2992

INTERPRETATION OF MULTIPLE-PEAK SHEAR FORCE CURVES OBTAINED WITH FRENCH FRIED POTATOES

L. R. Ross and W. L. Porter[1]

Increasing experimentation with shear force determinations of food textures has revealed many interesting problems. Shear presses equipped with amplifiers and recorders produce multiple-peak shear force curves when multi-textured or non-homogeneous foods are tested. Individual peaks have definite and significant causes and their meanings may usually be interpreted logically by several relatively simple procedures. However, special precautions must be exercised and control methods must be carefully followed to minimize extraneous variables. Since food samples are inherently variable, precision sampling methods must be developed for each food product. The exact meaning and importance of each section of the shear force curve must be known in order to relate it to texture as defined by subjective or consumer reaction (4).

Shear is defined as an action or stress resulting from applied forces which cause two contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact. The force that is registered on a shear force recorder is composed of varying ratios of shear and compressive force. These ratios can be determined with various sized punches (1). When a force is loaded on or applied to a food sample, deformation (compression) takes place. Upon unloading, complete recovery of the sample to its original shape can only be demonstrated if the yield point or initial tissue breakdown point has not been exceeded (3). In addition, stress relaxation takes place whenever the shear press ram is halted. These parameters, in addition to multiple-peak shear force curves, yield pertinent information about the texture and quality of food products.

Early shear presses employed a directly connected, indicating pressure gauge on a hydraulic cylinder (2). With this equipment rapid pressure changes were impossible to record and accuracy and sensitivity were low. Later shear presses used a maximum reading dial gauge to measure the distortion of a proving ring or dynamometer. The maximum force indicated by this instrument, being a single texture parameter, is of little value in examining non-homogeneous or multi-textured foods. Maximum shear force values cannot be indicative of the total work performed and cannot show the significant intermediate force changes (5). Most of the recent shear presses have utilized a transducer mounted in the proving ring and the signal generated is amplified and recorded on a strip chart.

The procedures described here have resulted from an attempt to develop objective means to predict quality of French fried potatoes after frozen storage but they may have applicability to certain other foods of similar or less complex texture.

Early in these investigations it was noted that there was a very poor vocabulary available for relating the objective to the subjective results.

[1]Eastern Regional Research Laboratory, 600 East Mermaid Lane, Philadelphia, Pennsylvania 19118. A laboratory of the Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.
Accepted for publication, May 24, 1968.

So, it was found necessary to obtain material of known textural characteristics which could be defined subjectively and which produced results similar to those obtained in certain sections of the shear force curves from French fries. It is the purpose of this paper to describe our progress in the development of a working relationship between the objective and the subjective methods of determining French fry texture.

Materials and Methods

In these studies, an Allo-Kramer,[2] Model S-2HE Shear Press was used (3). The various capacity proving rings are interchangeable to cover the range of force values encountered with various forms of potato tissue. The inclusion of such standard features in the press as ram direction control, ram speed control, a safety by-pass valve adjustable for different proving rings and flexible hydraulic lines for vibration reduction allows the study of various force values with relative ease.

The Allo Model C-IS test cell, modified by a change to square bottom blades (rather than slanted blades) on the moving assembly, was used for all tests. To facilitate comparison of results from the older Model R-IE Recorder Indicator with those from the latest solid state Model M2EZ amplifier with zero suppress, a specially constructed instrument containing both amplifiers was employed. Signals from the transducer were formerly recorded on a six inch strip chart recorder with a direct mechanical drive linkage with the shear press ram which did not allow variation of the chart speed and thus the time axis. This, in addition to its slow speed, made quantitative measurements difficult. An Esterline Angus Speed Servo recorder, with 10 inch paper and a chart speed changer was, therefore, installed. This sensitive and versatile recorder is time based and has no mechanical connection with the shear press ram. It allows wide variations in the relationship of ram speed and chart speed and produces curves which can be accurately analyzed for area under the curve. A Dietzgen Model No. D1804AM optical reading polar planimeter with magnifying lenses simplifies this measurement.

Potato samples were stored at 50 F (10 C) until used, and all tubers were numbered with marking pen. Specific gravities of the individual tubers were determined by weight in air and in water. To limit variability due to differing solids content, the tubers were grouped by specific gravity. Fried samples were normally prepared from a single specific gravity increment (range 0.005 units) and 400 g of well sampled, 3/8″ x 3/8″ x 2 5/8″ slices were processed at the same time. Room temperature slices were water blanched at 175 F (79.4 C) for 6 min, with occasional agitation, and drained for one minute. These slices were then fried at 365 F (185 C) for 5 minutes, with occasional stirring, in a 15 lb capacity, 4500 watt electric fryer. Lever Brothers' "Covo, Pure Vegetable Shortening, with methyl silicone," was used for all tests. The slices were shaken in the fry basket to remove excess oil. For shear testing, seven slices were laid in a single layer in the test cell, perpendicular to the cell elements. Shearing was started 45 sec after the slices left the fryer and the ram speed was maintained at 0.117″/sec (30 sec for full ram travel). The amplifier range switch was set at 500 lb full scale for fried slices

[2]Mention of company or trade names does not imply endorsement by the Department over others not named.

and at 1000 lb full scale for fresh slices. The recorder chart speed was set at 8 inches per minute.

Results and Discussion

There are three important observations associated with shear measurements for French fried potato texture, namely: (i) maximum force required for shearing; (ii) the shape of and the area under the entire shear curve; and (iii) the stress relaxation exhibited by the sample after stopping the ram travel. The original amplifier and recorder were capable of producing reliable data for the first criterion but not for the second and third. The overshoot, characteristic of this instrument, cast some doubt on the reliability of the individual peak data. However, with the newer instrument the peaks were found at the same locations without overshoot and, in addition, were sufficiently expanded for quantitative purposes. The larger high speed recorder produces larger curves and with its greater speed indicates more minor variations in compression and shear. Although organoleptic evaluation failed to detect differences among tubers varying by as much as 0.03 specific gravity units in a lot, the shear force testing apparatus, herein described, is capable of detecting shear curve differences between tubers differing by less than 0.005 specific gravity units. For this reason, all tests must be made on a relatively narrow specific gravity range. The variable speed available for the chart paper allows further expansion of the time axis and the zero suppress feature amplifies any desired section of the curve. Thus, areas under the curve can be measured more accurately with a planimeter. On a mechanically connected recorder as used earlier, the chart paper stops moving when the ram travel ceases. With the time based recorder, the recording of stress changes continues after the ram stops moving and stress relaxation data are automatically obtained.

Earlier work (5) has shown that relaxation of the individual peaks of the shear curve to actual events is made possible by use of a single layer of slices in the test cell. Under these conditions the order of events, indicated by peaks on the curve, is as follows: (i) yield point (crushing of cells); (ii) crust burst; (iii) crust shear; and (iv) squeezing of the remaining material between the blades and the cell elements.

The meaning of each part of the shear force curve may be studied by examining the curves produced by shearing of common substances that possess simple textures. A slight modification to the shear press, for the first curve interpretation method only, assists in demonstrating these texture differences.

The tracing obtained by the multiple blade shearing cell is produced in about 5 seconds and the large number of blades tends to average out small events .The exceptions are those produced by cell crushing, crust burst, and crust shear. To study these minor events, to evaluate both very hard and very limp substances and to understand and interpret shear curves more thoroughly, a flexion cell was designed. This new cell is shown in Fig. 1. The metal fingers that flex the sample intermesh but do not touch.

A list of common substances and their subjectives texture descriptions are shown in Table 1. Fig. 2[3] illustrates the flexion cell force curves for these substances. The lumpy putty curve (a) illustrates the gradual force

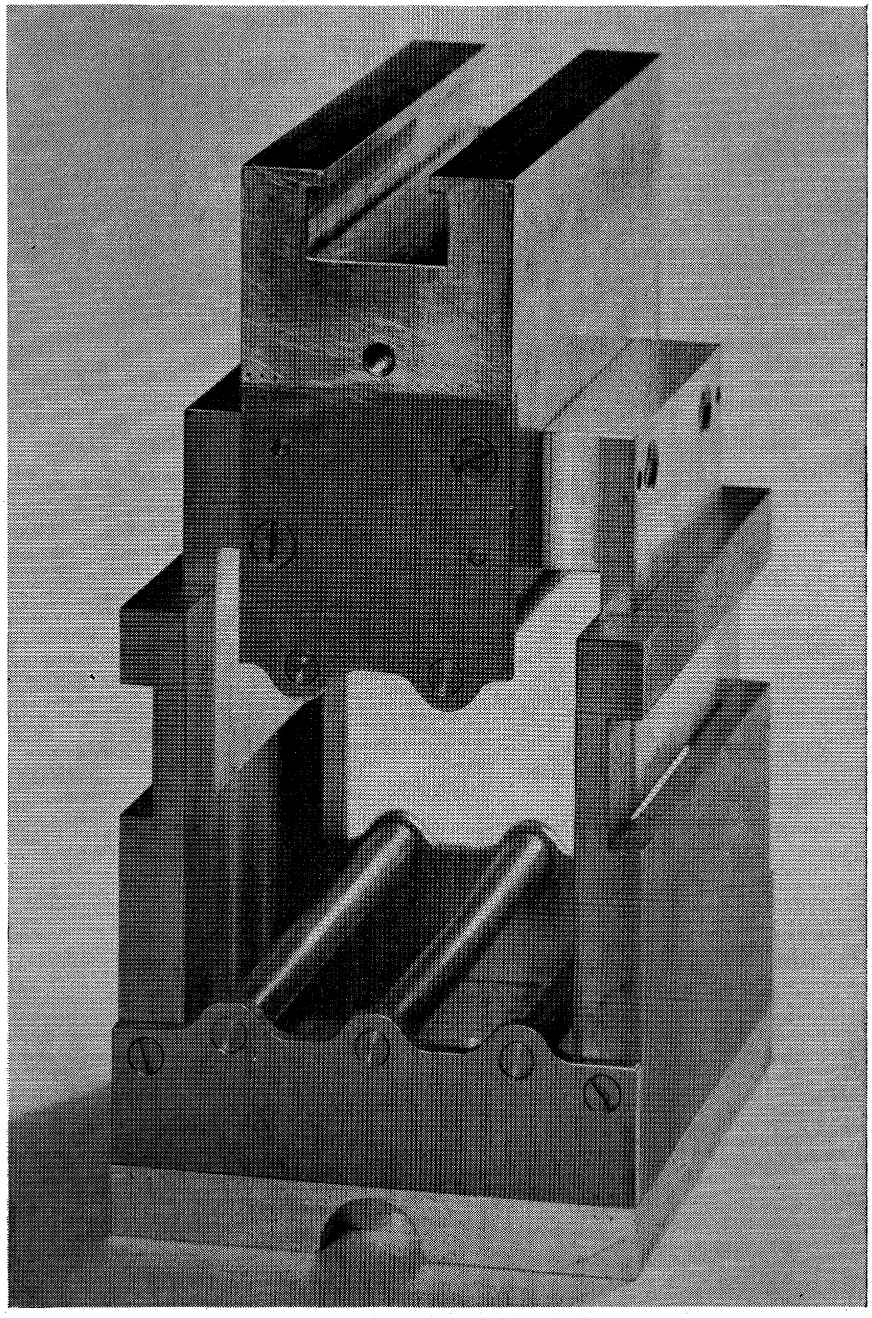

Fig. 1.—Shear press flexion cell.

TABLE 1.—*Description of materials of different textures as determined subjectively.*

No.	Material	Descriptive adjectives
1	Putty with lumps	Soft, plastic, extensible
2	Art eraser	Soft, crumbly, pliable
3	Rubber tubing	Soft, flexible, pliable
4	Cellulose sponge	Soft, tough, pliable
5	Wooden match	Hard, tough, fibrous
6	Fresh, firm potato tuber	Hard, firm, implastic, brittle
7	Old, stored potato tuber	Soft, flexible, pliable

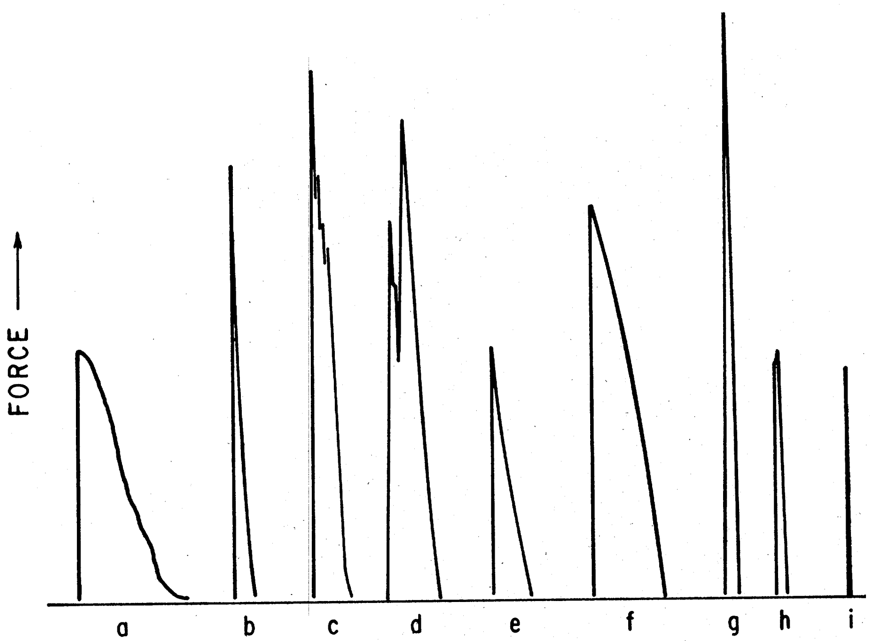

FIG. 2.—Flexion cell force curves

a. Putty containing lumps
b. Old flabby potato
c. New firm potato
d. Art eraser
e. Rubber tubing
f. Cellulose sponge
g. Wooden applicator (1/6″ dia.)
h. Wooden coffee stirrer (1/6″ x 1/4″ section)
i. Glass capillary

build-up typical of soft substances while the irregular shape indicates the uneven texture. A coarse cellulose sponge (f) yields a similar curve with smaller irregularities due to the porosity. An art eraser (d) is also soft but it cracks and gives the typical sudden force drop and subsequent partial recovery. The firm potato (c) shows several smaller cracks which

[3]The design of the recorder is such that the curves are drawn from right to left resulting in a mirror image of the usual plots.

would appear larger if the degree of flexing were increased. An old flabby potato (b) is pliable and hence does not crack. Rubber tubing (e) is soft and elastic so the force builds up in a gradually sloping but straight line. The wood applicator (g) is hard so the force build-up is rapid but straight. A higher degree of flexing would cause cracking as exhibited with the more brittle wooden coffee stirrer (h). Hardest of all is the glass capillary (i). Force build-up is almost instantaneous and, of course, in a straight line. In general, gradually sloping curves are produced by soft substances, sharply sloping curves are produced by hard substances, sudden decreases and partial recoveries of force are due to cracking or bursting, and wavy curves are produced by non-uniform texture or inclusions.

Another method of shear force curve interpretation involves the synthesis of similar multiple peak curves from combinations of substances with known textures (Fig. 3). Cooked potato slices coated with collodion (b) exhibit a crust shear peak and a crust burst peak similar to French fries. Styrofoam (c, d) exhibits a higher crust shear peak when sandwiched between papers. A polyethylene bag (e, f) filled with air shows a wide break in the curve where the force stopped after bursting and before the final shearing of the bag material. The width of the break is proportional to the amount of air. Two breaks in the force curve can be demonstrated by two polyethylene bags of air — one within the other (g). By these and similar syntheses, the shear force curve of French fried potatoes may be studied.

The third method for interpretation of the shear force curve involves the dissection of the multi-textured sample in question. Fig. 4 illustrates the curves from dissected French fried potato slices. It is obvious that the areas of the crust and the interior shear force curves do not add up to the area of the intact slice. Because the crust seals in the interior material, it must burst before the soft interior can be squeezed out from between the layers of crust. If the crust is broken in any way, the second or crust burst peak will all but disappear. This method proves the crust or skin effect on shear curves from French fries or similarly textured vegetables or fruits. The second peak is really a measure of the crust's tensile strength and the following valley is a measure of the resistance of the French fry interior to the shear cell elements.

A fourth method of interpretation involves the comparison of the shear curves with the actual observed condition of the sample during shearing. Shear test cells are small, opaque and removal of partially sheared French fry slices is a sticky problem. The open, large, hand-operated demonstration shear press, previously described (5), allows complete observation and photography. Rapidly spaced photographs are taken as the ram is slowly lowered. The percentage of the total ram travel on the shear curve is then determined for each event. When the picture is located that shows the same percentage ram travel as the event being studied on the curve, this picture then accurately depicts the condition of the sample during this event (Fig. 5). The indications of compression, crust burst, crust shear, fresh sample cracking, etc. may be located by this method. It must be borne in mind, however, that the width of a firm fresh potato slice curve is less than that of its fried counterpart because the fresh slices crack completely during shearing. Then the force

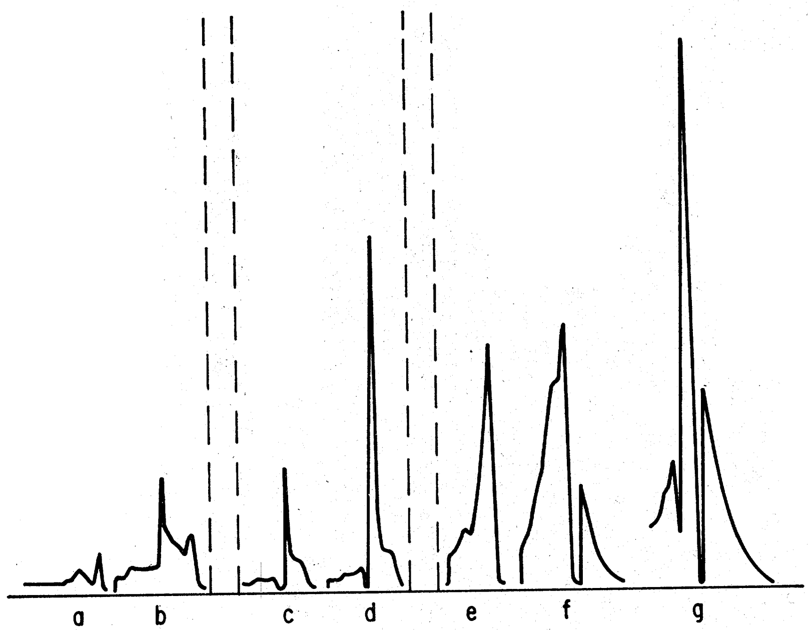

FIG. 3.—Shear force curve synthesis

a. Cooked potato slice
b. Same coated with collodion
c. Styrofoam slab
d. Same between papers
e. Empty polyethylene bag
f. Same filled with air
g. Same within a larger air filled polyethylene bag

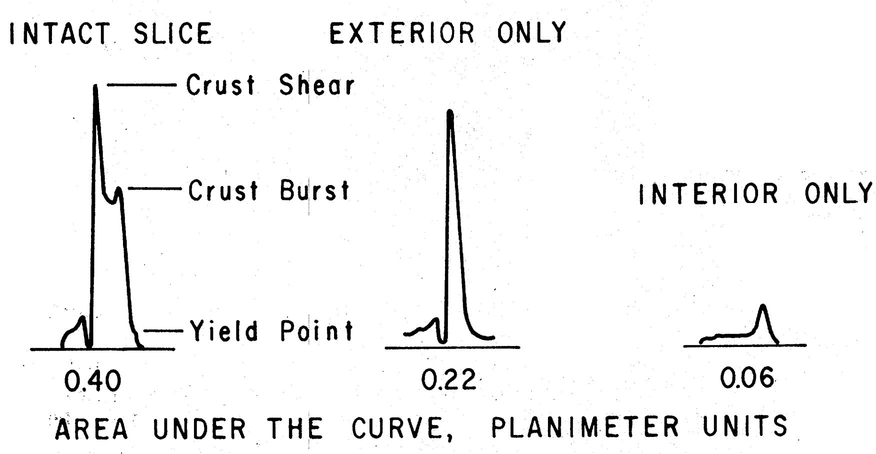

FIG. 4.—Shear curves of dissected French fried potato slices.

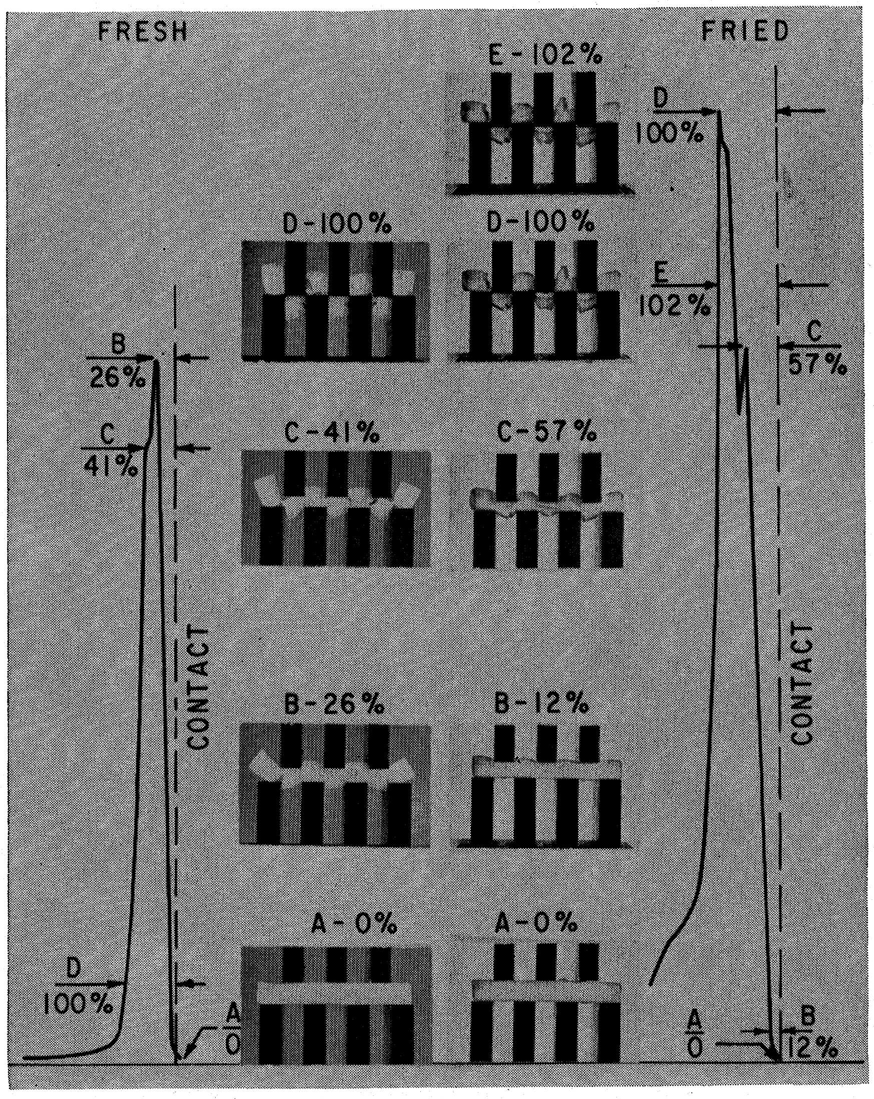

FIG. 5.—Comparison of potato shear force curves with photographs of corresponding events.

falls off to zero before the cell elements meet and the curve width is reduced.

Finally, fry time and cooling time curves of French fried potatoes (Fig. 6) may be usefully employed to trace the progress or degradation of each texture component (4). When potatoes are fried, the interior tissue softens and the crust shear and crust burst peaks increase. Upon cooling, the crust becomes flabby because of the interior moisture re-

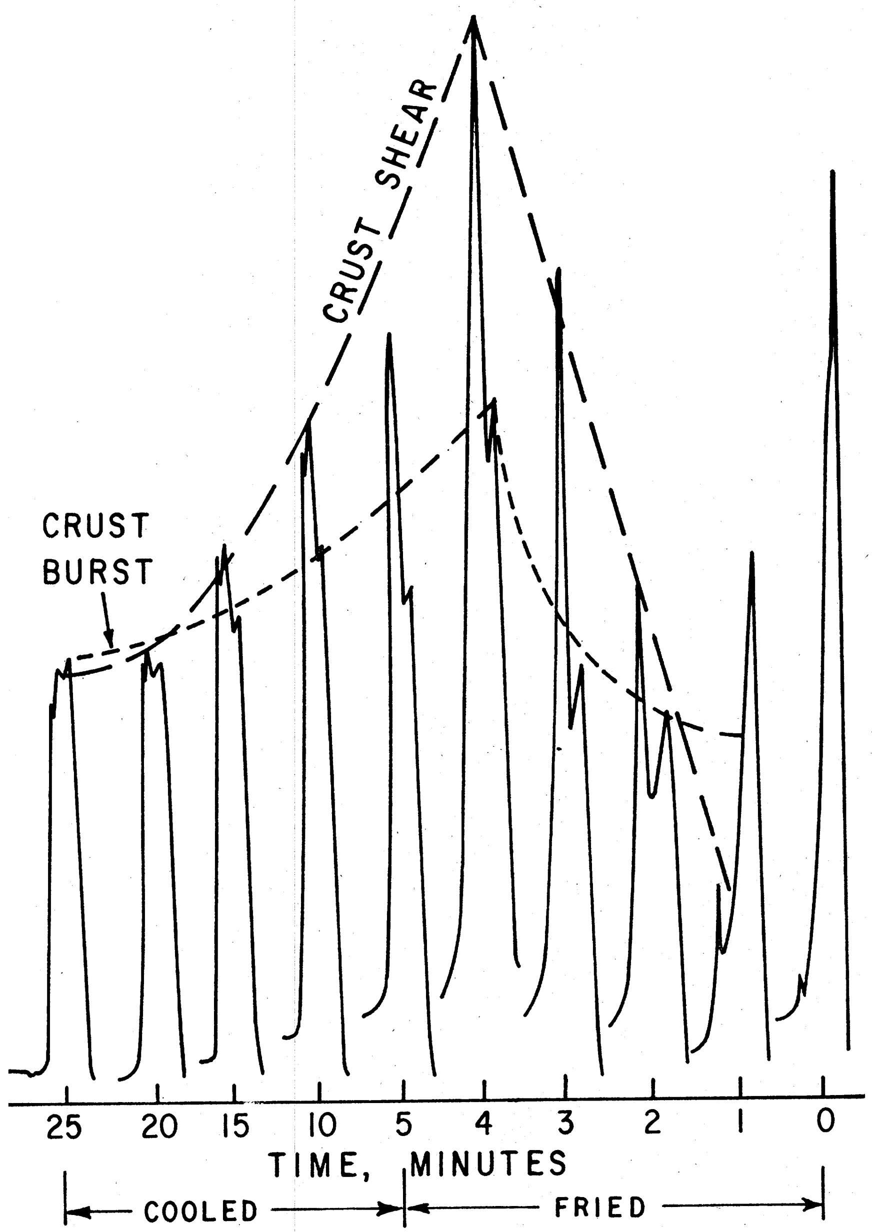

Fig. 6.—Effect of frying and cooling time on shear force curves of French fried potatoes.

distribution and crust shear falls off until it becomes a smaller value than thec rust burst peak. If the two curves intersect after only about 5 min cooling, the product quality is poor. If, however, the intersection takes place after 30 min cooling, the quality is excellent. High specific gravity of tuber usually produces the latter type of curve and fry time must be decreased or increased for high or low specific gravity potatoes to meet these conditions. In practice, the longer it takes before the curves intersect means that the last partially cooled French fried on your dinner plate will be almost as firm as the first hot ones.

The preceding discussion shows how shear force curve structure can be related to actual events which occur during the testing of heterogeneous food products. The quantitative approach to evaluations of complex food textural problems is brought nearer to reality by the instrumentation used here.

Summary

A commercial shear press with an electronic amplifier and recorder was used for quality and texture studies of French fried potatoes. A new type of experimental shear press flexion cell is described. Methods are presented for modifying available instruments to facilitate interpretation of multiple-peak shear force curves. Five procedures are listed for interpretation of such curves from non-homogenous food products like French fried potatoes. These are the comparison of the objective curves of substances with known subjectively evaluated textures, the synthesis of similar curves from less complex materials, the dissection and subsequent individual shearing of component textural fragments, an open demonstration shear press combined with rapid photography, and the detailed study of fry time and cooling time curves.

Resumen

Una prensa comercial de presión con un amplificador eléctrico y registrador fue usado para estudiar la calidad y textura de las patatas fritas. Un nuevo tipo prensa experimental de célula de flexión es descrita en este trabajo. Se presentan métodos para modificar instrumentos ya disponibles para facilitar la interpretación de los picos múltiples de las curvas de fuerza de la gráfica registrada. Cinco procedimientos se describen para ayudar a interpretar dichas curvas obtenidas de productos no homogéneos como patatas fritas. Estos son: las comparaciones de las curvas objetivas de substancias de conocida textura evaluados subjetivamente; la síntesis de curvas similares obtenidas de materiales menos complejos; la disección y corte individual subsecuente de los componentes texturales de los fragméntos; una demostración de la fuerza de presión, abierta, combinada con fotografía rápida; y un estudio detullado de las curvas del tiempo de freir y enfriar.

Acknowledgment

The authors are indebted to Walter C. Sparks of the University of Idaho Agricultural Experiment Station for the specially grown potato samples and suggestions on the design of the flexion cell, and to William Eglinton for its construction. Also, the authors would like to acknowledge the able assistance of Robert O. Pierce in the preparation of samples.

Literature Cited

1. Bourne, M. C. 1965. Studies on punch testing of apples. Food Technol. 19: 413-415.
2. Kramer, A., G. J. Burkhardt, and H. P. Rogers. 1951. The shear press: a device for measuring food quality. Canner 112 (5): 34-36, 40.
3. Mohsenin, N. N. 1963. A testing for determination of mechanical and rheological properties of agricultural products. Penna. Agr. Exp. Sta. Bull. 701.
4. Porter, W. L. and L. R. Ross. 1966. Factors affecting the textural quality of French fried potatoes. Proc. Plant Sci. Symposium, Camden, N. J., Campbell Inst. Agr. Res., 27-39.
5. Ross, L. R. and W. L. Porter. 1966. Preliminary studies on application of objective tests to texture of French fried potatoes. Amer. Potato J. 43: 177-183.