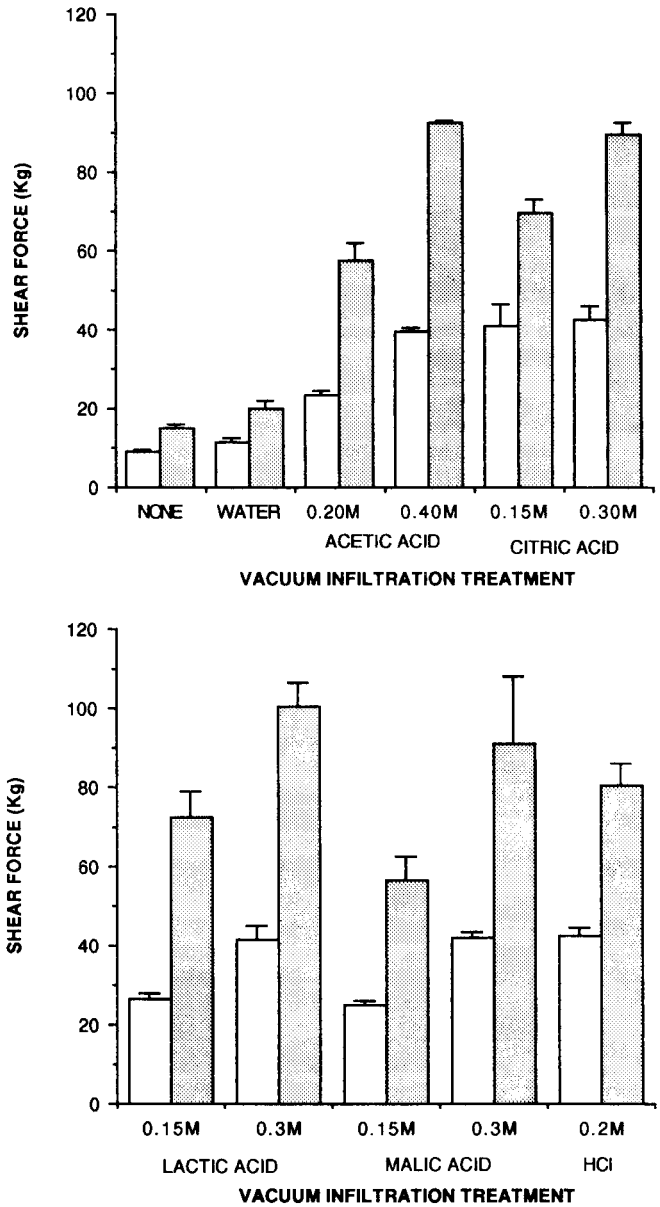

Fig. 1.—Shear force for 'Jewel' sweetpotato French fries for 1988 and 1989 crop years. Each value is the mean ± standard deviation of three replicates. □ 8 wk, ▨ 27 wk.

to processing and were the firmer of the two sets, while those prepared from the 1989 crop had been stored 8 wk prior to processing. Differences in firmness most likely indicated dissimilarities in the amount of acidic solution absorbed by the strips. The disparate degree of uptake was confirmed by differences in weight and tissue pH. The 27-wk strips had absorbed more liquid and had a lower tissue pH than did the 8-wk strips (Table 1). Increased solution uptake by the 27-wk strips was most likely due to increased intercellular space which developed during storage of sweetpotatoes (Kushman and Pope, 1972) and to increased osmotic potential of the cells caused by sugar accumulation during storage. Experiments indicated that 'Jewel' had an intercellular air space at harvest of ca. 5–7% of volume which increased to 9–11% after 6 mo storage. Figure 1 shows that strips vacuum-infiltrated with water were firmer than no-treatment strips and that acid-treated strips were firmer than either. Strips treated with the higher acid concentrations were firmer than those treated with lower levels.

Several experiments on fries from roots which had been

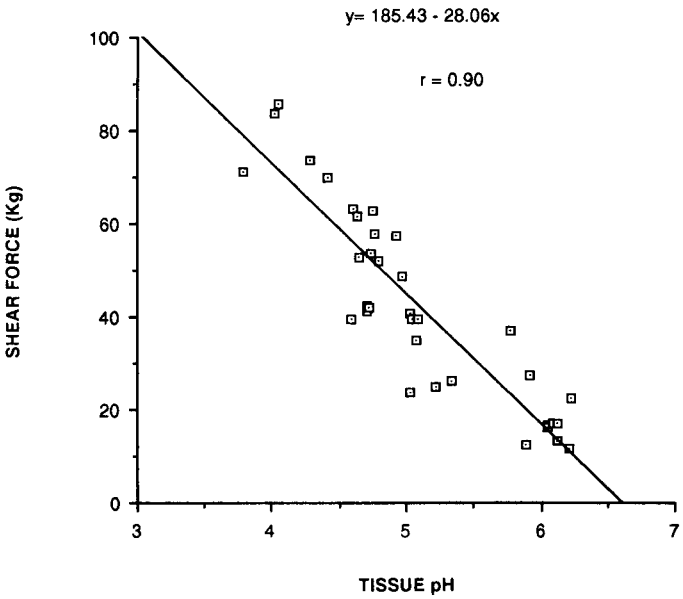

Fig. 2.—Relationship between the shear force and tissue pH for 'Jewel' sweetpotato French fries from 1988 and 1989 crop years vacuum-infiltrated with acetic, lactic, citric, malic, and hydrochloric acids (P <0.01). Number of observations = 34.

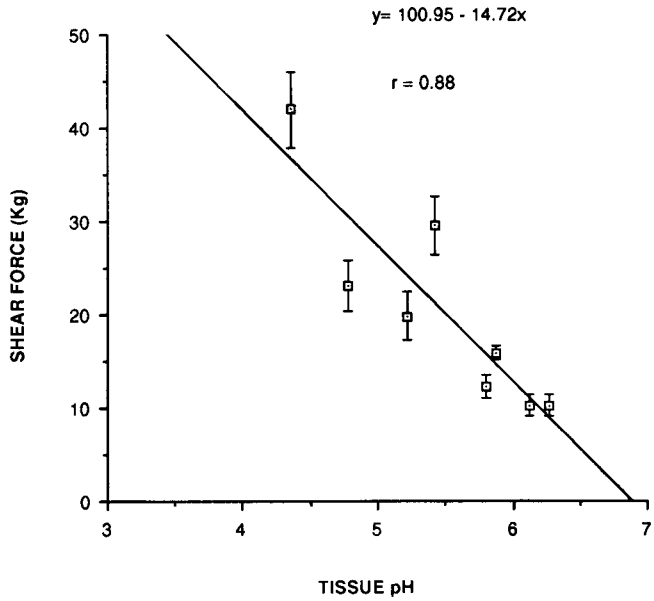

Fig. 3.—Relationship between the shear force and tissue pH for 'Jewel' sweetpotatoes vacuum-infiltrated with 0.3M sodium chloride solution acidified to concentrations of 0.0, 0.005, 0.01, 0.02, 0.03, 0.04, and 0.05M with hydrochloric acid. Vertical lines represent standard deviation of three replicate determinations of shear force (P <0.01).

Table 1—Effects of different acidulant treatments on percent weight gain and tissue pH of stored sweetpotatoes, sliced into strips and vacuum-infiltrated[a]

Acid Treatment	% Weight gain		Tissue pH	
	27 wk (1988 Crop)	8 wk (1989 Crop)	27 wk (1988 Crop)	8 wk (1989 Crop)
Water	22.60	12.40	5.79	6.21
0.2M Acetic	17.02	11.30	4.74	5.03
0.4M Acetic	16.22	10.99	4.41	4.59
0.15M Lactic	16.28	10.79	4.90	5.33
0.3M Lactic	16.03	10.30	4.38	4.71
0.15M Malic	17.40	11.32	4.84	5.22
0.3M Malic	16.07	10.02	4.46	4.72
0.15M Citric	16.86	11.86	4.67	5.03
0.3M Citric	16.51	10.89	4.35	4.71
0.2M Hydrochloric	13.90	8.42	4.09	4.47

[a]Sweetpotatoes stored for the indicated time and then sliced into strips and vacuum-infiltrated.

stored for varying times and treated with 3 concentrations of citric acid or 2 concentrations of acetic, citric, lactic, or malic acids were subjected to regression analysis (SAS, 1988). The shear force and tissue pH were linearly related with a correlation coefficient of 0.90 (Fig. 2). The linear model accounted for 80% of the variability (R-square = 0.80). This indicated that the H+ ion was primarily responsible for the firming effect and that the conjugate base was less important.

We wanted to determine if firmness retention was due to the ionic strength of the acidulant. Seven solutions containing NaCl and HCl with ionic strengths increased incrementally from 0.3 to 0.35 and pH decreased from 6.0 (no HCl added) to 1.4 were prepared. These were used to vacuum-infiltrate portions of strips. The ionic strength due to NaCl, the major contributor to ionic strength, was held constant at 0.3, and addition of increasing amounts of 3M HCl lowered the pH and accounted for the remainder of the increased ionic strength. Strips were vacuum-infiltrated with these solutions, and along with a control set of strips, were blanched, frozen, and fried. We found that the shear force increased four-fold between the highest and lowest tissue pH (Fig. 3), while the difference in ionic strength between the two extremes was 17%. This suggested that H+ ion concentration and not ionic strength of the acidulant was responsible for firmness retention. The shear

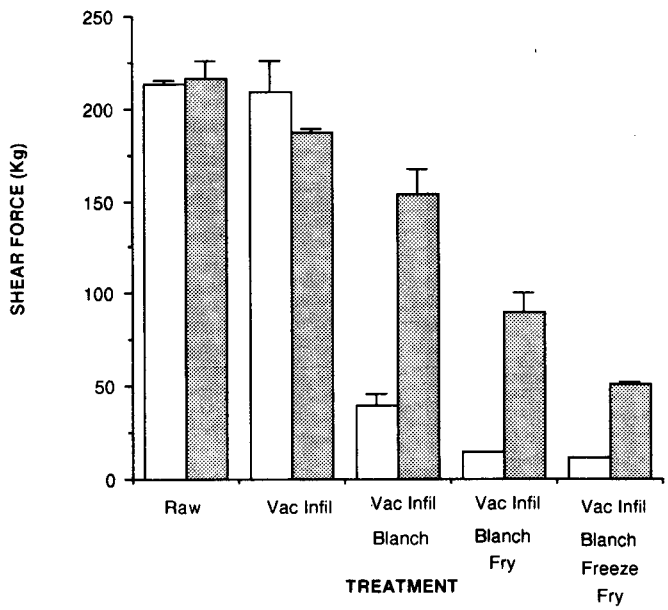

Fig. 4.—The effect of processing treatment on shear force for sweetpotato strips. □ control; ▨ acidified.

force of control strips was compared with the shear force of strips vacuum-infiltrated with 0.3M NaCl solution. Results showed that the strips vacuum-infiltrated with 0.3M NaCl were less firm (10.3 kg) than were the control strips (15.9 kg), indicating high ionic strength decreased firmness. Further evidence that ionic strength decreased firmness retention was provided by the regression equations (Fig. 2 and 3). The slope of the line for Fig. 2 is −28.1, while the slope for Fig. 3 is −14.7. This means that, for a given tissue pH, those slices vacuum-infiltrated with NaCl plus acid (Fig. 3) were less firm than those vacuum infiltrated with only acid (Fig. 2).

The force required to shear strips decreased as the degree of processing increased. Raw strips were slightly firmer than vacuum-infiltrated strips (Fig. 4). After the blanching step,

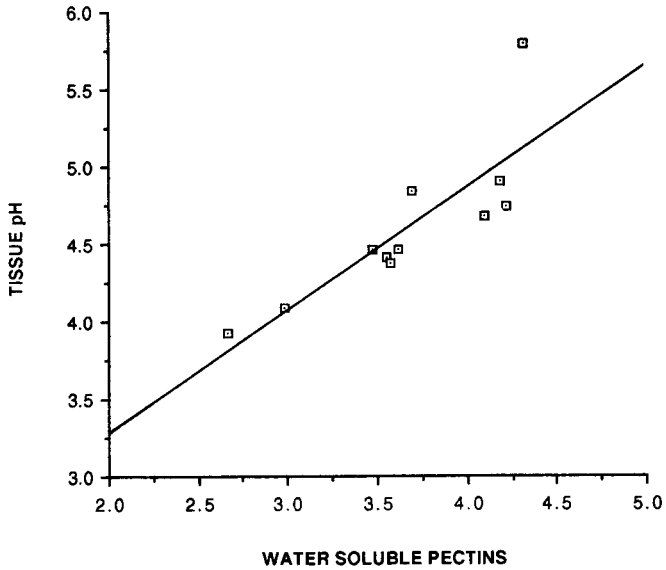

Fig. 5a.—Relationship between the tissue pH and % water-soluble pectin of alcohol-insoluble solids (dry basis) from 'Jewel' sweetpotatoes vacuum-infiltrated with acetic, lactic, citric, malic, and hydrochloric acids (r = 0.83; p <0.01).

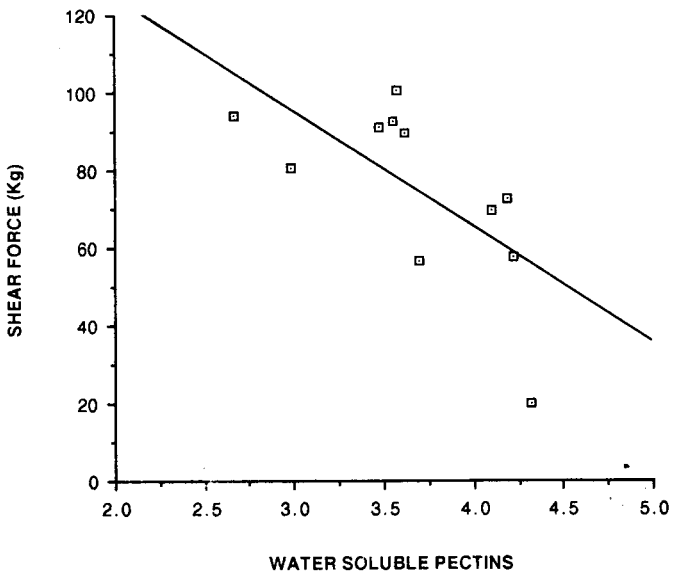

Fig. 5b.—Relationship between the shear froce and % water-soluble pectin of alcohol-insoluble solids (dry basis) from 'Jewel' sweetpotatoes vacuum-infiltrated with acetic, lactic, citric, malic, and hydrochloric acids (r = −0.66; P <0.05).

acid-treated strips had lost about 18% of their firmness, while the control strips had lost 83% of their firmness. Frying further decreased strip firmness. Fried acidified strips retained 48% of their firmness, while the firmness of fried control strips had decreased to 7% of their original value. When the frozen strips were fried, another decrease in firmness occurred, with the acid-treated strips retaining 25% of their original firmness and the control strips retaining 5% of their original firmness. Thus, freezing prior to frying caused a greater decline in firmness of acid-treated strips than in control strips. These data showed that tissue acidification caused decreased heat-mediated softening.

Tissue firmness as measured by the shear force is due to a combination of factors. Shearing in raw plant tissue is characterized by fracture of the cell walls (Sterling and Bettleheim, 1955; Diehl et al., 1979), whereas fracture of cooked tissue occurs by cell separation at the middle lamella. This occurs because heating promotes degradation of the polymeric materials (primarily galacturonosyl-containing polysaccharides) which hold the cells together. In addition, the starch content can affect firmness. The combination of heat and water availability during cooking causes starch gelatinization, distinguished by irreversible granule expansion, which for some vegetables fills the cell and thereby increases firmness.

Table 2.—Correlation coefficients for starch content, shear force, and tissue H+ concentration for sweetpotato French fries

Storage time (wk)	Log H+ tissue concentration vs		Starch content vs
	Starch content	Shear force	Shear force
9	0.86*	0.99**	0.83*
16	0.99**	0.99**	0.96**
17	0.82*	0.95**	0.74*
27	0.85**	0.93**	0.73*
29	0.91*	0.93*	0.80
16 & 17	0.89**	0.95**	0.84**
27 & 29	0.83*	0.89**	0.77**
Pooled data	-	0.93**	0.52**

* = P <0.05; ** = P <0.01.

The mechanism by which acidulants increase tissue firmness has been studied for several parenchymatous vegetables. The factors which significantly affect textural properties of vegetables are the constitution of the cell wall and middle lamella. Doesburg (1961) found that when vegetables were heat-processed at pH 3.0 to 6.5, they were firmest at a pH range of 4.0–4.5, and the lowest amount of soluble pectin was found in the pH range of 4.5–5.0. He suggested that, at pH >4.5, polyuronide hydrolysis via β-elimination caused decreased firmness and that, at pHs <4, softening was the result of acid hydrolysis of glycosidic bonds. Thus, it was assumed that, in the firmest cooked product, the least amount of pectin solubilization had occurred and the middle lamella was less disrupted than the middle lamella of tissue cooked at higher pH values.

Our results tended to confirm those of Doesburg since over the pH range of 5.9 to 3.8 the amount of water-soluble pectin decreased linearly as pH decreased (Fig. 5a) and tissue firmness tended to increase as the water-soluble (WS) pectin content decreased (Fig. 5b). Calculation of the R-square value (R^2) revealed that the linear model explained 68% of the variability for tissue pH and WS pectins (Fig. 5a), but only 44% of the variability for shear force and WS pectin content (Fig. 5b). Overall, the structure of the pectic substances was affected by tissue pH and possibly influenced tissue firmness.

Another possible route to increasing firmness would be partial inactivation of endogenous amylolytic enzymes by altering tissue pH. Most sweetpotato cultivars have active α- and β-amylase systems which have pH optima near 6 (Ikemiya and Deobald, 1966; Balls et al., 1948). Consequently, shifting the pH away from this value would result in less than optimal enzymatic activity. Starch hydrolysis would thus be inhibited and the tissue would be firmer. A series of experiments was conducted on the 1988 crop of sweetpotatoes stored from 9 to 29 wk in which strips were vacuum-infiltrated with two concentrations of acetic, lactic, malic, and citric acids prior to blanching and frying. Calculation of the correlation coefficients for tissue pH and starch content gave values ranging from a high of 0.99 for 16-wk samples to a low value of 0.82 for the 17-wk samples (Table 2). Since starch content decreased with storage time, a linear regression on pooled data was not appropriate. Thus, when the data were analyzed by storage time and by experiments conducted within 2 or 3 wk of each other, there was a statistically significant linear relationship between tissue H+ concentration and starch content (Table 2). This indicated that amylolytic enzyme activity was inhibited as tissue pH decreased. Tissue firmness correlated positively with tissue H+ concentration for each of the storage

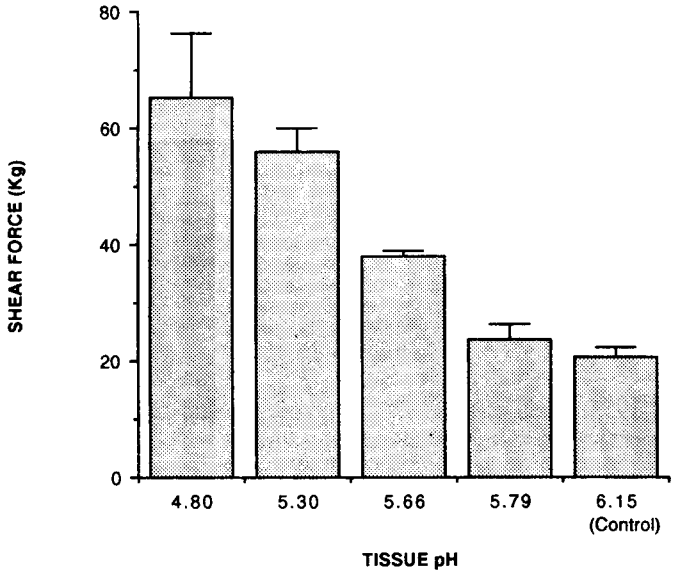

Fig. 6.—Effect of increasing tissue pH of acidified strips on the shear force of a French fry-type product made from the strips. The treatments were: final tissue pH 4.80 = vacuum-infiltrated with 0.25M acetic acid, blanched, vacuum-infiltrated with water, blanched, frozen, and fried; final tissue pH 5.3 = vacuum-infiltrated with 0.25M acetic acid, blanched, vacuum-infiltrated with phosphate buffer, pH 6.0, blanched, frozen, and fried; final tissue pH 5.66 = vacuum-infiltrated with 0.25M acetic acid, blanched, vacuum-infiltrated with phosphate buffer, pH 6.5, blanched, frozen, and fried; final tissue pH 5.79 = vacuum-infiltrated with 0.25M acetic acid, blanched, vacuum-infiltrated with phosphate buffer, pH 7, blanched, frozen, and fried; final tissue pH 6.15 = vacuum-infiltrated with water, blanched, vacuum-infiltrated with water, blanched, frozen, and fried (control).

periods, as well as for pooled data. This was because the magnitude of acid-induced firmness retention was several times greater than the normal softening which occurred during storage.

If decreased starch hydrolysis were primarily responsible for the firming effect, regression of starch content on shear force should show a correlation coefficient near one. For single experiments, the correlation coefficients, with exception of the 16-wk samples, ranged from 0.84 to 0.73 (Table 2). However, for the pooled data, the correlation coefficient was 0.52 and the R^2 value was 0.27, indicating that only 27% of the variability could be explained by the linear model. In that case, it was valid to analyze the pooled data because, even though the starch content decreased during storage, these reductions would be accounted for by a diminished shear force. Thus, it appears that, although enzymatic starch hydrolysis decreased with decreasing tissue pH, firmness retention was most affected by factors other than starch content.

In order to determine if acid-induced firmness retention could be reversed, an experiment was conducted in which tissue was acidified and blanched. Portions of the acidified, blanched tissue were then vacuum-infiltrated with buffers at pH 6.0, 6.5, and 7.0, in order to increase tissue pH, and blanched again prior to freezing and frying. The data showed that acid-caused firmness retention was reversed when the acidified, blanched tissue was made less acidic and again blanched (Fig. 6). A second blanch treatment alone did not cause decreased firmness. Those strips treated with pH 7.0 buffer and then blanched had a tissue pH near that of the control and shear force only slightly higher than the control. These results seemed to indicate that firmness retention was due to chemical rather than enzymatic processes. If enzymatic processes were involved we would expect that blanching of the tissue after vacuum infiltration of acidulant would partially or totally inactivate enzyme systems and prevent or decrease further activity. Then cell wall structure would not be affected by subsequent pH increases and, thus, no further changes in firmness would occur. Since the opposite was observed, we hypothesize that chemical processes were responsible.

Fried, acidified strips had an acidic flavor with intensity related to the strength and identity of the infiltrated acidulant. Use of low flavor impact acidulants could perhaps provide a more bland product. The texture of the acidified product was reminiscent of lightly steamed vegetables.

CONCLUSIONS

SOFTENING of cooked sweetpotato products can be decreased by lowering tissue pH prior to heat processing. The H+ ion was probably responsible for the firming effect and the conjugate base played a minor role. When ionic strength of the acidulant solution was increased to 0.3 or more with NaCl, firmness retention was lowered. This process could possibly be used as a means to control textural properties of other types of sweetpotato products.

REFERENCES

Ahmed, E.H. and Scott, L.E. 1957. Pectic constituents of the fleshy roots of the sweet potato. Proc. Am. Soc. Hort. Sci. 71: 376.
Balls, A.K., Thompson, R.R., and Walden, M.K. 1948. A crystalline beta-amylase from sweet potatoes. J. Biol. Chem. 173: 9.
Baumgardner, R.A. and Scott, L.E. 1963. The relation of pectic substances to firmness of processed sweet potatoes. Proc. Amer. Soc. Hort. Sci. 83: 629.
Deobald, H.J., McLemore, T.A., Hasling, V.C., and Catalano, E.A. 1968. Control of sweet potato alpha-amylase for producing optimum quality, precooked, dehydrated sweet potato flakes. Food Technol. 22: 627.
Diehl, K.C., Hamann, D.D., and Whitfield, J.K. 1979. Structural failure in selected raw fruits and vegetables. J. Text. Studies 10: 371.
Doesburg, J.J. 1961. Relation between the behavior of pectic substances and changes in firmness of horticultural products during heating. Qual. Plant. Mat. Vegetal. 8: 115.
Feustel, I.C. and Kueneman, R.W. 1967. Frozen French fries and other potato products. In *Potato Processing*, W.F. Talburt and O. Smith (Ed.), p. 340. Avi Publishing Co., Inc., Westport, CT.
Heil, J.R. and McCarthy, M.J. 1989. Influence of acidification on texture of canned carrots. J. Food Sci. 54: 1092.
Hughes, J.C., Grant, A., and Faulks, R.M. 1975. Texture of cooked potatoes: the effect of ions and pH on the compressive strength of cooked potatoes. J. Sci. Food Agric. 26: 739.
Ikemiya, M. and Deobald, H.J. 1966. New characteristic alpha-amylase in sweet potatoes. J. Agric. Food Chem. 14: 237.
Kattan, A.A. and Littrell, D.L. 1963. Pre- and post-harvest factors affecting firmness of canned sweet potatoes. Proc. Amer. Soc. Hort. Sci. 83: 641.
Kramer, A. 1972. Texture—It's definition, measurement, and relation to other attributes of food quality. Food Technol. 26: 34.
Kushman, L.J. and Pope, D.T. 1972. Causes of pithiness in sweetpotatoes. N.C. Agric. Expt. Sta. Tech. Bull. No. 207, Raleigh, NC.
McFeeters, R.F. and Lovdal, J.A. 1987. Sugar composition of cucumber cell walls during fruit development. J. Food Sci. 52: 996.
SAS Institute, Inc. 1988. *SAS/STAT® User's Guide.* Cary, NC.
Scott, L.E. and Twigg, B. 1969. The effects of temperature of treatment and other factors on calcium firming of processed sweet potatoes. Maryland Proc. Report 15, Univ. of Maryland, College, Park, MD.
Sistrunk, W.A. 1971. Carbohydrate transformations, color and firmness of canned sweet potatoes as influenced by variety, storage, pH, and treatment. J. Food Sci. 36: 39.
Sterling, C. 1968. Effect of solutes and pH on the structure and firmness of cooked carrot. J. Food Technol. 3: 367.
Sterling, C. and Bettleheim, F.A. 1955. Factors associated with potato texture. III. Physical attributes and general conclusions. Food Res. 20: 130.
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.
Walter, W.M. Jr. and Hoover, M.W. 1986. Preparation, evaluation, and analysis of a French fry-type product from sweet potatoes. J. Food Sci. 51: 967.
Walter, W.M. Jr., Purcell, A.E., and Nelson, A.M. 1975. Effects of amylolytic enzymes on "moistness" and carbohydrate changes of baked sweet potato cultivars. J. Food Sci. 40: 793.
Woodruff, J.G., Dupree, W.E., and Cecil, S.R. 1955. Canning sweet potatoes. Georgia Agric. Expt. Sta. Bull. No. NS12.
Ms received 3/21/91; revised 8/08/91; accepted 8/18/91.

We express appreciation to Dr. D. D. Hamann and Mr. Randy Koch for expert advice with regard to texture measurements.

Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agriculture or North Carolina Agricultural Research Service, nor does it imply approval to the exclusion of other products that may be suitable.