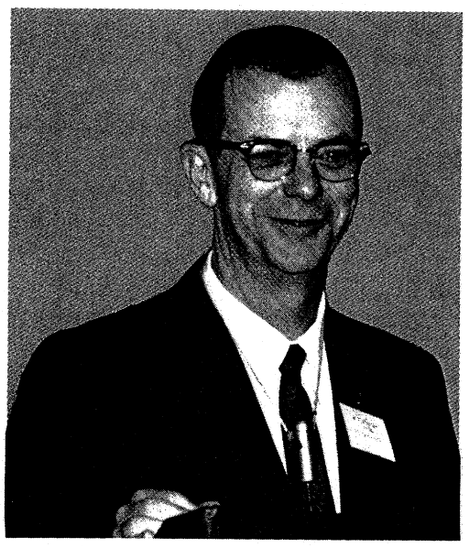
2516

Reprinted without change of paging
from
Proceedings
Plant Science Symposium
1966

Campbell Institute of Agricultural Research
Camden, New Jersey

FACTORS AFFECTING THE TEXTURAL QUALITY OF FRENCH FRIED POTATOES

W. L. PORTER AND L. R. ROSS
Agricultural Research Service, U.S. Department of Agriculture
Philadelphia, Pennsylvania



In any analysis of factors affecting the quality of a processed product, it is important that a discussion of the available yardsticks of quality be presented. There are often differences of opinion among consumers as to what constitutes ideal texture. However, such a discussion almost always leads to ambiguous terms which are difficult to describe and many times leads to disagreement among those involved. This paper describes the French-fry quality factors we usually associate with the product, and some preliminary efforts on objective methods for their evaluation.

QUALITY FACTORS

In the evaluation of French fried potatoes, the general consensus seems to be that in addition to defects such as broken pieces, unpeeled areas, dark carbon specks, small pieces, and abnormal blemishes resulting from sunburn, hollow heart, burned ends, dried cut surfaces and after-cooking discoloration, there are seven criteria of quality(1). These seven criteria can be grouped into three main categories; color, flavor, and texture. The first two factors will be discussed in much less detail than the third because this paper is centered on the texture problem.

Good color, according to the U. S. Grade Standards, means that the product: "possesses a characteristic light cream to golden color typical of properly prepared frozen French-fried potatoes; that the product is bright, practically uniform in color and after heating is practically free from units which vary markedly from the predominating color." As

with chip production, the color is developed by a Maillard type of reaction between the amino acids and the reducing sugars(13). The limiting factor is the quantity of reducing sugars. Control of color in the product is through selection of raw material with low reducing sugar content, by soaking in water with or without chemicals, and blanching to remove excess sugar. The intricacies of the Maillard Browning reaction and its accompanying Amadori rearrangements followed by sugar and amino acid degradation, aldol condensation, and aldehyde-amine polymerization(4, 5) could be the subject of an entire paper. Color is an important factor but in this paper it will be emphasized less than texture.

Flavor, under U. S. Grade Standards, is considered but is not given a numerical score. Good flavor means: "the good characteristic flavor and odor of properly prepared French-fried potatoes. Such flavor is free from rancidity and bitterness; pronounced scorched, or caramelized flavors and from off-flavors and off-odors of any kind." The flavor is derived from the natural potato flavor, the flavor of the oil and from flavor developed by the Browning reaction and caramelization. Since the components of potato flavor are the basis of another paper in the symposium, this subject will not be discussed further.

TEXTURAL FACTORS

It is generally conceded that there are four criteria of textural quality, namely crispness, tenderness, mealiness, and oiliness(6). In addition, it is necessary to know the changes in one or more of these factors which occur during the final heating and consumption.

A detailed examination of the textural factors is necessary to indicate the reasons for the direction taken in the objective studies to follow.

Crispness. The desirable factor would imply that the product was crisp to the taste but would not exhibit hardness, leatheriness or gumminess. This factor, in our estimation, is a measure of the feel of the French fry slice in the mouth at the time when the teeth, lips and tongue just come in contact with and prior to actually breaking through the crust. It implies a slice which holds its shape and is definitely not soft at the surface.

Tenderness. The desirable factor would imply that the product, although crisp, would be relatively easy to bite through. It would have no toughness or leatheriness. This factor is related to the outer crust

and to the inner contents, which complicates the subjective estimation to a certain degree and, as will be shown later, also complicates the objective measurements.

Mealiness. This factor is related to the inner contents only. It denotes dryness to both sight and feel. It is related to the total solids, the starch content and the pectinic materials of the cell walls, singly or collectively(15). In a mealy potato, the inner contents break into small crumbs which show little coherence and which display a glistening white surface. In non-mealy potatoes, big lumps form or a pasty, glue-type of material is observed. Strong mutual cohesion and no glistening white is apparent and the contents exhibit a more or less wet surface. Again there is an interrelationship which tends to make it difficult to completely separate these factors subjectively, because a subfactor enters into the overall quality measurement. This subfactor involves the prerequisite that a good French fry will exhibit no separation between the inner contents and the outer crust, and no open spaces should appear in the inner contents.

Oiliness. This factor implies a product which does not contain sufficient oil to produce a greasy taste but does have enough oil to give it a characteristic flavor and feel. A product with too little oil has a tough crust as differentiated from a crisp crust, and the flavor is deficient of recognized French fry flavor.

As a French fry slice remains on a dinner plate, it cools. During this cooling period, certain changes occur which cause a deterioration in the quality with respect to crispness and oiliness. The cooling cannot be controlled except, perhaps, by serving the product on a heated plate, but it can be hoped that prior treatment, selection of raw material, *etc.* may sometime yield a product which will not change so drastically during the time it takes to consume a serving.

PROBLEMS INVOLVED IN SUBJECTIVE MEASUREMENTS

Subjective measurement of these quality factors is difficult due to variations in the taste senses of the judges. Schippers(11), reporting from Wageningen, The Netherlands, summarized these problems very succinctly: "In judging color we regularly experience difficulties caused by a quickly occurring discoloration or by a certain degree of disintegration. In judging mealiness, the color of the potato may play a part and also softness. Very strong is, we think, the influence of discoloration on

the appreciation of flavor and the influence of flavor on all properties which are judged by taking potato tissue into the mouth. Although we never tried to establish these influences quantitatively, it may be assumed that several properties exert an influence on the judgment of other properties and that it is not likely that judges are able to separate all quality characteristics during judgment." Although Schippers was working only with steamed potatoes, his description of the problems encountered in subjective measurements fits very closely our experiences with French fries. However, a trained panel usually can yield a measure of the quality of a product, but this measurement is based upon an empirical description of the best quality. Consumers in different areas of the United States have different ideas of quality factors for French fries just as they do for potato chips. As a result, the panels must be trained to evaluate samples for different preferences. Due to individual variation in the abilities of panel members to delineate differences in quality factors, it is necessary to have a large number of people on the panel in order to obtain a true measure of the mean preference. It is not always convenient, practical or economical to have panels of this kind available. Also, since panels can evaluate only the end product and not the raw material, it would be highly advantageous to have available objective methods for evaluating and possibly predicting the quality of the processed product.

FACTORS INFLUENCING THE TEXTURAL CRITERIA

Numerous factors have a definite relationship to French fry quality as measured by the criteria just described. Variety, fertilization, water availability, length of day, amount of sunlight, types of pest control, method of vine killing, time of harvest, maturity, specific gravity, soil type, and others, all affect the processing quality of the potato. Selective breeding probably can produce, in time, new varieties which will possess all or most of the attributes necessary to produce a frozen French fry having only the best quality factors. However, at present, knowledge of these factors is of value only in a general way, since, when a crop is harvested and purchased by a processor, the future quality of the product has largely been established. Treatments such as precooking and cooling, chemical additions, *etc.*, may be employed to modify quality to a certain extent but some chemical or physical objective method, or both, is needed to predict quality and, possibly,

to predict treatments necessary for modifications.

Specific gravity has been used for predicting processed quality. However, more and more information is becoming available which indicates a degree of unreliability requiring further thought. We published data, both old and new, indicating that the specific gravity-total solids relationship was valid if sufficient samples over a wide range were used(8). However, the confidence limits, at any specific gravity, for total solids was ±1.5%. This means that for any sample, a range of 3% solids could be expected for any specific gravity. For example, a specific gravity of 1.075 usually indicates a solids content of 19.16%. However, the actual total solids could be as low as 17.66% or as high as 20.66%. This range is broad enough that, for samples on or just above the borderline between a good processing potato and a poor one, a fairly large loss in production could occur due to poor quality. This broad range of confidence limits is probably due to entrapped gases in the tissue, because the range can be narrowed by vacuum treating the potato sample prior to making an air and water specific gravity determination. Also, it was pointed out that all available specific gravity-total solids tables were calculated from data obtained with European potatoes which generally have a higher solids content than American varieties. In addition, data from 135 American potato samples, consisting of six varieties from five geographical areas, produced a regression curve which almost paralleled the original regression curve. However, each specific gravity value indicated a higher percent solids than the original. The old regression curve fell within the confidence limits of the new regression curve. Therefore, textural qualities probably will show a direct relationship with specific gravity on an overall basis, but many instances of non-correlation will be found which are due to variation in the association of specific gravity and total solids.

Aside from the solids differences just discussed, it would be interesting to investigate other possible reasons why two potatoes of exactly the same specific gravity can exhibit relatively different degrees of mealiness. If the solids content is not the controlling factor, then some other specific constituent or constituents must be responsible. The literature contains several hypotheses on the subject, but, to date, little proof. Schippers(11) stated that the degree of swelling of the starch must be considered as the second factor. He points out that Dow reported experiments in which 0.5 gm of starch swelled to a volume of 50-140 ml when heated in

distilled water, but only to 22-33 ml when heated in potato juice. Dow also reported that the same starch swelled more in the juice of a mealy variety than it did in the juice of a non-mealy variety. Unfortunately, as Schippers points out, Dow gave too little information about the specific gravity of the tubers and about the manner in which the experiments were carried out. As a result, the fact that Dow found no absolute correlation between the swelling capacity of the starch and the mealiness of the sample is not explained. Unrau and Nylund(16) found high correlation coefficients between mealiness and properties of the starch, but as these properties were highly correlated with dry matter content, the material offers no proof, quite apart from the fact that only seven samples were investigated. The smallness of the numbers of samples investigated in the past is quite probably the reason why we cannot report yet on the causes for differences in mealiness.

The possible effects of the pectin constituents cannot be excluded. The swelling of the gelatinized starch is probably a major factor in causing rounding of cells and cell separation. However, this tendency is opposed by the molecular size and calcium content of the pectic material of the middle lamella and cell wall. Heating at 158 F causes changes in the pectic substances of the middle lamella(9, 14). Also, an addition of calcium salts to the cook water often results in firmer cooked tissue. Schwimmer(12) suggested that phytic acid, present in the potato tissue, may affect texture since it could conceivably compete with pectic acid for available calcium.

Another interesting observation on mealiness of mashed potatoes is that precooking and cooling prior to the final cooking of the potato in flake manufacture allows the use of lower solids potatoes than does straight cooking(3). This may explain why blanching has been reported to improve the quality of frozen French fries.

This short discussion was presented to show that some objective method, in addition to specific gravity, for predicting French fry quality would have very decided advantages.

INVESTIGATIONS ON TEXTURAL MEASUREMENTS

Texture measurements are designed to estimate qualitatively and quantitatively, by objective means, the usual textural characteristics responsible for consumer reactions to a product. There are four methods available for measuring texture, all of which employ forces greater than

gravity: cutting force, compression, tensile strength and shear. Of these, it was thought that shear techniques would have the greatest applicability to French fry studies, although it is practically impossible to obtain shearing without some compression. For several products, the exact proportion of shear or compression can be calculated, because shear is proportional to the perimeter of the shearing blade while compression is proportional to the area of the blade(2). This observation may help later in developmental research.

Most work on shear testing with French fries has employed instrumentation which measures the maximum shear force developed. Since texture involves several basic phenomena, it was believed that some recording procedure which would indicate a sequence of events would be more advantageous. As a result, the Allo-Kramer shear press[1], with automatic recording of the force variations during the actual shearing test, was selected for these studies. As with all instruments of this type, interpretation of the curves produced must be made before any definite conclusions can be drawn. Some of the information to be discussed was reported at the 15th National Potato Utilization Conference in Grand Forks, N.D. in 1965 and has been accepted for publication(10).

In the preliminary work, the Allo Recorder Model No. RIE was used. Because of some problems attributed to overshooting of the recording pen, the new Model No. E2EZ amplifier was added to the recording system. We can obtain the same results with the two recorders, although with less overshooting in the E2EZ, but the new one is much more versatile. The shear press consists of a set of ten blades, about ⅛ inch wide, which move downward through the product to a stationary set of blades adjusted, with relatively fine tolerance, so that it will mesh with the moving set. This moving set is attached to a 3000-pound proving ring which is distorted by any back pressure against the blades. The amount of distortion is transferred as an electrical signal, by a transducer, to a recording mechanism which amplifies and records it on a strip chart. This chart is driven at a rate proportional to the rate of blade movement and, as the moving set of blades proceeds downward, the sample in the test cell exerts a back pressure which is recorded. Each time something happens to give a relaxation of the back pressure, the proving ring returns toward its normal shape. As a result, a graph

[1] Mention of this item does not imply endorsement of this product by the Department of Agriculture over any other similar products not named.

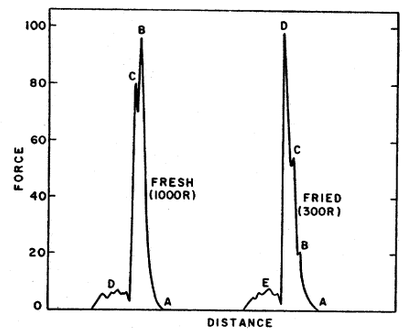


Fig. 1. Typical shear curves for fresh and French fried potato slices.

is produced which rises with back pressure and decreases as the back pressure is relaxed. Due to the chart drive system employed, all graphs start on the right and proceed toward the left. In this work, a piston speed of 0.12 inches per second was employed. At a sensitivity of 300 R (an electrical resistance setting) the pressure recorded gave 300 pounds full scale. At 1000 R this value was 1000 pounds full scale.

When one first makes a measurement on a new product, French fries for example, the resulting curve must be interpreted. Typical raw potato and French fry curves are shown in Figure 1. Before shear can take

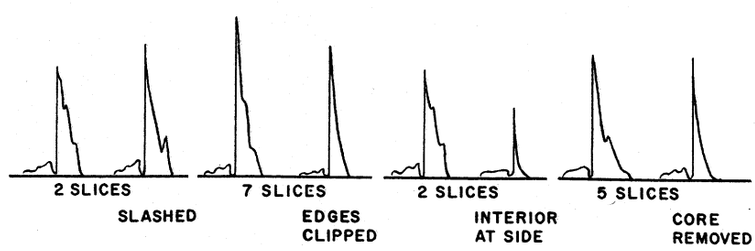


Fig. 2. Effect of potato slice alteration on shear results.

place a certain amount of compression must occur. The amount will be determined by several factors. Any changes in the physical structure of the product will produce a change in the slope of the compression curve. Therefore, curves having peaks and valleys are obtained. One question we wished to settle in these earlier experiments was: "What does each of the observed peaks mean and what causes them to occur?"

Experimentally it was found that the most informative curves were

obtained with a single layer of potato strips which completely filled the bottom of the shear cell. Multiple layers or random introduction caused amorphous type curves due to several different actions occurring at the same time. As a result we have standardized on the use of seven strips, ⅜″ x ⅜″ x 2⅝″, or five strips, ½″ x ½″ x 2⅝″.

Following some shearing experiments using a Model Shear Press (constructed in the laboratory) in which the shearing operation could be observed, the experiments outlined in Figure 2 were carried out. On the left are two curves, each the result of shearing two fried slices. The left one is the normal curve; the right the result of slashing all four long faces. Peak No. 2, which had been thought to be due to crust failure and flow of inner contents, disappeared. The second set of curves are the normal shear and the shear obtained when the four long corners were clipped off with scissors. As a result, both the first peak, previously ascribed to initial cell rupture, and the second peak were eliminated. The third pair of curves resulted from dissecting the slice to remove the inner contents. These contents were placed beside the hollow crusts. Again both peaks disappeared. The fourth set shows the results of removing the interiors and shearing the crusts without the contents. Since only the crusts were sheared, the remaining peak is due to this event. The comparison of the peak position with the ram travel also proves this point. These experiments indicate that the intact crust has something to do with the first two peaks and that the inner contents also play a part but only when they are enveloped by the intact crust.

Both time of frying and temperature of frying have an effect on the shear diagram (Fig. 3), although time of frying is apparently more important. If only the 8-minute curves are studied it can be seen that the maximum heights of the peaks are approximately the same for the different frying temperatures. However, the curve shapes are different. Until the strip is sufficiently cooked the peak attributed to crust shear is lower than the other peak. This is because a raw potato does not really shear, but splits prior to shearing.

The blanching period also plays a part in the reaction of a fry strip to shearing (Fig. 4). As the blanch time is increased, the crust shear value increases. This is especially true with the shorter fry times. After the fry time has been increased sufficiently to cause complete cooking, the effect of blanch time is decreased. Blanching apparently puts the fry strip in such a condition as to allow water to be removed at a more

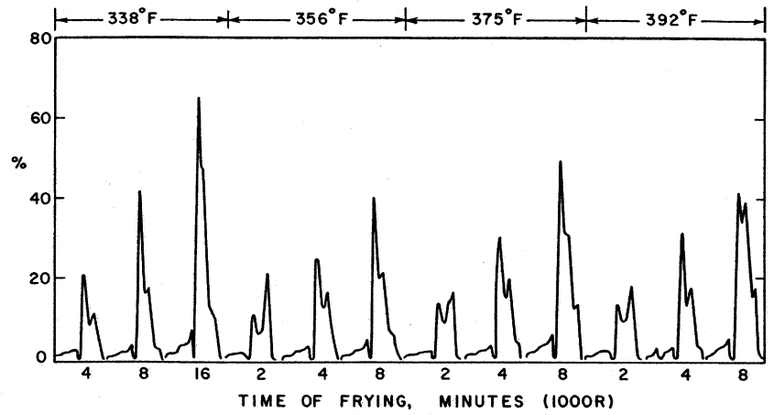


Fig. 3. Effect of frying time and temperature on shear results.

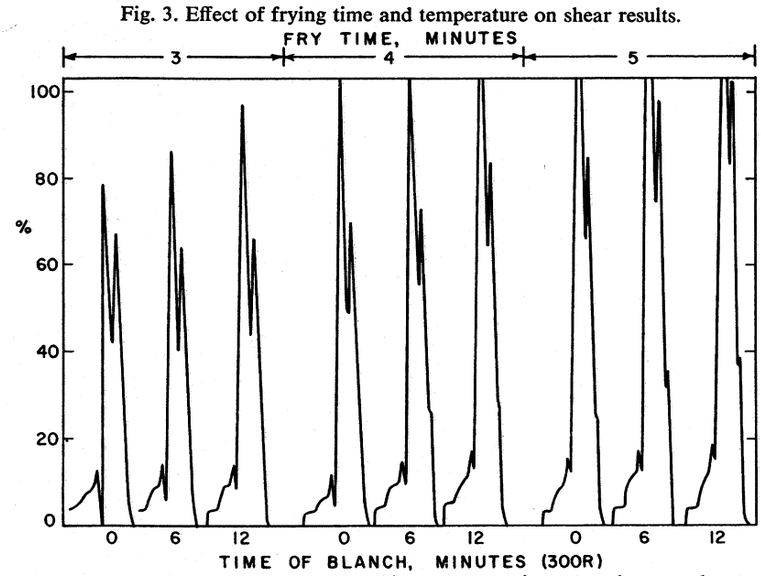


Fig. 4. Effect of frying and blanching of potato tissues on shear results.

rapid rate, thereby allowing a drier crust to be formed.

In the discussion of textural characteristics, it was noted that coolin of the fried strip causes a deterioration of the quality. It was also note that specific gravity had an effect on the quality. Figures 5 and 6 illu: trate the effects of the cooling of frozen and reheated French fry strip made from Russet Burbank potatoes having specific gravities of 1.070 and 1.0900 respectively. As each set of strips cools, there is a revers:

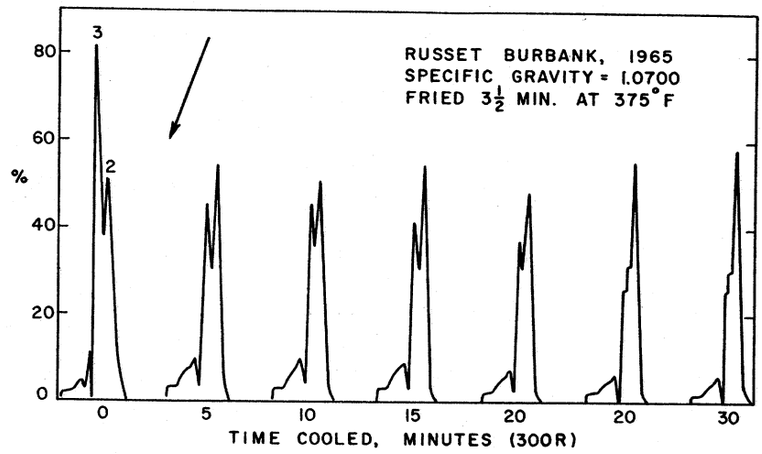


Fig. 5. Effect of cooling time on shear results with low specific gravity potatoes.

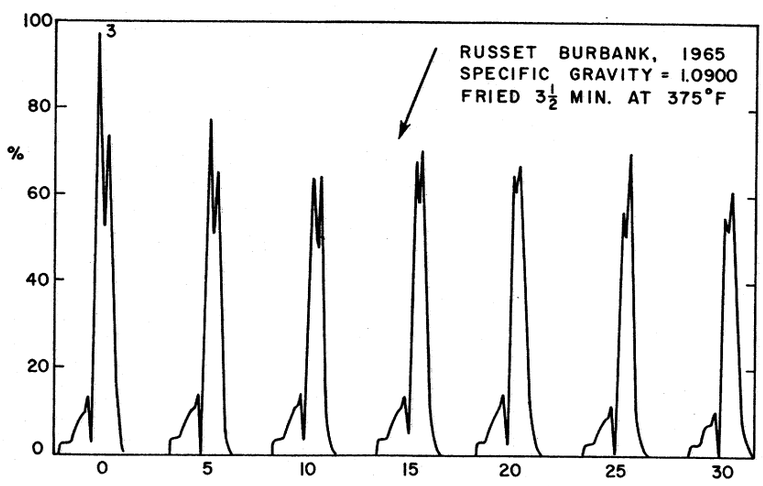


Fig. 6. Effect of cooling time on shear results with high specific gravity potatoes

of the second and third peaks. This is due to a redistribution of the wa from the inner contents to the outer crust causing the latter to beco soggy. In all tests made to date, the time of reversal is less for l gravity tubers, as indicated by the large arrows on each figure. It is

known whether other factors are involved. However, anything which can be done to drive the arrow to the right in these figures will improve the textural quality of frozen French fries. Recent work shows that freezing and reheating may prevent or slow down the peak reversal. The effect of specific gravity can also be seen in the relative heights of the peaks for the two specific gravities.

In future work, effects of storage of raw tubers, storage of frozen French fry strips, variety, area of growth, and other factors must be studied in detail before measurements of this kind can become quality-control tools. In addition, some method for expressing the results quantitatively must be found. Since the actual shearing operation occurs over a period of about five seconds, it has been difficult to use electronic integration of peak areas. Planimeters have not been successful because of the sharp peaks involved. Weighing of cut out curves has been found to be too inaccurate. Work along these lines is continuing. As more laboratories try the technique and a greater background is developed, it is felt that the techniques will ultimately play an important role in the improvement of frozen French fry products.

LITERATURE CITED

1. Anon. 1954. United States Standards for grades of frozen French fried potatoes. Agricultural Marketing Service, U. S. Department of Agriculture.

2. Bourne, M. C. 1965. Studies on punch testing of apples. Food Technol. **19**:413-415.

3. Cording, J., Jr., J. F. Sullivan, and R. K. Eskew. 1959. Potato flakes. A new form of dehydrated mashed potatoes. IV. Effects of cooling after precooking. U. S. Dep. Agr., Agr. Res. Service, ARS 73-25, 26 p.

4. Fitzpatrick, T. J., E. A. Talley, and W. L. Porter. 1965. Preliminary studies on the fate of sugars and amino acids in chips made from fresh and stored potatoes. J. Agr. Food Chem. **13**:10-12.

5. Hodge, J. E. 1953. Chemistry of browning reactions in model systems. J. Agr. Food Chem. **1**:928-943.

6. Kirkpatrick, M. E., P. H. Heinze, C. C. Craft, B. M. Mountjoy, and C. E. Falatko. 1956. French frying quality of potatoes as influenced by cooking methods, storage conditions and specific gravity of tubers. U. S. Dep. Agr. Tech. Bull. 1142, 46 p.

7. Murphy, E. F., R. Bonde, and F. E. Manzer. 1963. The specific gravity, mealiness, and flavor of baked Maine potatoes as related to fungicide treatment. Amer. Potato J. **40**:35-46.

8. Porter, W. L., T. J. Fitzpatrick, and E. A. Talley. 1964. Studies of the relationship of specific gravity to total solids of potatoes. Amer. Potato J. **41**:329-336.

9. Roberts, E. A. and B. E. Proctor. 1955. The comparative effect of ionizing radiations and heat upon the starch-containing cells of the potato tuber. Food Res. **20**:254-263.

10. Ross, L. R. and W. L. Porter. 1966. Preliminary studies on the application of objective tests to texture of French fried potatoes. Submitted for publication to Amer. Potato J.

11. Schippers, P. A. 1963. Investigations about the possibility to measure some quality characteristics of cooked potatoes by instrumental methods. Pub. No. 87, IBVL, Wageningen, The Netherlands, 113 p.

12. Schwimmer, S. 1956. Phytic and other acids of the potato tuber. Federation Proc. **15**:351.

13. Shallenberger, R. S., O. Smith, and R. H. Treadway. 1959. Role of sugars in the browning reaction in potato chips. J. Agr. Food Chem. **7**:274-277.

14. Shewfelt, A. L., D. R. Brown, and K. D. Troop. 1955. Relation of mealiness in cooked potatoes to certain microscopic observations of the raw and cooked product. Can. J. Agr. Sci. **35**:513-517.

15. Talburt, W. F. and O. Smith. 1959. Potato Processing. Avi Publishing Co., Inc., Westport, Conn. 475 p.

16. Unrau, A. M. and R. E. Nylund. 1957. The relation of physical properties and chemical composition to mealiness in the potato. I. Physical properties. Amer. Potato J. **34**:245-253.