Effects of Blanching Conditions on the Mechanical Properties of French Fry Strips

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ABSTRACT

Control of the various processing operations is crucial for achieving optimal texture in french fries. This, in turn, requires precise measurement of the effect of each processing operation on the mechanical properties of the fries. A puncture test was used to measure the effects of blanching and freezing on peak force of french fry strips. Potatoes (cv. Russet Burbank) were grown at two locations in Manitoba in 1994 and 1995. Two blanching treatments (a 1-stage process, and a 2-stage process with a low-temperature long-time step) were followed by blast freezing. Strip position within the tuber was found to be a major source of variation for mechanical properties. Because peak force varied widely within and between tubers, it was necessary to compare the efficacy of the two blanching regimes using a pair of strips taken from as close a position as possible in the tuber. For both locations and crop years, blanched french fry strips taken from the pith of the tuber (referred to as inner strips), exhibited higher peak force than outer strips taken from the cortex. The 2-stage blanching process decreased the variation seen in the mechanical properties of different potato strips. Overall, strips blanched by the 2-stage process had significantly higher peak force than strips blanched by a single blanching process. The effect of blanching was evident in the mechanical properties of strips even after freezing and thawing. Microstructural analysis revealed that cells in the outer strips had a "balloon-like" appearance due to the degree of starch swelling pressure generated by swollen granules. For inner strips, this "balloon-like" appearance was less evident. Such appearance is in support of the starch swelling pressure hypothesis. The research shows that measurement of the effect of processing can be achieved by comparing treatments on adjacent strips in order to minimize variation between strips, and that a 2-stage blanching treatment can ameliorate texture differences between strips taken from different parts of the tuber.

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ADDITIONAL KEY WORDS: Processing, starch swelling pressure, compositional variations, texture, puncture test.

INTRODUCTION

French fry texture is of critical importance to consumer acceptability. The texture associated with any cooked potato is largely determined by the mechanical properties of the parenchyma tissue. Within the tuber, compositional and anatomical variations are evident (Reeve *et al.*, 1970). These variations significantly affect the textural quality of french fries processed from the various regions of the tuber (Mohr, 1972).

Processing conditions play a crucial role in determining french fry texture. A typical french fry line consists of various process operations: blanching, drying, parfrying and freezing (Lingle, 1988), all of which can influence final product texture. Many investigations of texture have focused on the effect of heat on the properties of the cell wall and middle lamella (Andersson *et al.*, 1994), and on the extent to which textural changes are ascribable to either pectin changes (Sharma *et al.*, 1959) or to cell separation that is induced by starch swelling pressure acting on the middle lamella (Fedec *et al.*, 1977). The time-temperature treatment during the blanching process has a significant effect in this regard (Andersson *et al.*, 1994). For example, the beneficial effect of low-temperature blanching conditions on the texture of frozen vegetable products has been previously investigated (Steinbuch, 1976; Kawabata *et al.*, 1976; Canet *et al.*, 1984; Fuchigama *et al.*, 1995a; 1995b). Time-temperature treatment also affects texture in the freezing operation. Although freezing was generally found to cause losses in textural integrity, the rate of freezing was particularly important in determining final product quality (Canet *et al.*, 1984; Kawabata *et al.*, 1976; Fuchigami *et al.*, 1995a). Losses in textural quality during quick freezing was minimal whereas slow freezing caused extensive disruption of cellular components due to the formation of large extracellular ice crystals (Fennema, 1989).

The objectives of this study were: 1) to determine the effects of blanching conditions on the mechanical properties of french fry strips as measured by a puncture test; 2) to determine the extent to which differences in mechanical properties between the two blanching conditions were modified by a second process operation (freezing); and 3) to examine and quantify quality differences between french fry strips taken from different regions of the tuber.

MATERIALS AND METHODS

Plant Material and Storage

Processing potatoes (cv. Russet Burbank) were commercially grown at Shilo and Portage, Manitoba in 1994 and 1995. The potatoes were pre-conditioned at 15 C for two weeks. Temperature was subsequently dropped to 8 C at the rate of 1 C per week (Pritchard and Adam, 1992). The tubers were stored for approximately three months prior to use.

Selection and Marking of Strips

Average-sized tubers, approximately 6-7 cm wide and 12 cm long, were randomly selected from a 45 kg bag. Potatoes were washed, hand-peeled and cut into 1 cm strips using a mechanical french fry cutter (Bloomfield Industries, Chicago, IL). To minimize compositional variations within the tuber, one blanching treatment was compared to the other using a pair of strips taken from as close a position as possible in the tuber. Care was taken to hold the tuber firmly together as it came through the cutter. Tubers were divided into two halves along the center plane as shown in Figure 1. Five strips adjacent to the center plane were removed from one half-tuber while another five strips adjacent to the center plane were removed from the second half-tuber. Potato strips were marked 1-5 from the left to right side of the tuber with a permanent marker. Using this numbering system, strips 1 and 5 were designated the outer strips and strip 3 the inner strip. Because compositional variations occur from the stem to bud end of the tuber (Artschwager, 1924), these ends were distinguished from each other. By uniformly selecting the appropriate tuber end, the imprints of the french fry cutter grid on the stem end was used as a distinguishing mark.

Specific Gravity Determination

The specific gravity of potato strips was determined by the weight in air-weight in water method (Dean and Thornton, 1992) just prior to processing. All measurements were performed at a water temperature of 22±1 C.

The Processing Operations

Potato strips from one half-tuber were blanched in a temperature-controlled open-jacketed steam kettle (Dover Corporation, Elk Grove Village, IL) at 97±2 C for 2 min to inactive undesirable enzymes such as peroxidase (Canet *et al.*, 1984). To facilitate transfer into and out of the blanch

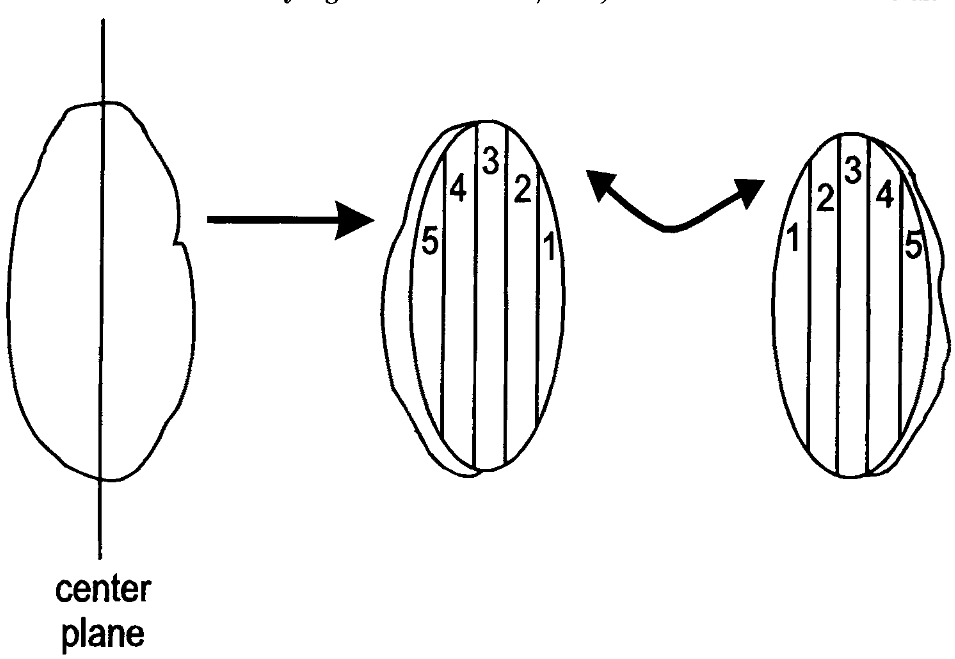

FIGURE 1.
Selection and marking of strips for comparing two processing regimes.

water the strips were placed in a metal basket with 3 mm spacings. The blanched strips were cooled to room temperature for 10 min prior to measurement of the mechanical properties. The time taken to attain room temperature had been previously ascertained by inserting a thermocouple into the center of the strip. This procedure was designated the "1-stage" blanching treatment. Potato strips from the other half-tuber were blanched first in a thermostat-controlled water bath at 70±1 C for 10 min. These strips were then cooled at 4 C for 2.5 min and blanched again at 97±2 C for 2 min in the temperature-controlled open-jacketed steam kettle. This blanching process was designated the "2-stage" blanching treatment. Because mechanical properties change with time, while strips from one half-tuber were being tested, raw strips from the other half-tuber were wrapped in moist paper towels and placed in a sealable plastic bag to prevent significant moisture loss. These strips remained in the bag for a maximum of 45 min prior to blanching. All blanching experiments were randomized.

In separate experiments, potato strips from one half-tuber were blanched by the 1-stage process and immediately frozen in a blast freezer at -20 C while strips from the other half-tuber were blanched by the 2-stage process and frozen under the same conditions. The frozen strips were thawed at room temperature for 2.5 h prior to the measurement of mechanical properties. Time taken to attain room temperature had been determined by inserting a thermocouple into the center of the strip.

Measurement of Mechanical Properties

The mechanical properties of the strips were measured using a 2 mm diameter flat-ended cylindrical punch attached to a 100 N load cell of a Chatillon Universal Testing Machine (Model ET 1100, John Chatillon and Sons, New York, NY). The punch was allowed to penetrate halfway (5 mm) into the strips at a crosshead speed of 2 cm min^{-1}. Four indentations were made on each strip, one at each of the stem and bud ends, 2 cm away from the end of the strip, and two in the middle, 5 mm apart. Prior to testing, the locations to be punctured were identified by dotting with the tip of a marker. Load-deformation data generated from the tests were recorded by a computer software program (Quick Basic software program, written at the Department of Biosystems Engineering, University of Manitoba).

Peak force was obtained from load-deformation curves and used as an index of textural quality. Peak force is defined as the maximum force (N) required to penetrate the strip and a high peak force would be interpreted as increased french fry firmness (Bourne, 1965).

Measurement of Volume of Cell Agglomerate of French Fry Strips

The method of Freeman *et al.* (1992) was used with some modification to examine differences between inner and outer strips. The first modification was that low specific gravity (LSG) (inner) and high specific gravity (HSG) (outer) strips were used instead of LSG and HSG tubers. The strips were cut to 1 x 1 x 8 cm by removing material from both ends. These strips were blanched by the 1-stage process. Secondly, because the blanched strips were too hard to be pressed between glass plates, a mechanical blender (Ivan Sorvall Inc., Norwalk, CT) was used to disrupt the tissue. The strips were homogenized in 50 mL of distilled water for 30 s.

Microscopy

A stereomicroscope (Model SZH, Olympus, Japan) and a fiber-optic illumination system (Model Lumina-1, Chiu Technical Corp., King's Park, NY) was used to examine structural differences between french fry strips. The strips were blanched for 30, 40 and 120 s at 97 C and cooled for 30 min at room temperature. The strips were cut into approximately 1 cm-thick sections using a sharp blade, rinsed with distilled water to remove surface-gelatinized starch and stained with 0.1% (w/v) iodine solution for 15 s. Excess iodine was washed off and the sections were viewed and photographed under the microscope equipped with a 35 mm camera (Model OM-2S, Olympus, Japan).

Experimental Design and Analysis

A paired comparison design was used as the experimental design. Statistical analyses were performed using the SAS computer software program, version 6.11 (SAS Institute Inc., Cary, NC). Analysis of variance was performed using the general linear model (GLM) procedure and differences between treatments were determined by Duncan's multiple range test ($p<0.05$). For experiments on the measurement of volume of cell agglomerate of french fry strips, statistical analysis was performed using the TTEST procedure for paired comparisons ($p<0.05$).

For the blanching and blanching/freezing experiments, five replicates were performed for each location in 1994 and 1995. For measurement of volume of cell agglomerate, eight replicates were performed for both Shilo and Portage using potatoes grown in the 1995 crop year. Specific gravity determinations of potato strips were performed on ten replicate tubers (i.e. 100 strips) for each location and year except for Shilo (1994 crop year) which was performed on five tubers (50 strips).

RESULTS AND DISCUSSION

Strip Position and Specific Gravity

The specific gravity of potato strips from different regions of the tuber is shown in Figure 2. For both locations in 1994 and 1995, a typical V-shaped curve was found in which the inner strip (strip 3) consistently had the lowest specific gravity and outer strips, 1 and 5, had the highest specific gravity. Sharma *et al.* (1958) and Sayre *et al.* (1975) also reported that potato strips from the inner region of the tuber had lower specific gravity than strips from the outer regions of the tuber. Strips 2 and 4, and likewise, strips 1 and 5, were not significantly different from each other with respect to specific gravity (Table 1) since the probability (p) value in each case is greater than 0.05. Consequently, the results of strips 2 and 4, and 1 and 5 were pooled together.

Effect of Strip Position on Mechanical Properties

The effect of strip position on peak force of french fry

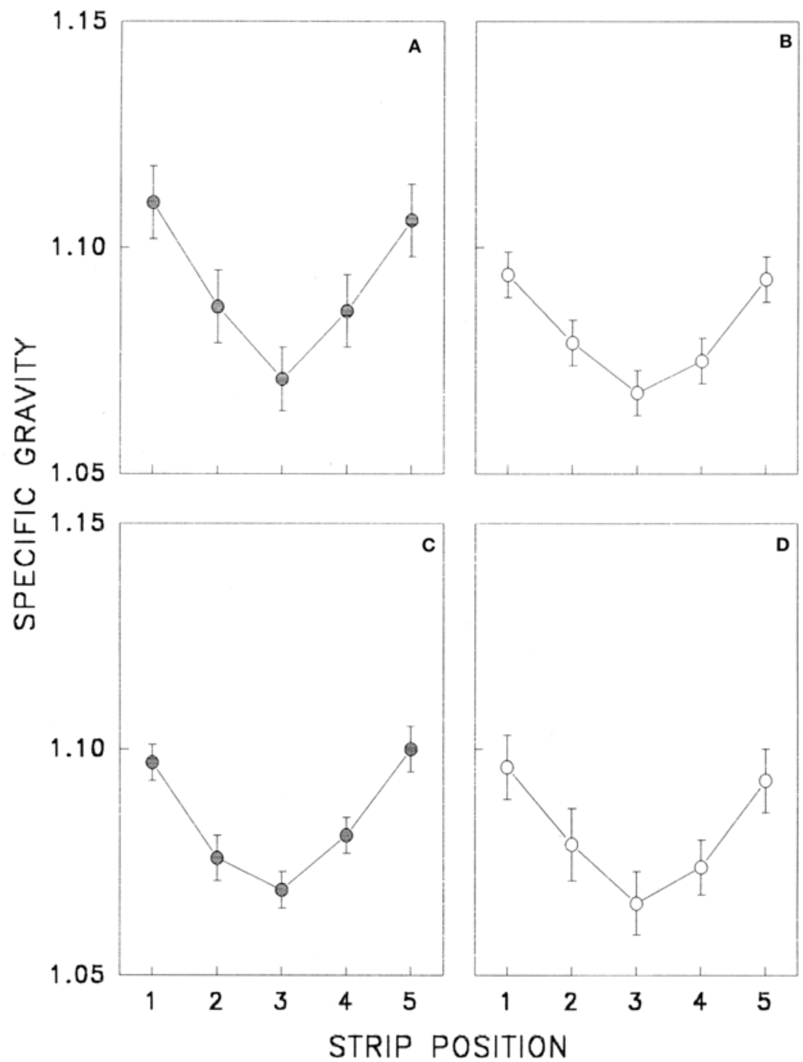

FIGURE 2.
Mean (n=10) specific gravity of potato strips from different regions of the tuber. Error bars are ± 95% Confidence Limits (CL). A - Shilo (1994) (n=5); B - Shilo (1995); C - Portage (1994); D - Portage (1995).

TABLE 1.—*Results of paired comparisons of specific gravity values of strips 1 and 5, and 2 and 4 for Shilo and Portage in 1994 and 1995 (n=10).*

Site	Year	Strips 1 and 5		Strips 2 and 4	
		T statistic[1]	Prob >T	T statistic	Prob >T
Portage	1994	1.01	0.3208	1.36	0.1832
	1995	0.70	0.4945	1.44	0.1575
Shilo	1994[2]	0.69	0.4945	0.27	0.7930
	1995	0.21	0.8320	0.91	0.3689

[1]The T statistic tests the null hypothesis that the means of a pair of strips are equal.
[2]n=5.

strips blanched by the two processes is shown in Figure 3. Strips I and II are the pooled data from strips 1 and 5, and 2 and 4, respectively, while strip III is the inner strip. For both blanching conditions, strips of low specific gravity (strip III) generally had higher peak force than strips of higher specific gravity (strips I and II), strip III values being, on average, 22% greater than those of strip I. This is consistent with the results obtained by Fedec *et al.* (1977) for longer blanching times. However, the results indicated that differences in peak force between inner and outer strips were decreased by blanching by the 2-stage process.

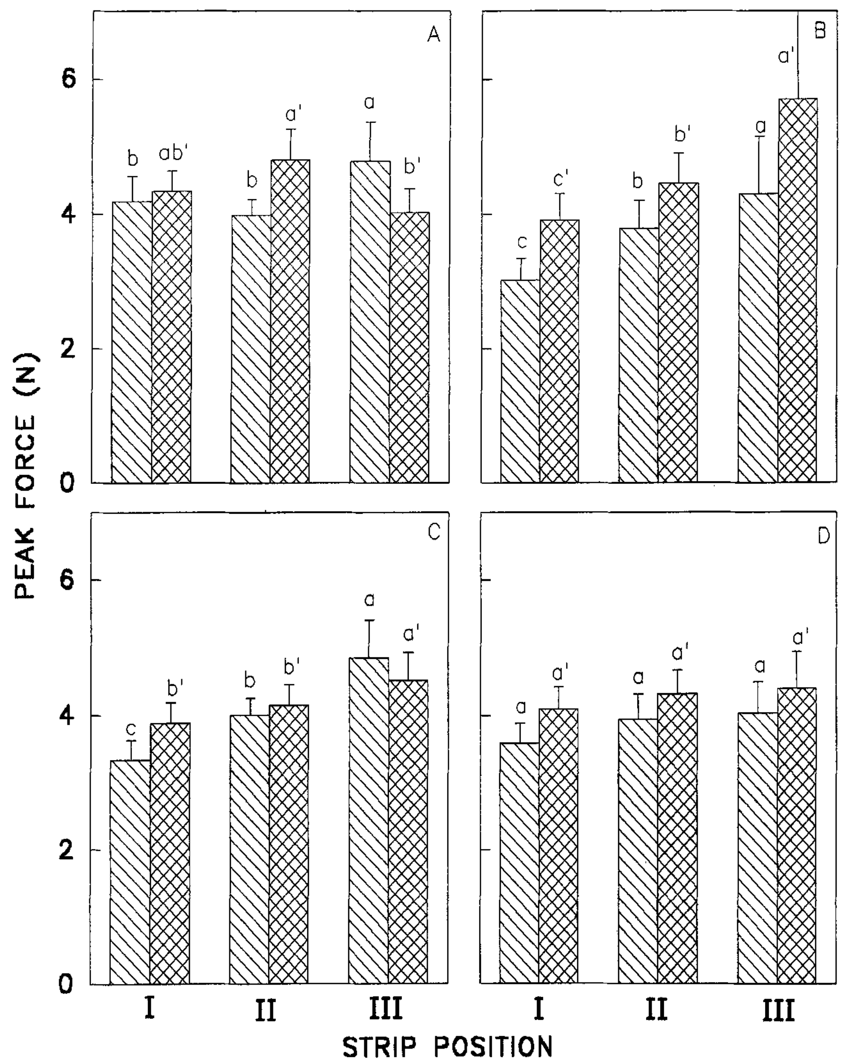

FIGURE 3.
Effect of strip position on mean (n=5) peak force of french fry strips blanched by two different methods. Error bars are ± 95% CL. The 1-stage process on the left (hatched) having means followed by different letters (e.g., a) are significantly different from each other (p<0.05). The 2-stage process on the right (cross-hatched) having means followed by a different letter with a prime symbol (e.g., a') differ significantly from each other (p<0.05). A - Shilo (1994); B - Shilo (1995); C - Portage (1994); D - Portage (1995).

For blanched and frozen french fry strips, although peak forces were approximately half those of blanched strips, a similar trend was observed: peak force was generally higher for strip III than for strips I and II (Figure 4). As with no freezing, differences between strip III and strips I and II were greater when strips were blanched in one step compared to the 2-stage process. It is therefore apparent that the effects of blanching were evident in the mechanical properties of the strips, even after freezing. These results concur with those of Canet *et al.* (1984) who noted that the effects of different blanching conditions could be seen in the shear rupture force of cooked potato tissue, even after freezing.

Overall Effects of Blanching Conditions on Mechanical Properties

Examining the overall effect of different blanching conditions for both Shilo and Portage in 1994 and 1995, peak force was generally greater in strips that had been blanched in two steps. On average, peak force for the 2-stage process was 12% greater than the 1-stage process (Table 2). These results are in agreement with those of Canet *et al.* (1984). Similarly, for blanched and frozen french fry strips (Table 3), the results indicated that peak force was greater in strips blanched by a 2-stage process, in this case, 19% greater.

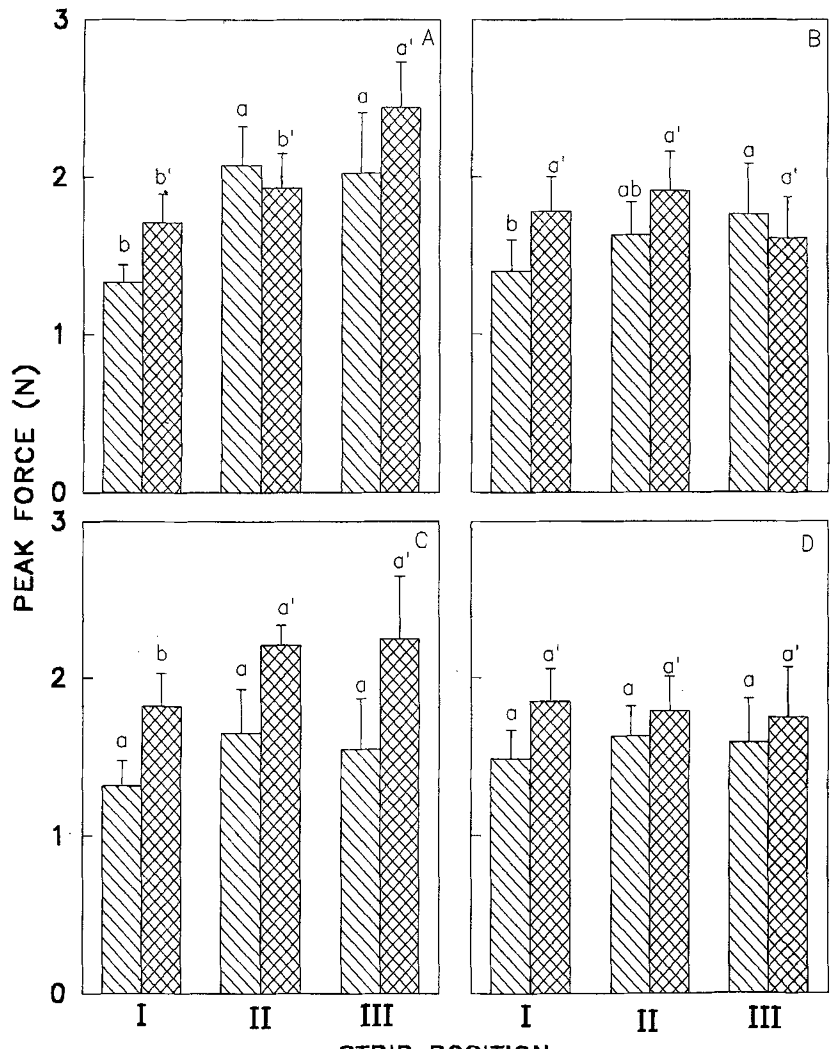

FIGURE 4.

Effect of strip position on mean (n=5) peak force of french fry strips blanched by two different methods and then frozen. Error bars are ± 95% CL. The 1-stage process on the left (hatched) having means followed by different letters (e.g., a) are significantly different from each other (p<0.05). The 2-stage process on the right (cross-hatched) having means followed by a different letter with a prime symbol (e.g., a') differ significantly from each other (p<0.05). A - Shilo (1994); B - Shilo (1995); C - Portage (1994); D - Portage (1995).

TABLE 2.—*Effect of blanching conditions on peak force of french fry strips from Russet Burbank potato grown at Shilo and Portage in 1994 and 1995.*

Blanching Conditions	Peak Force (N)			
	Shilo		Portage	
	1994	1995	1994	1995
1-stage	4.23a	3.59b	3.91b	3.82b
2-stage	4.46a	4.49a	4.12a	4.24a

Note: Values in columns followed by the same letter are not significantly different from each other using Duncan's multiple range test at p=0.05.

The extent to which structural changes occur in potato tissue during blanching is dependent upon the processing regime (Canet *et al.*, 1984). Low-temperature long-time conditions induce more structural changes than high temperature - short time conditions (Andersson *et al.*, 1994). Intercellular adhesion, due to formation of Ca^{2+}-pectate complexes (Haydar *et al.*, 1980) and amylose complexes (Linehan and Hughes, 1969; Hoover and Hadziyev, 1981) contribute significantly to these structural changes. Additionally, starch gelatinization and retrogradation during blanching are suggested to play an important role in structural changes in potato tissue (Canet *et al.*, 1984). Therefore, the extent of such changes would be more manifest in the strips subjected to 2-stage blanching.

Differences Between French Fry Strips

Differences in the measured mechanical properties between outer and inner potato strips were further investigated using the method of Freeman *et al.* (1992) where the volume of cell agglomerate passing through a 1 mm sieve was measured. Since both inner and outer strips have been comminuted for the same length of time, cells that adhere to each more strongly would be less prone to break down to smaller (< 1 mm) size; the 1 mm sieve would thus retain more material and reduce the volume of cell agglomerate. Conversely, a large volume passing the sieve is indicative of more friable intercellular adhesion. For both Portage and Shilo, the measured volume of cell agglomerate of outer strips was almost two-fold that of inner strips (p=0.0011 and p=0.0006, for Shilo and Portage, respectively) (Figure 5), indicating that intercellular adhesion in

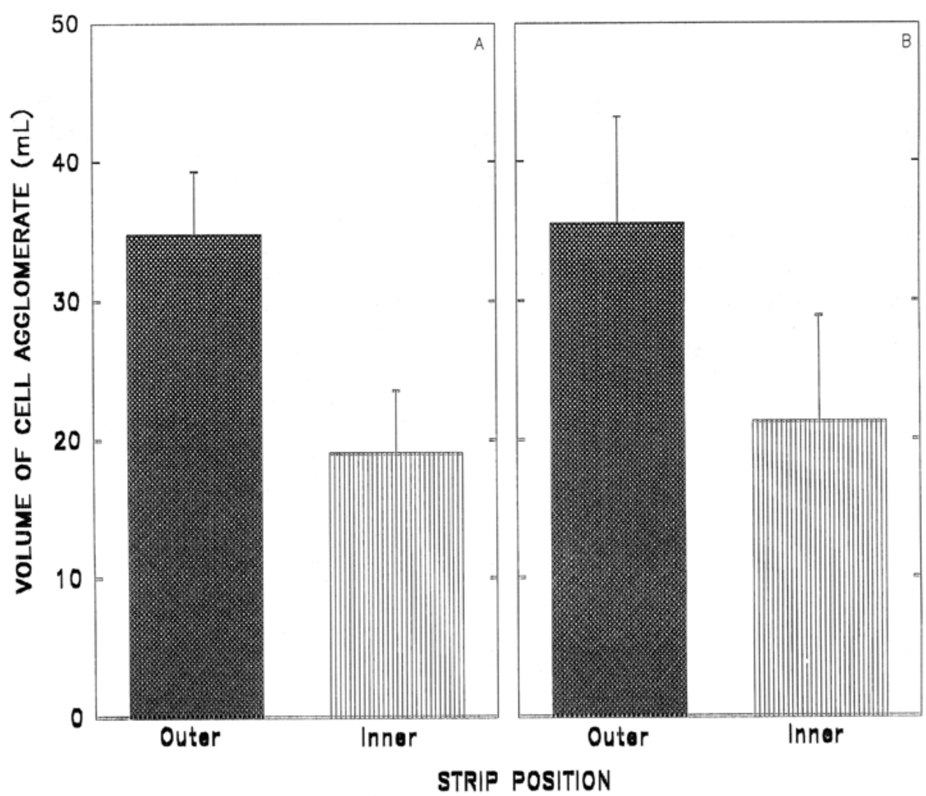

FIGURE 5.
Volume of cell agglomerate of inner and outer blanched french fry strips (n=8). Error bars are ± 95% CL. A - Shilo (1995); B - Portage (1995).

TABLE 3.—*Effect of blanching conditions followed by freezing on peak force of french fry strips from Russet Burbank potato grown at Shilo and Portage in 1994 and 1995.*

Blanching Conditions	Peak Force (N)			
	Shilo		Portage	
	1994	1995	1994	1995
1-stage	1.76a	1.56b	1.50b	1.56b
2-stage	1.94a	1.80a	2.02a	1.81a

Note: Values in columns followed by the same letter are not significantly different from each other using Duncan's multiple range test at p=0.05.

outer strips was poorer. These results are consistent with the findings of Freeman *et al.* (1992) who reported that tubers of high specific gravity had higher volume of cell agglomerate than tubers of low specific gravity.

Examination of the microstructure of inner and outer strips revealed that after 30 s of blanching (Figure 6), cells at the periphery of the strips which had received the most heat treatment contained gelatinized starch. Further inwards, the cells contained starch granules undergoing incipient gelatinization. The innermost part of the strip contained mainly ungelatinized starch granules. Differences in cell size were apparent between the strips, with inner strips containing smaller cells than outer strips. After 2 min (Figure 7), the cells in the outer strips were engorged with swollen starch granules appearing "balloon-like", probably due to the magnitude of starch swelling pressure. Such "balloon-like" appearance has been previously observed during cooking of potato tissue (Reeve, 1967; Fedec *et al.*, 1977). The cell walls of both inner and outer strips appeared intact and there was no evidence of cell separation after 2 min of blanching. Cell wall staining using 0.5% ruthenium red solution also indicated that no cell separation had occurred (results not shown). Jarvis and Duncan (1992) noted that cell separation was not apparent in potato tissue that had been boiled for 3 min.

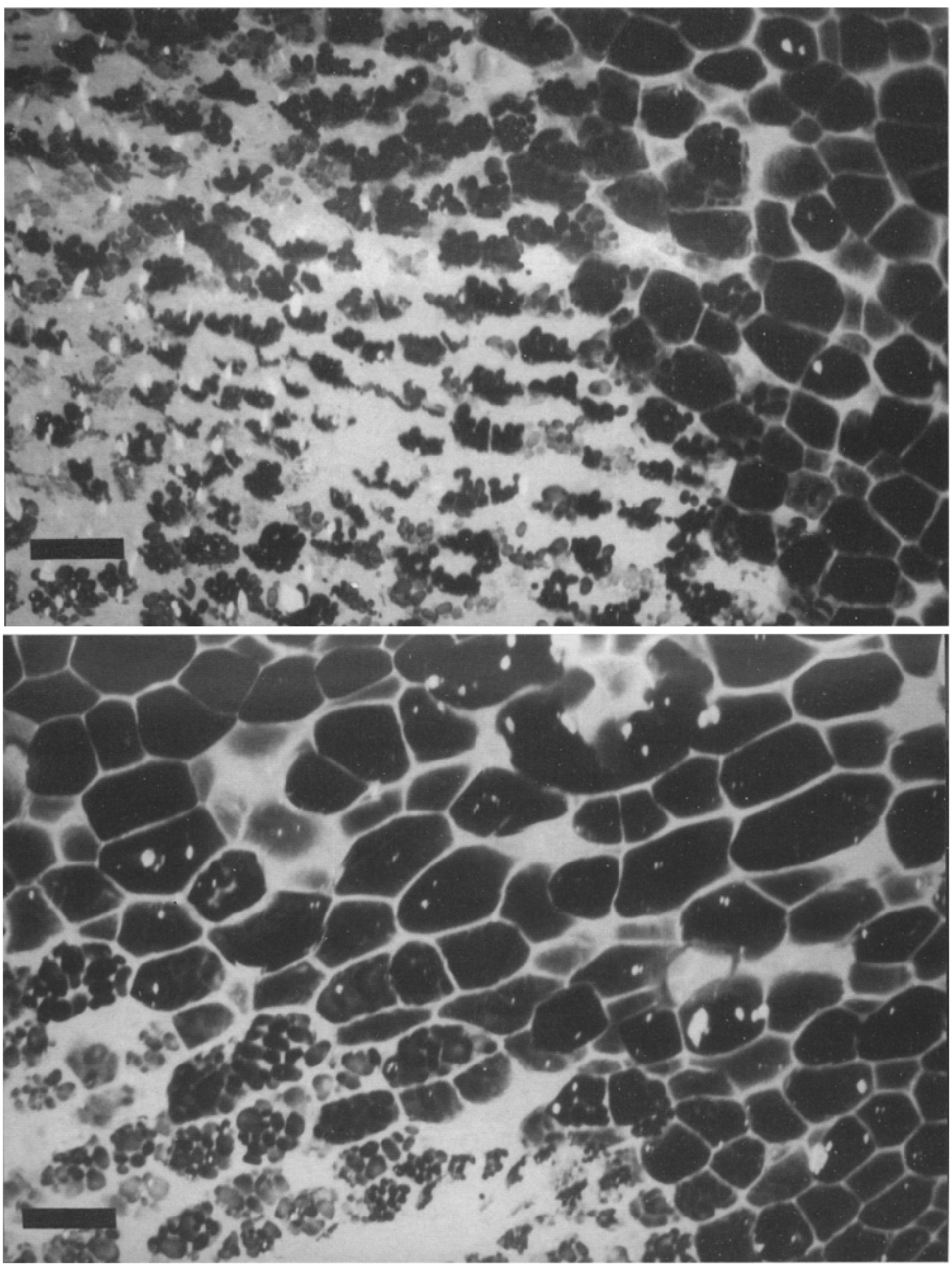

FIGURE 6.
Micrograph of inner and outer blanched french fry strips after 30 s of blanching by the 1-stage process. Micrograph shows top right-hand corner of a sample of 1 cm^2 in cross-sectional area. Top - inner strip; bottom - outer strip. Scale bar in bottom left hand corner represents 250 µm.

Blanching induces swelling of starch granules which creates a starch swelling pressure, analogous to turgor pressure in raw tissue (Jarvis *et al.*, 1992). The magnitude of starch swelling pressure appeared to be greater in outer strips due to a greater number of starch granules in the outer strips (Reeve, 1967). Starch swelling pressure induces deformation in the cell walls causing cells to bulge. Under an external stress, such as in a puncture test, the parenchyma cells deform away from the direction of the applied load. In the pre-stressed cells where swelling pressure is greater, less force is required to induce failure. Because starch swelling pressure appears to be greater in outer strips, maceration of these strips, where cells are more friable, results in a higher volume of cell agglomerate.

Effect of Puncture Location on Mechanical Properties

For both locations and crop years, the results showed that peak force was generally higher at the stem end than at the bud end (Table 4), being on average 39% higher at the stem end. These results were consistent for fries blanched by both conditions. Generally, the peak forces of the two middle puncture locations did not significantly differ from each other ($p > 0.05$). Similar trends were found for blanched and frozen french fry strips (data not shown). The stem and bud ends of tubers show a differential distribution of dry matter due to the deposition of starchy material during tuber formation (Artschwager, 1924), with the stem end having higher dry matter content than the bud end. These differences could influence cell wall characteristics such as wall thickness and consequently have an effect on the extent to which cell walls withstand starch swelling pressure. These results are in agreement with those

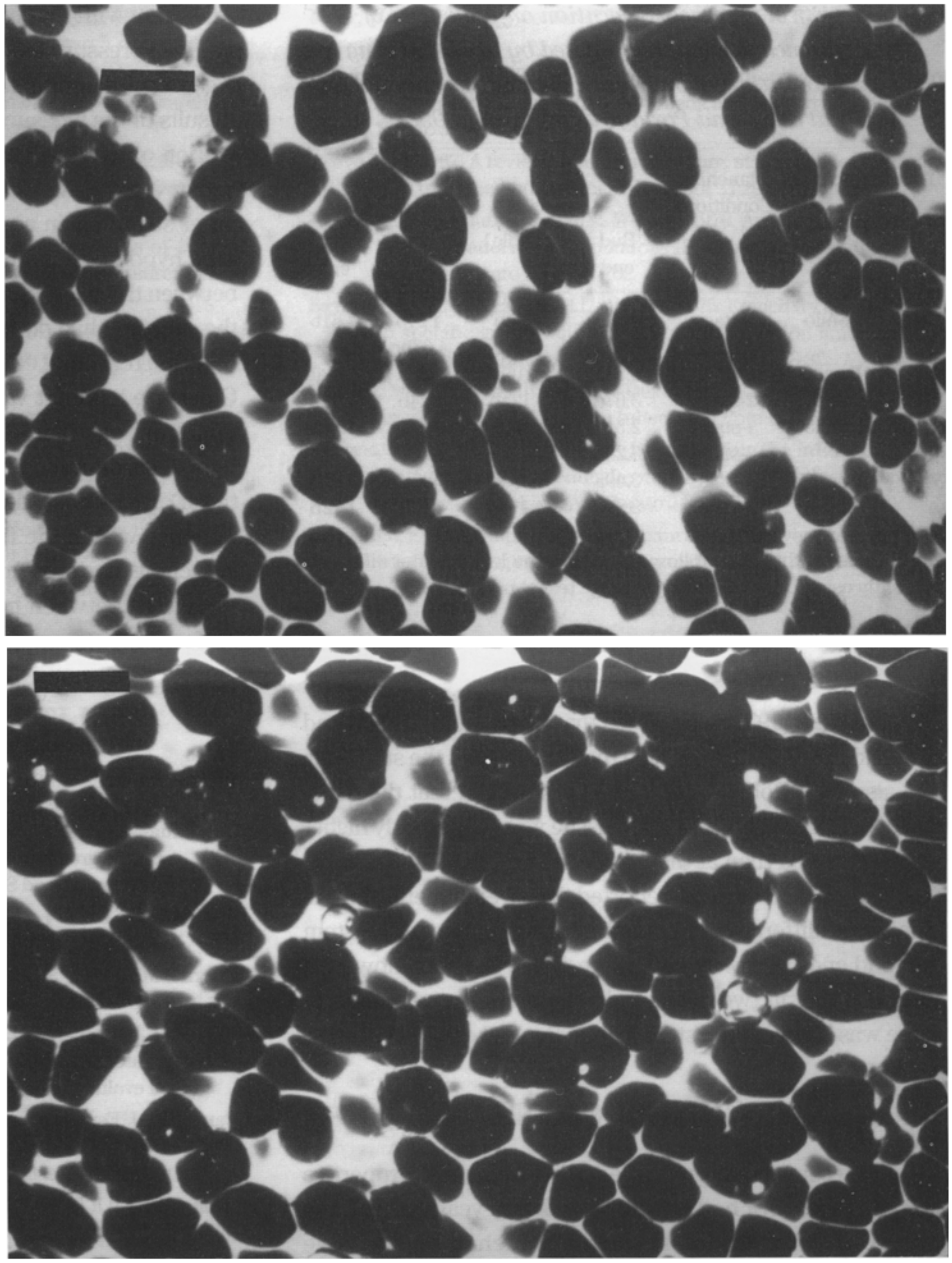

FIGURE 7.
Micrograph of inner and outer blanched french fry strips after 2 min of blanching by the 1-stage process. Micrograph shows top right-hand corner of a sample of 1 cm^2 in cross-sectional area. Top - inner strip; bottom - outer strip. Scale bar in top left hand corner represents 250 µm.

TABLE 4.—*Effect of puncture location on peak force of french fry strips processed by two blanching conditions from Russet Burbank potato grown at Shilo and Portage in 1994 and 1995.*

Year	Location	Blanching Conditions	Peak Force (N)			
			Bud end	Middle1	Middle2	Stem end
1994	Shilo	1-stage	3.54a	4.54b	4.21b	4.61b
		2-stage	3.63a	4.41b	4.67bc	5.13c
	Portage	1-stage	3.55a	4.16b	4.13b	3.80ab
		2-stage	3.67a	4.12ab	4.24b	4.43b
1995	Shilo	1-stage	2.51a	3.44b	3.53b	4.87c
		2-stage	3.23a	4.39b	4.75bc	5.58c
	Portage	1-stage	3.49a	3.78ab	3.80ab	4.21b
		2-stage	3.87a	4.17ab	4.21b	4.72b

Note: Values within rows followed by the same letter do not differ significantly using Duncan's multiple range test at p=0.05.

of Iritani *et al.* (1977) who stated that tissue from the bud end softened faster during cooking than tissue from the stem end, and also with Böhler *et al.* (1987) who noted that the penetration energy of cooked potato tissue was significantly higher at the stem end than at the bud end. Anzaldúa-Morales *et al.* (1992), on the other hand, reported that overall there were no significant differences in puncture force between the stem and bud ends of raw potato tissue. These authors, however, indicated that in two of five cultivars investigated, puncture force was higher at the stem than at the bud end of the tuber.

CONCLUSIONS

Processing conditions affect the mechanical properties of french fries. For both locations and crop years, peak force was greater for french fry strips blanched by a 2-stage blanching process than by a single process, on average 12% greater. The effect of blanching was evident in the mechanical properties even after freezing. Strip position within the tuber was found to be a critical determinant of the peak force values. This finding has serious implications for french fry processors. Inner strips, located in the pith tissue exhibited, on average, 22% greater peak force than outer strips taken from the cortex. Examination of the microstructure of blanched inner and outer strips indicated that during blanching the extent of starch swelling pressure appeared to be greater in outer strips than in inner strips. These results are consistent with the starch swelling pressure hypothesis. High swelling pressure induces deformation in the cell walls leading to intercellular failure when an external stress is applied. Results of the measured volume of cell agglomerate on maceration of strips indicated that outer strips had significantly higher volume than inner strips, indicating greater friability in outer strips, again consistent with the starch swelling pressure hypothesis. Differences in the mechanical properties between the stem and bud ends of the tuber were also found; the stem end had on average 39% greater peak force than the bud end, reflecting compositional variations within the tuber. Given the inherent variability in potato tubers, to minimize the effect of within-tuber variability in processing experiments it is advisable to compare different processing conditions on potato strips taken from as close a position as possible within the tuber. An additional low-temperature blanching step appears to be an effective means of reducing variability between inner and outer strips to attain greater uniformity in textural quality of strips leaving the blancher.

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