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OBJECTIVE MEASUREMENT OF TEXTURE VARIABLES IN RAW AND PROCESSED FRENCH FRIED POTATOES[1]

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ABSTRACT

The five most important variables encountered in french fry production and texture measurement are: specific gravity, raw potato storage, raw potato firmness, freezing of fried product, and cooling of hot french fry slices. Shear force curves are presented to illustrate the effects of these variables. A double maximum crust shear peak is exhibited by properly processed french fried potatoes when they are hot. Bursting of the crust is less evident with less desirable fries and with frozen and reheated samples. Shear press punch tests proved to be best for analyzing raw potato firmness. In order to determine and study the texture variations within a potato, Durometer[3] tests were conducted on concentric zones and sections from bud to stem end of most firm and least firm raw tubers. Higher resistance to penetration was encountered in the most firm potatoes. Durometer values vary directly with solids within a tuber which can be explained by certain morphological conditions. Because of turgidity, however, solids and Durometer values vary inversely between firm and non-firm tubers. A table is presented which lists the texture inferences derivable from changes which occur in the french fried potato shear force curves.

The production of frozen french fried potatoes recently exceeded an annual value of one billion dollars. In spite of this production, the industry has problems such as evaluation, control and improvement of texture as well as prediction of texture from the quality of the raw material. Many variables are encountered during laboratory-scaled french fried potato processing for use in texture evaluation and research. These variables include source, variety, storage, blanch, fry, freeze, frozen storage and reheat. Obviously, these variables must be studied and controlled before a valid method of texture prediction can be developed. Potato texture varies among different varieties and among samples of the same variety grown in different locations. Tubers grown in the same manner at the same location vary in specific gravity, size, shape and even in firmness among potatoes from the same specific gravity lot. In addition, potatoes change in texture at different rates during storage. Tubers themselves are far from homogeneous since the texture varies from stem to bud end and from inside to outside. If a valid texture prediction method is to be ultimately developed it is necessary to determine the effects of certain variables on shear and Durometer values and to determine the range of these objective values to be expected. For these reasons the following research was conducted.

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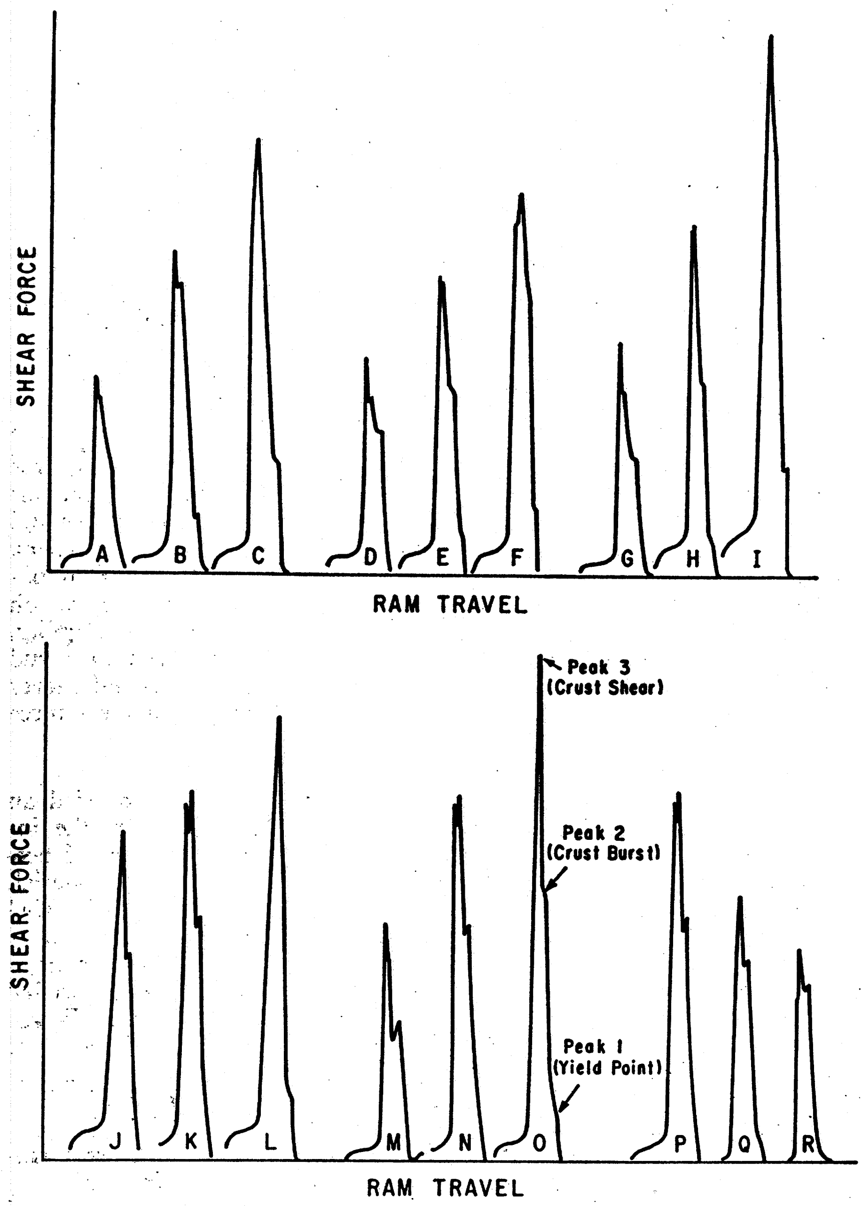

Fig. 1.—French fried potato processing variables.

	AUC (Integrator Counts)
A—Fried, frozen and oven heated 15 minutes	277
B—Same 20 "	433
C—Same 25 "	538
D—Fried, frozen and refried in hot fryer 1 minute	306
E—Same 2 minutes	406
F—Same 3 "	532

G—Fried, frozen and refried (starting with cold fryer)	12 minutes	313
H—Same	15 "	436
I —Same	18 "	720
J —5 min. fry after blanching	0 minutes	436
K—Same	6 "	495
L—Same	12 "	572
M—6 min. blanch before frying	3 minutes	294
N—Same	5 "	495
O—Same	7 "	512
P—6 min. blanch and 5 min. fry before cooling	0 minutes	495
Q—Same	10 "	335
R—Same	30 "	261

Materials and Methods

All tubers used in these studies were of the Russet Burbank variety grown in the same way each year at the same location in Idaho. They were stored at a constant temperature of 42 F (5.6 C) in a constant humidity room until processed or evaluated for raw texture. Fried and frozen strips were stored in a laboratory freezer at 0 F (—17.8 C). The standardized laboratory processing procedure previously published (6) was used exclusively. Three lots of tubers, selected into specific gravity groups of 1.080, 1.085 and 1.090 ± 0.0025 were stored for periods up to nine months.

An electronic recording shear press equipped with a Disc Integrator and a standard test cell was used for some of the experiments. However, because of the large number of closely spaced texture measurements required to study the variation of texture within single tubers, a Durometer, type A-2[3] (made by Shore Instrument Company) was selected for this work. Originally intended for rubber testing, this instrument has a small, truncated cone-shaped tip connected to a dial force indicator. Its small size would make it ideal for field tests. Sixteen Durometer readings were taken in each of three concentric zones, half on each side of five transverse cuts (see Fig. 4). Three most firm and three least firm tubers were selected subjectively from the 1.085 spcific gravity lot and were evaluated by the Durometer in this manner. Moisture determinations (vacuum, 60 F (15.6 C), 20 hr.) were made on samples from the bud and stem ends and from each of the three concentric zones.

Results and Discussion

A characteristic french fried potato shear force curve, showing the three distinctive peaks is indicated in Fig. 1. These peaks are identified in curve O. All curves read from right to left. These shear force curves can be used to point out and measure many french fry textural characteristics (Table 1). French fry shear force curves vary because of the differences in tubers and because of the nature of the processing of these tubers.

Processing variables include the time, temperature and nature of the raw potato storage; the time and temperature of blanch; the time and temperature of frying; the type of frying fat used; the type of fryer employed; the kind and amount of agitation during blanching and frying; the method of freezing; the type, time, and temperature of frozen storage; the

TABLE 1.—*Texture inferences from french fried potato shear force curve characteristics.*

High peak 3—Slices hot, desirable; dry if peak 3 too high; crust crisp; made from high specific gravity potatoes of low raw storage time.
Double peak 3—(at apex of shear force curve) approximately ideal potato processing.
Low peak 3—Slices undercooked; cooled; moist; crust flabby; made from overstored or low specific gravity potatoes.
Indistinct peak 2—Non-elastic crust cracks more than bursts (under shear) resulting in a slow pressure change; slices flabby; shear press recorder overdamped.
Distinct peak 2—Slices desirable; crust elastic.
No peak 2—Crust has cracks or holes; shear press recorder overdamped.
Low but distinct peak 2—Slice interior soft; weak but elastic crust.
No peak 1—Slices undercooked; shear press recorder overdamped.
Distinct peak 1—Unreliable indication of processing variables.
After peak—Supplies no useful information. Caused by the crushed french fry tissue between the intermeshing cell blades.
Variations in either source or variety will introduce variables in all the peaks. Crust shear drops off more rapidly than crust burst when french fry slices are cooled. Underprocessed slices have lower crust shear values than crust burst when cool. The longer the time that is required for the crust shear to drop to the crust burst value, the better the quality of the product.

type, temperature and time of reheating; and the amount of cooling before consumption or testing. Fig. 1 shows how six major processing variables affect the shear force curves. Each group of three curves, with the exception of the cooling curves, indicates the effect of underprocessing, approximately normal processing, and overprocessing.

When fry time is increased, the heights of peak 2 and peak 3, as well as the area under the curve (AUC) increases. Since blanching is also part of the cooking, increased blanching also increases these same parameters, but to a lesser degree since the temperature is lower. Peak 2 tends to be less prominent with overcooked samples. This is due to the firming of the slice interior and to the hardening of the outer surface. The former reduces the force drop after bursting. The latter causes the hardened crust to crack gradually instead of bursting suddenly as is usual with normally fried slices. On cooling, these parameters decrease but crust shear (peak 3) drops off more rapidly than crust burst (peak 2). When cooled, under processed slices possess a peak 3 lower than peak 2.

With frozen slices, longer oven-reheating or refrying also increases the second and third peak and the AUC. In frozen and reheated slices the peak 2 produced is less prominent than the peak 2 resulting from shearing freshly fried samples. This peak is the least prominent in curves from oven-reheated french fries and its prominence decreases with more time of heating. When french fried potato slices are frozen, the crusts undergo a structural alteration and, hence, are less firm after reheating than non-frozen strips. Instead of bursting, the frozen crusts tear gradually and the shear force second peak becomes less discernible. Refried frozen slices have crusts more like freshly fried slices than those reheated in the oven. The more prominent the peak 2, the more appeal the slices have to the consumer.

An interesting variation in the shear force curve is one having a double peak at the apex (peak 3). As the standard shear test cell blades approach each other during the shear operation, they first burst the crusts and squeeze out the inner contents. The applied force bends the remaining crust material into a sawtooth shape with the crust at a 45° angle to the test cell blades. With underprocessed slices, the blades merely shear the softer crusts and form a single peak. If the slices are overprocessed, the crusts are hard and completely crack at one time resulting in a single peak again. However, when the tubers are fried to the recognized appealing texture, the crusts are not homogeneous and the inner surface is much softer. Angular force imparted by the opposing blades causes the outer hard portion of the crust to shear and form a peak. Then the upper and lower crusts (with the softer parts in contact) slide past each other and the force relaxes slightly forming a valley. At the same time, new unsheared portions move between the blades. Finally, the force increases again until the unsheared portions are sheared and a second peak results The overall result is a double peak 3, with a small valley between, located at the apex of the shear force curve. Since the examples of effect of processing time were chosen arbitrarily and in even increments of time, all the double peaks in Fig. 1 are not of the same height. Apparently, specific gravity and storage have little or no effect on this phenomenon. In most cases, a well defined double peak 3, with approximately equal peak heights, will diminish significantly as the slices cool. The valley changes shape and the two peaks become unequal in height. However, little significance can be attributed to the relative heights of the unequal peaks.

Two specific gravity groups (1.080 and 1.090) of potatoes were chosen to study the effect of specific gravity and raw potato storage on the texture of fresh, and frozen and reheated slices. It has been previously demonstrated that the shear press is extremely sensitive to small diffences in specific gravity (6). Stored tubers were evaluated periodically for texture as raw slices, for texture after frying, and for texture after frying, freezing, and reheating. The measurements employed for raw slices included the shear force curve, peak 1 (yield point), peak 2 (sample cracking), and the area under the curve (work). Fried slice parameters measured included shear force curve peak 2 (crust burst) (2), shear force curve peak 3 (crust shear), and area under the curve (work).

High-speed photographic records of the shearing of raw potato slices proved that the standard shear test cell cracks the more firm raw potatoes before the cell blades meet (4). This obviously makes more difficult the evaluation of texture of a raw tuber by this method. However, several conclusions may be drawn from the data obtained on the 42 F (5.6 C) raw storage tests.

Potatoes of specific gravity 1.090 always produced fried shear force values higher than those of specific gravity 1.080 (Fig. 2, B vs. C). Non-frozen samples always demonstrated this result better than frozen samples. It was expected that frozen and reheated slices would give a much lower crust shear value (peak 3) because they tend to be less crisp and firm than non-frozen slices. However, the crust shear force for reheated frozen slices is only very slightly less than that for non-frozen slices (Fig. 2, C vs. H). In frozen slices, the crust has been damaged by freezing and tends to tear, rather than stretch, when put under tension. As a result, there is no definite stretching and bursting to give a prominent peak 2.

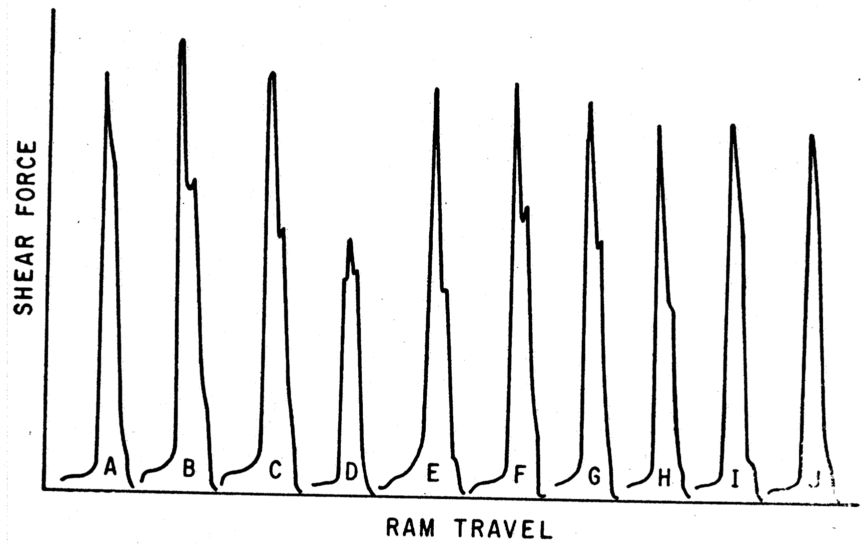

FIG. 2.—Factors that affect the French fried potato shear press crust burst peak #2.

	AUC (Integrator Counts)
A—1.090 sp. gr. tubers cooled 30 min. after a normal fry	406
B—1.090 sp. gr. tubers after a normal fry	481
C—1.080 sp. gr. tubers after a normal fry	465
D—1.080 sp. gr. tubers cooled 30 minutes after a normal fry	235
E—1.080 sp. gr. tubers stored 9 months then fried normally	354
F—1.080 sp. gr. most firm tubers after a normal fry	368
G—1.080 sp. gr. least firm tubers after a normal fry	336
H—1.080 sp. gr. tubers fried frozen and reheated	328
I —1.080 sp. gr. tubers stored 9 months then fried, frozen and reheated	327
J —1.080 sp. gr. tubers stored 9 months then fried, frozen, reheaed, cooled 30 minutes	312

which is a measure of the tensile strength of the crust. Further addiiton of force to the shearing phase of the operation (peak 3) produces almost the same value as obtained with freshly fried french fries.

Fig. 2 also illustrates the reduction in prominence of peak 2 that is caused by lower raw slice specific gravity (compare B and C), by 42 F (5.6 C.) raw potato storage (C vs. E and H vs. I), by less raw tuber firmness (F vs. G), and by fried slice cooling (A vs. B, C vs. D, I vs. J).

No major continuous decrease in shear parameters was observed during the nine months storage period. Raw tubers, however, became less firm during the long storage. The lack of significant shear force change is probably due to the fact that both the most firm and the least firm tubers gained in specific gravity by an average of about 0.008 to 0.009 units. This slight increase in solids apparently balanced any possible decrease in the shear values.

With stored and with unstored samples, specific gravity 1.080 potatoes exhibited an extremely large crust shear force drop (peak 3) after 30 minutes cooling as compared with specific gravity 1.090 tubers (Fig .2, A vs. D). Cooling time measurements illustrate the loss in quality in slices dur-

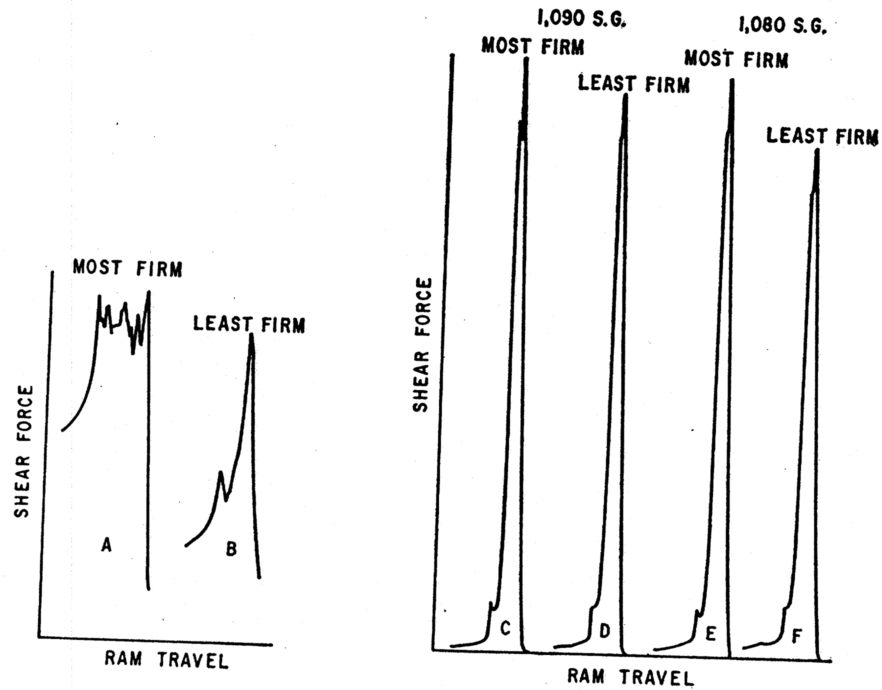

FIG. 3.—The effect of varying firmness on raw tuber shear press curves.
A—Most firm tuber in shear press equipped with a punch.
B—Least firm tuber in shear press equipped with a punch.
C—Most firm 1.090 sp. gr. tuber in shear press with standard test cell.
D—Least firm 1.090 sp. gr. tuber in shear press with standard test cell.
E—Most firm 1.080 sp. gr. tuber in shear press with standard test cell.
F—Least firm 1.080 sp. gr. tuber in shear press with standard test cell.

ing the time they are on the plate before consumption. Low quality, poor french fries deteriorate rapidly after only a few minutes cooling (5). Area under curve and measurements on peak 1 proved of little value for these comparisons.

One of the difficulties with evaluation of potato texture is the variation in firmness among tubers, even those of identical specific gravity. After 2 or 3 months storage, the differences in firmness are even more pronounced than when freshly harvested. The firmest and the least firm tubers in the 1.080 and 1.090 specific gravity classes were selected subjectively for these tests. Fig. 3 shows the results of shear press punch tests on these most firm and least firm tubers. The most firm tuber curve depicts a series of peaks resulting from a series of tissue cracks occurring as the punch was forced into the tubers. An immediate force drop after the yield point characterizes the least firm tuber punch curve. The standard shear test cell curves show the crackling peak 2 most pronounced on the high specific gravity firm tuber while lower specific gravity and firmness reduce the yield point (peak 1). It is obvious that high specific gravity, least firm potatoes could exhibit lower shear force values than low specific gravity, most firm tubers. From these curves it was deduced that raw tuber objective firmness evaluation is best made by use of any electronic recording shear press equipped with a punch. To eliminate the variation encountered in firmness of tubers of the same specific gravity, shear press punch tests can be run on the ends of raw tubers. The values obtained by averaging the bud end and stem end readings, can be used to select tubers of equal firmness for normal shear measurements on the remaining center pieces.

Measuring the texture of individual morphological zones of a potato was found to be extremely difficult. The following zones are present, beginning with the outside: (a) thin skin; (b) narrow cortex ring; (c) very thin xylem band; (d) wide perimedullary band; and (e) small pith zone in the center with pith rays branching out to the basal region of the eyes and again branching to the bud axes (3). To locate and measure the major texture variations within a potato, a small, rapid-reading, penetrometer-type instrument was needed. This requirement was filled by a Durometer. Despite the small size of the Durometer tip, the individual zones still could not be measured for this work in a practical manner. Instead, the potatoes were divided into six transverse sections and three concentric zones for comparison. The results are shown in Fig. 4.

The outer zones have higher solids contents than inner zones and they exhibit higher Durometer readings. Intermediate zone readings differ only slightly from those of the inner zones. Outer potato cells are smaller, have smaller vacuoles and have a higher percentage of cell wall material than inner cells, i.e. high solids, which accounts for the direct relationship between Durometer and solids values.

Stem end moisture contents are lower and Durometer readings are higher than the bud end values. Like the outer cells, stem end cells have a higher percentage of cell wall material and less moisture than the newer and more tender bud end cells (7). Once again, a direct relationship exists between Durometer readings and solids content.

An inverse relationship, however, exists between Durometer readings and solids content in most firm and least firm whole tubers. This relationship is apparently due to the higher turgidity of the higher moisture content, most firm tubers. More turgid cells resist Durometer penetration to a greater extent. This could be compared to a highly inflated basketball which resists penetration by the fingers more than does an underinflated ball. There is one exception to this relationship. As the Durometer value curve slopes upward from the bud end to the stem end, there is a significant decrease in the slope for most firm tubers and an increase for least firm tubers at the center section. Thus, the firmness of the center section of a least firm tuber is slightly higher than that of a most firm tuber. Loss of firmness, which increases with storage, apparently develops at the ends of the raw tubers. The difference in moisture content between most firm and least firm tubers of the same specific gravity is approximately equal to the standard error in the specific gravity-solids curve (1).

When processing potatoes for objective french fry texture research, texture variations due to the differences found within the tuber can be controlled by selecting slices from the same zone in each tuber. Since the perimedullary zone is the largest (includes from under skin to, but not

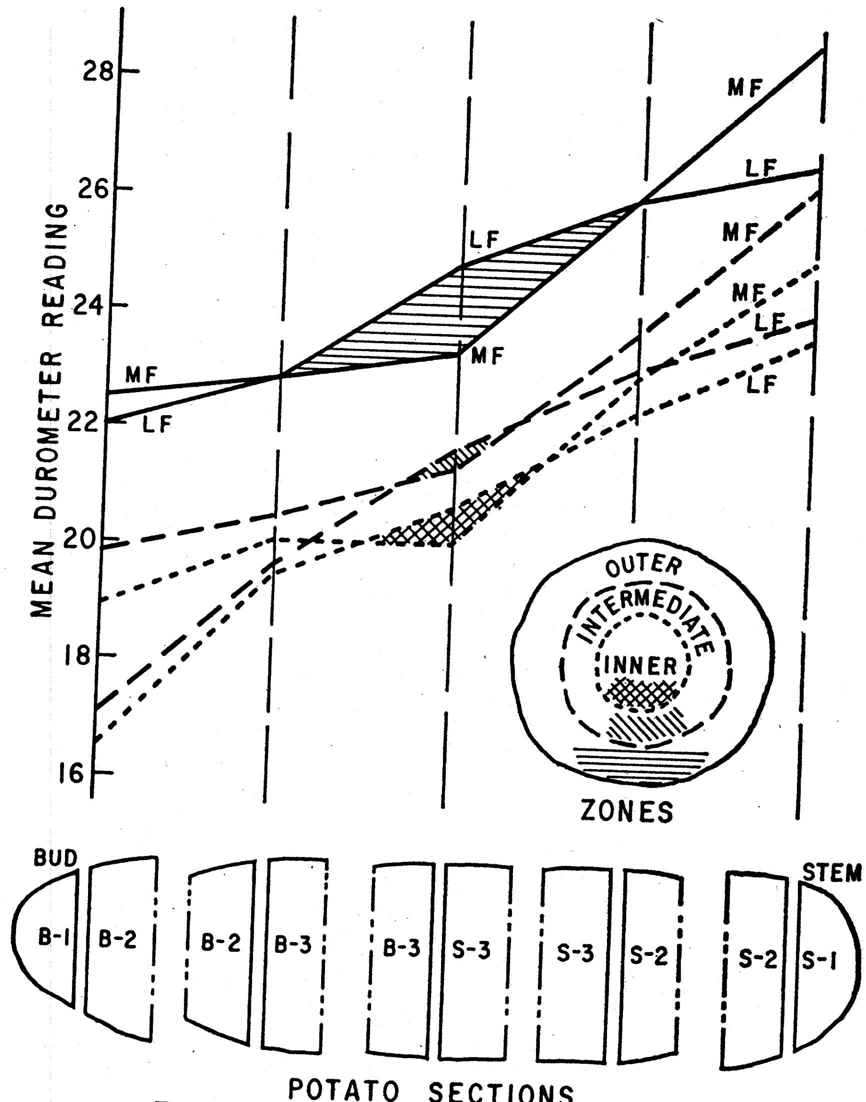

FIG. 4.—Spatial raw potato texture and moisture study.

Durometer reading at five different cuts and in three concentric zones of a potato. The sections are indicated by the vertical lines with the illustration below and the zones are indicated by the type of line used for the curve. Most firm tubers are abbreviated MF and the least firm tubers are marked LF. The moisture variation within a tuber is shown in the table.

Tuber Moisture

Most firm tuber	77.95%	Bud end	79.45
Least firm tuber	76.03	Stem end	75.48
Inner zone	79.48		
Intermediate zone	75.99		
Outer zone	74.56		

including, the pith in the center) all samples should be selected from this area. This method minimizes the percentage of outer zone tissue at the ends. In addition, the stem and bud end variation will be cancelled out by the presence of both. Because of the extremely variable nature of potatoes, all texture measurements should be repeated to obtain a reliable average.

Using these methods, future work will be aimed at developing a method for prediction of frozen french fry quality from tests of the raw material.

Acknowledgment

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