THE EFFECT OF FREEZING ON
MICROSCOPIC STRUCTURE AND
PALATABILITY OF FRENCH-FRIED POTATOES

by

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French-fried potatoes are popular in the American diet. This statement is substantiated by the results of a restaurant survey conducted in two large cities, Cincinnati and New Orleans, in 1948, in which it was found that more potatoes were used for French frying than for any other single method of preparation (32, p. 5).

Even though French-fried potatoes are already popular in the American diet, it is reasonable to expect that if the quality of French-fried potatoes could be improved, the popularity would increase. This is especially important from the sellers' viewpoint for it would mean increased sales and more profit. The consumer, as always, is interested in a high-quality food product.

Probably at one time or another, everyone has been served French-fried potatoes of poor quality. For instance, during a one-day study of nine restaurants in Corvallis, it was found that French-fried potatoes varied greatly in quality. Some of the fries were of excellent quality while others were undesirable. The poor fries tended to
be limp, were lacking mealiness or were too brown and had a
burned flavor (25).

There are many problems involved in making good
French-fried potatoes and in achieving a standardized prod-
duct time after time. Such factors as the specific gravity
of the potatoes, the storage of the tubers, and the prep-
eration methods used have been shown to influence the
product.

Kirkpatrick et al. (18, p. 17), studied four
varieties of potatoes and for all but one found that taste-
panel scores for lack-of-oiliness, crispness, and mealiness
showed a gradual increase as specific gravity of the tubers
increased. Since crispness, mealiness, and lack-of-
oiliness are desirable in French-fried potatoes, the
specific gravity of the tubers would be one factor to con-
sider when purchasing potatoes for French frying.

Storage conditions under which tubers are held in-
fluence the French-frying quality. Potatoes which contain
sugar in excess of one per cent will produce undesirably-
dark French fries. At harvest most potato varieties
contain less than one per cent sugar, but when placed in
cold storage at 4.5°C. (40°F.) or below, some of the

1/ Temperatures are given as degrees Centigrade followed
by degrees Fahrenheit. Conversions were taken from
the Handbook of Chemistry and Physics (14, pp.2312-
2315).
starch is converted to sugar (3, p. 2). Potatoes which have been held in cold storage will not make French fries of desirable, light-brown color unless the potatoes have been conditioned, that is, held at 21°C. (70°F.) or above for two to three weeks after removal from cold storage.

The preparation methods used also influence the quality of the French fries. If frying is too slow or too rapid, a poor product is produced (3, p. 5). Slow frying is said to result in excessive absorption of oil. Too rapid frying causes over-browning or uneven browning and a burned flavor.

Freezing as an intermediate step in the preparation of French-fried potatoes may have an additional influence on quality. Preliminary studies have indicated that French-fried potatoes prepared by parfrying, freezing, and finish frying have a different and more desirable texture than do French fries which have not been frozen (24). This observation was the background for the intensive work herein reported in which a trained taste-panel judged French-fried potatoes prepared in various ways, and in which a microscopic study of potato tissue was carried out to ascertain changes which occur during freezing.

If freezing is shown to improve French-fried potatoes and if the changes which occur can be determined so as to control or improve quality, both the consumer and
seller should benefit from such knowledge. Developing methods for achieving an improved food product should make it possible to supply better food for the consumer. In addition, increased sales resulting from the improvement of the product should reflect to the benefit of the grower, manufacturer, and retailer.

Parfried, frozen potato strips should be of value in saving restaurants' time in preparation. Kirkpatrick et al. (18, p. 7) in reporting the findings of others, state that in single-stage frying, 77 pounds of potatoes could be French fried in an hour; but with two-stage frying, 300 pounds of potatoes could be finish fried in the same fryer in one hour. The frozen, parfried potato strips not only would save preparation time, but would make possible quick service to customers.

The homemaker also would benefit from the use of prepared potato strips. The frozen parfries would not only save the homemakers' time in washing, peeling, and cutting the potatoes and disposing of waste; but would save preparation time during the latter period of meal preparation when there are many other tasks to perform. This is especially important in light of Feustel and Harrington's (9, p. 1) statement that a factor which they believe has contributed to the decline in per capita consumption of fresh potatoes during the past 40 years
has been the inconvenience of home storage, peeling and cooking. They state that per capita consumption has not declined during recent years when large amounts of processed, potato products have become available (9, p. 1).

The purpose of this investigation was to study the textural changes which occur in French-fried potatoes during freezing. The study was planned for Russet Burbank potatoes only, because this is the major potato variety grown in Oregon. This variety is generally of high specific gravity and keeps well in storage, which are characteristics of importance for tubers that are to be French-fried. High specific gravity has been shown to have beneficial effects on the qualities of French-fried potatoes, and good storage qualities should insure uniform supplies of raw material throughout most of the year. Potatoes could be processed into frozen French fries during seasons of the year when other more perishable products are not available, thus equalizing the work load of freezing plants.
CHAPTER II

REVIEW OF LITERATURE

Composition of Russet Burbank Potatoes

Starch occurring abundantly in potato cells is the constituent which gives some of its most characteristic textural properties to a food such as French-fried potatoes. Other constituents which may play a part in determining texture are the solutes and the intercellular cementing substances.

Lampitt and Goldenberg (20, p. 748-761) have reviewed and summarized the literature up to 1940 dealing with the composition of the white potato. These writers indicate that some of the analyses were carried out on peeled potatoes; whereas in other cases, the whole potato was analyzed. They report average percentages, secured by various workers, for the major constituents of the potato to be as follows: water 72.07 to 79.98 per cent, starch 12.4 to 17.85 per cent, and total nitrogen 1.66 to 2.62 per cent. The fat varies from 0.056 to 0.11 per cent, and the crude fiber varies from 0.40 to 0.98 per cent. Sugars, pectins, acids, minerals, and vitamins are present also (20, p. 753-755). Approximately 50 per cent of the total nitrogen is present as protein (20, p. 752).
Helaze, Kirkpatrick, and Dohcterman (13, p. 36) found the average composition of Russet Burbank potatoes from several locations to be as follows: dry matter 23.6 per cent, alcohol insoluble solids 22.1 per cent, starch 18.7 per cent, total nitrogen 0.30 per cent. The above data were obtained from the 1949 crop, and the averages are expressed on a fresh-weight basis (13, p. 36).

It has been found that no two potatoes are identical in their chemical composition. Variety, degree of maturity, method of culture, amount and kinds of fertilizers, locality and soil, seasonal variations, temperature during growth, and the storage period have been listed as factors which influence the composition of potatoes (13, p. 2). For example, Yungen, Hunter, and Bond (36, p. 391) studied the effects of nitrogen fertilizer on the specific gravity of Russet Burbank, White Rose, and Bliss Triumph potatoes from eastern Oregon. Fourteen farms were studied, and on 10 of these farms the effect of nitrogen on specific gravity was significant. Specific gravity decreased as nitrogen fertilizer was increased. This was thought to be related to the degree of maturity at harvest.
Histology and Composition of Raw Potato Tissue

General Structure of White Potatoes

The white potato consists of a white or light cream, starchy interior surrounded by a light or dark tan skin. The tuber contains a central pith which has large amounts of water and some starch-filled parenchyma cells (2, p. 813, 818). Branches of the pith extend to the potato eyes at the surface of the tuber. The vascular ring, composed of conducting tissue, lies close to the skin and is surrounded by thick storage parenchyma. Numerous, small islets of phloem, conducting tissue are embedded in this parenchyma tissue (2, p. 813). The general structure of the potato is illustrated in Figure 1, page 9. A number of the details shown are described by Artschwager (2, p. 813-818, 836).

The Russet Burbank potato, one variety of white potato, is characterized by a cylindrical shape and a tan skin often showing a heavy netting (7, p. 35).

Structure of Potato Tissue

According to Reeve (27, p. 135), the diameters of normal cells in fresh potato average 250 to over 500 microns. These cells are mostly isodiametric with many sides; therefore, they do not fit together perfectly
Figure 1

Structure of the White Potato

(ARTSCHWAGER 2, p. 813-818, 836)
According to Weier and Stocking (33, p. 301), the intercellular spaces which are formed are filled with air. The cells are held together by a network of pectic-compounds called the middle lamella. Calcium pectate is considered to be the chief constituent of this middle lamella (26, p. 299).

Composition of Cells

Potato cells contain a central vacuole. According to Weier and Stocking (33, p. 306), the vacuole of most parenchyma cells is "a dilute aqueous solution of various inorganic and organic salts, pigments and food materials separated from the protoplasm by a thin cytoplasmic membrane". Stiles (31, p. 923) says that the vacuole consists of a solution of substances such as acids, salts, and sugars.

The vacuole is surrounded by protoplasm. "The protoplasm in parenchyma cells is generally parietal, lying close to the cell wall, with thin strands transversing a relatively large central vacuole" (33, p. 306).

Starch grains fill the cells. Starch is a polymer of glucose (28, p. 22A). The glucose units are joined by primary bonds between carbon one and carbon four (22, p. 389-390). See Figure 2, page 13. According to Meyer (23,
most starches contain two principal constituents—straight-chain amylose and branched-chain amylopectin. For structure of amylopectin see Figure 2, page 13. The starch constituents or molecules are organized into granules.

The hilum is the center of the starch granule around which the granule has grown. It usually does not correspond to the geometric center of the granule (17, p. 5). The term "striations" is applied to the series of markings arranged concentrically around the hilum of some starches such as potato starch (17, p. 6).

When possible the amylose and linear segments of the amylopectin associate to give parallelwise bundles called micelles. "A long linear chain may pass through several of these micelles, or the outer fringes of branched molecules may participate in a number of such micelles. But between these organized areas are regions of looser and more amorphous character, where the chains and branches criss-cross in various degrees of randomness" (28, p. 26A).

Hydrogen bonding occurs between the hydroxyl groups of the starch molecules. See Figure 2, page 13. This helps to hold the granule together (28, p. 24A). The granule is composed of concentric shells. Meyer (23, p. 414) says that each shell is composed of an
outer layer which is resistant to solution and an inner, water-soluble portion.

The outer shell does not lose its coherence when swollen but forms a large bubble. According to Meyer (23, p. 414) this outer shell consists of 90 per cent amylpectin and 10 per cent amylose which are separable only on complete solution. The inner part of the shell consists of amylose which may partially dissolve from damaged granules (23, p. 414).

According to Kerr (17, p. 10), amylose is leached from the granule during cooking. Kerr says that the exterior layer of the potato starch granule may detach itself from the interior of the granule during heating in the presence of water; thus, forming a membrane which encloses a watery interior.

Meyer (23, p. 414) states that starch granules act like small osmotic cells. They will shrink if salt or sugar is added to the warm water in which they are being gelatinized.

The cell contents are surrounded and protected by the cellulose cell wall.
Figure 2

Structures of Amylose and Amylopectin and an Example of Hydrogen Bonding

(Schoch, 28, p. 24A-26A)
Physiology of Normal Cells

Weier and Stocking (33, p. 307) state that "the crisp, firm texture of normal fresh plant tissue is, in addition to cellular cohesion and structure, chiefly due to cell turgidity which is a function of the water absorbing power of the cell and the availability of water".

Cells maintain turgidity by sucking themselves full of water (33, p. 307). The water is taken up by the vacuole which becomes large and causes the protoplasm to be pushed against the cellulose cell walls. When the cell wall is stretched to a maximum, the cell is said to be at full turgidity (33, p. 307).

The living protoplasm acts as a differentially permeable membrane which allows water to pass readily into the cell, but prevents or impedes the penetration of dissolved substances. The cellulose cell wall is permeable (33, p. 307).

Because of metabolic activity, plant cells accumulate and retain large quantities of inorganic solutes (33, p. 307). These substances increase the water-retaining power of the cell (33, p. 308).

Plasmolysis is the condition which occurs when the vacuole loses water and shrinks and when the protoplasm is drawn away from the cell walls (33, p. 308).

Parenchyma cells of the raw tuber are alive and
carrying on respiration and other life processes. They may be killed by various methods. According to Johansen (16, p. 27), "killing means the sudden and permanent termination of the life processes". Cooking rapidly kills cells (6, p. 445). Woodroof (34, p. 11) says that formation of ice crystals produces death of cells. Killing may also be accomplished by placing tissue in certain chemical reagents.

The changes in potato cells which are associated with cooking or freezing may be partly due to changes in the protoplasmic material. Weier and Stocking (33, p. 308) state that the death of a cell causes an increase in the permeability of the protoplasm. If the cell is in a dilute aqueous medium when death occurs, there will be a rapid diffusion of solutes out of the cells to the medium of lower concentration (33, p. 308). When this occurs, water will be lost and cell turgidity reduced (33, p. 308).

If much of the stored food is in the form of starch granules, the water loss will not be as great as if soluble, food constituents were present in higher percentages (33, p. 309). This might also be true of starch products in which the starch is gelatinized (33, p. 309). The granules swell and fill the cell (33, p. 309). Reeve (27, p. 135) states that the gelled starch limits the shrinking of cooked potato cells.
Changes Induced in Vegetables During Cooking

Before studying the changes which occur in French-fried potatoes during freezing, it is necessary to know what happens to the potatoes during the French-frying process. Since starch is the most abundant, single constituent of potato cells, the changes which occur during cooking of starch will be considered first.

Gelatinization of Starch

Gelatinization is a term used to apply to the changes which take place in starch granules when they are heated in the presence of water. The granules swell, increase in viscosity, become more soluble, become translucent, and cannot be recovered in their original form (22, p. 392). Lowe (22, p. 392) states that gelatinization occurs gradually over a range of temperatures.

The gelatinization temperature is the temperature range required to initiate swelling of starch (19, p. 43). Schoch (28, p. 26A) states that gelatinization occurs for potato starch in the temperature range of 56 to 67°C (133 to 153°F). Lowe (22, p. 392) reports that potato starch gelatinization begins at 60 to 70°C (140 to 158°F). Higher temperatures are necessary for maximum gelatinization.
After gelatinization, the individual starch grains within cells are no longer visible under the microscope (33, p. 319).

When uncooked starch grains are observed under polarized light, the granules appear light with the exception of two dark lines which intersect to form a black cross. Cooked starch granules do not show this cross; therefore, the appearance under polarized light can be used as a test to see whether the starch is completely gelatinized (17, p. 5), (28, p. 26A).

**Softening of Cellulose**

Simpson and Halliday (30, p. 196) in their studies on the disintegration of cell membrane materials in vegetables during cooking observed that in raw carrot and parsnip tissue, large proportions of the cell walls were thick and continuous; whereas, the cell walls of cooked tissue were thin and broken. This change was progressive during the steaming or cooking period (30, p. 196).

**Changes in Pectic Substances**

Simpson and Halliday (30, p. 189-206) carried on a study to observe the chemical and structural changes which take place in vegetables during cooking. They found that during cooking, the pectin-protopectin ratio changed in
carrots. The pectin increased by about one-half during 20 minutes of steaming and was double the original amount after 45 minutes of steaming. At the same time, the protopectin decreased so that after 45 minutes, approximately one-fourth of the original amount was present (30, p. 193-194).

These authors state "obviously, these changes have been brought about by the hydrolysis of protopectin to form pectin. If this were the only change occurring, however, the increase in pectin would be exactly the same as the decrease in protopectin and this is not the case. The decrease in protopectin is considerably greater than the increase in pectin, and it may, therefore, be concluded that some of the pectin itself has been decomposed during steaming" (30, p. 194).

Simpson and Halliday (30, p. 194) found that the changes in the pectic substances of parsnips were in the same direction as the changes observed in carrots. The changes in parsnips were to a lesser degree, and the parsnips were not as soft as were the carrots after a comparable steaming period.

Loss of Intercellular Air

Weier and Stocking (33, p. 330) state that large intercellular spaces filled with air are typical of most
parenchyma tissue found in fresh vegetables.

Crafts (6, p. 444) observed air-filled intercellular spaces between the corners and edges of parenchyma cells in the raw fruits—apricots, pears, peaches, and prunes—that he studied. By means of a hot-stage microscope, he observed changes during heating of a variety of fruit and vegetable tissues. He found that intercellular air is displaced during heat treatment. Heating caused the air to expand and thus forced it out (6, p. 445).

Based upon his study, Crafts makes the following statements concerning changes in intercellular air during heat treatment. If the tissue is in water during heating, gas is driven off; but the gases which are not driven off contract during cooling, and liquid is drawn in (6, p. 445). During cooking, sap is pressed from the cells; and upon cooling, this sap is available to displace intercellular air (6, p. 445). Softening of the cell walls further alters the tissue structure and allows the cells to distort and to fit together more closely (6, p. 445). Steam blanching has the same effect as water blanching except the cells are not surrounded by water (6, p. 445).

Crafts (6, p. 446) found that when cooking takes place, the air bubbles first rise in the intercellular spaces at the cut edges of the tissue. Then small air
bubbles begin to move through the intercellular space system. The sap from the cells replaces the intercellular air in the finer passages. The air bubbles which remain after prolonged heating are found in the larger intercellular spaces (6, p. 446).

The white potato in contrast with many other vegetables has relatively large cells and few air-filled intercellular spaces (6, p. 447). Crafts (6, p. 449) blanched and dried some white-potato tissue and observed the processes with the microscope. He observed that as the gelatinization temperatures were reached, the starch gelled rapidly. The reticulated, translucent starch soon filled the cells. The fine, air-filled intercellular spaces failed to lose their air. Crafts (6, p. 449) says that if the sections had been heated longer, the air would have been displaced by water vapor. He states "more time is required in potato, however, because the moisture normally lost from cells as they are killed by blanching is absorbed by the gelling starch, leaving the cells relatively free of fluid water" (20, p. 449). From this study one would assume that some of the intercellular air would be driven out of potato tissue during French frying.
Loss of Moisture and Absorption of Fat

Benes, Carlin, and Logan (3, p. 6) state that when a potato is put into fat at a temperature of 182 to 193°C. (360 to 380°F.), some of the water of the potato is rapidly changed into steam. As the water is lost, an open porous structure remains, into which fat is absorbed (3, p. 6). When a potato is properly French fried, it will have lost about 20 per cent (variable) of its original moisture content and added eight to ten per cent of its finished weight in absorbed fat (3, p. 6). If the French-fried potato absorbs much more than 10 per cent fat, it will have a poor texture and appearance (3, p. 6).

Changes Occurring in Tissue During Freezing

Gardner (10, p. 233), in reference to the edible tissue of fruits and vegetables, states that when tissue is subjected to temperatures below freezing, the water films surrounding the cells freeze; thus, ice formation begins on the outside of cells. The water within the cells has a lower freezing point. If the temperature is lowered slowly, more water is withdrawn from the cells and more ice is formed in the spaces between cells.
Slow freezing causes a dehydration of the cells with the result that the cells are crushed by ice crystals and collapse (10, p. 233). If very rapid freezing occurs, very little water is withdrawn from the cells. The osmotically-held water is frozen within the cells (10, p. 233).

Lee and Gortner (21, p. 148-151, and 184-195) carried out a study to see whether extreme differences in the rate of freezing vegetables would cause differences in texture. Whole kernel corn and lima beans, examples of starchy vegetables, were blanched and frozen at different rates. They were then stored at -18°C. (0°F.) for six months. After being removed from freezer storage and cooked, no differences due to rate of freezing could be found in the palatability of either lima beans or corn (21, p. 151). When viewed under the microscope, the more slowly-frozen vegetables showed larger ice veins and apparently greater damage to the tissues, but "in the corresponding thawed samples of the two starchy vegetables these differences disappeared and the samples looked alike, regardless of the conditions under which they were originally frozen" (21, p. 184).

Woodroof (34, p. 23) in his studies on frozen fruits and vegetables found that ice crystals were always more numerous at or near the periphery of the products being
frozen, lessening towards the center. He states (34, p. 23) that "the ice masses grew for awhile after freezing began. When the latter was slow and the cell walls were highly permeable to the movement of water, crystals were large and few in number. If, however, free water became available more slowly than heat was removed; "seeding" occurred in more than one place and many, but smaller, ice crystals formed".

Woodroof (34, p. 11) found that "the formation of ice crystals produced death of the cells and a collapse of structure regardless of the freezing temperature used. Starchy foods were exceptions. The starch grains remained virtually unaltered and gave support to cells of thawed tissues".

One type of vegetable which Woodroof studied was immature seeds such as peas, corn, and lima beans which contain a high percentage of starch. He found that these vegetables have the capacity to absorb or give up large quantities of water with little damage (34, p. 17). In this type of plant material, the cell walls are thin with very small intercellular spaces. Starch grains fill the cells (34, p. 17).

Woodroof (34, p. 17) found that "on freezing, the cell walls are both separated and ruptured by ice crystals and at the same time, the entire contents of each cell
coagulated into a shrunken mass. Ice crystals push the masses of starch grains into heaps, but the grains are seldom ruptured."

"On thawing, the water from ice crystals is temporarily held by the seed coat until it is reabsorbed by the masses of starch grains. Therefore, if the seed coat of products of this group is uninjured, there is no leakage, and very little loss of structure, even though practically all the cell walls are either broken or separated" (34, p. 17).

Woodroof (34, p. 17) concluded that as far as microscopic changes were concerned, it made little difference at what temperature starchy vegetables were frozen.

Diehl, Campbell, and Berry (8, p. 65) found that the cells in scalded, frozen peas separated more readily than did the cells in unfrozen peas. These workers observed no change in the starch grains of frozen peas (8, p. 65).

Changes Occurring in Starch Paste During Freezing

Woodruff and Hayden (35, p. 233-237) prepared corn and wheat starch gels. The pastes were poured into molds, allowed to cool and set over-night, and then frozen. One set of gels was frozen in the freezing compartment of a refrigerator at -2 to -3°C. (28.4 to 26.6°F.), while
another set was frozen in dry ice. The gels were thawed at room temperature and observed with a microscope.

After freezing, the cornstarch gels from the freezing compartment of the refrigerator were spongelike, and water could be pressed from the gels without the gels losing shape. These gels could readily absorb water. The unfrozen gel did not give up water when pressed and could be remoistened only with difficulty when dried (35, p. 234).

The cornstarch gels frozen in dry ice changed less. Water could not be pressed from the gel. When dried, it resembled the unfrozen gels.

The frozen, wheat-starch gels were similar to the cornstarch gels, but water could not be pressed out as readily. Those frozen in the freezing compartment of the refrigerator at approximately -2 to -3°C (28.4 to 26.6°F.) did not readily reabsorb water.

A veinlike structure appeared in the frozen starch gels. This structure was not noted in the unfrozen gels. This veinlike structure transmitted polarized light (35, p. 236).

These writers believed that the reticulation of the starch gels frozen at -2 to -3°C (28.4 to 26.6°F.) may possibly have resulted from the association of micelles or aggregates which in turn had formed when the
dehydration of the swollen starch granules by ice crystal formation permitted the molecules to be drawn closer together through secondary valance forces" (35, p. 236).

Lesser changes were observed in the gels frozen in dry ice. This was explained by the fact that less injury occurred and the temperature was too low to permit physical reorientation (35, p. 236).

**Methods for French Frying**

Alexander, Schopmeyer, and Anderson (1, p. 182) considered the following characteristics when judging French-fried potatoes: color, texture, flavor, degree of oiliness, and edible quality or acceptability. They considered a crisp and tender exterior to be desirable while the texture of the interior should be mealy, flaky, and popped (1, p. 182).

Benes, Carlin, and Logan (3, p. 6) list the characteristics which should be considered when scoring French-fried potatoes for quality as follows: flavor, color, fat absorption, form and symmetry, and external and internal texture. The external texture should be crisp but not hard. The interior of the fried potato should be mealy and dry (3, p. 6).

Kirkpatrick et al. (18, p. 9-11) report scoring French-fried potatoes for the following palatability
characteristics: color, uniformity-of-browning, lack-of-oiliness, tenderness, crispness, mealiness, and flavor. These authors stated that a golden, uniform color, a very slightly oily exterior, a tender and crisp crust, a dry and mealy interior, and "natural" flavor were the most highly desired characteristics.

French-fried potatoes may be prepared by single-stage frying or two-stage frying. In the single-stage method, the potatoes are placed in fat once and fried to completion. For the two-stage method, the potatoes are parfried, stored, and then finish fried directly before serving.

Alexander, Schopmeyer, and Anderson (1, p. 182-186) prepared French-fried potatoes by various methods with the objective of working out a standard procedure for obtaining good quality French fries. They found that the frying time and temperature should be adapted to the size of the cross section of the potato strips. Cooking procedures which produced good French fries from potato strips one-fourth by one-fourth inch in cross section failed to produce a good product with strips one-half inch by one-half inch in cross section. Frying temperature, since it influences frying time, appeared to be a major factor affecting the texture of French-fried
potatoes (1, p. 186). Fat temperatures were affected by ratio of fat to potato and the moisture content of the potatoes.

These authors reported great differences in the temperature of the fat at different stages of frying. For example, during parfrying when the ratio of fat to potato was 11.7:1 and the initial temperature of the fat was 195°C. (383°F.); the lowest temperature during frying was 175°C. (347°F.), and the final temperature was 176°C. (349°F.) (1, p. 185).

Kirkpatrick et al. (18, p. 7-8) used the two-stage frying method for French frying potatoes. When iron frying kettles were heated on electrical units, an eight to one ratio of fat to potato was used. The initial temperature of the fat and the time of frying were 185°C. (365°F.) for four minutes followed by 199°C. (390°F.) for one and one-half minutes (18, p. 8).

Kirkpatrick et al. (18, p. 8) report that when an automatic fryer was used, the following oil temperatures and times of frying were found to be satisfactory for two-stage frying: 182°C. (360°F.) for four and one-half minutes followed by 191°C. (376°F.) for one and one-half minutes.

Benes, Carlin, and Logan (3, p. 4) recommend the following temperatures for two-stage frying: initial
temperature for first frying 177 to 185°C. (350 to 365°F.) and initial temperature for final frying 191 to 199°C. (376 to 390°F.). One hundred seventy-seven degrees Centigrade to 185°C. (350 to 365°F.) for the first-stage frying may be used provided the ratio of potato to fat is no greater than 1:8. A potato to fat ratio of 1:6 may be used for the final-stage frying (3, p. 4).

The potato-to-fat ratio influences the frying time and temperature. As mentioned previously, the frying time and temperature influence the finished product. According to Benes, Carlin, and Logan (3, p. 5), if the frying time is too slow, the inside of the French fry may pull away from the outer shell before suitable surface color is produced. If the potatoes are undercooked, they will have a raw, uncooked flavor and texture. Potatoes that are fried too rapidly will have a surface which appears burnt while the center is only partially cooked. Overcooked potatoes will have concave surfaces and collapsed centers.

Benes, Carlin, and Logan (3, p. 5) in reference to potatoes French fried in the restaurant kitchen, state that "the time interval between undercooking and overcooking is not more than one minute and usually will be found as short as one-half minute".
Methods for Preparing Plant Tissue for Microscopic Study

Many methods have been developed for preparing tissues for microscopic study. The objective of all these methods is the same—to prepare the tissue so that it will resemble as nearly as possible an undistorted picture of the raw or cooked material. The very processes of killing and fixing, dehydrating and embedding, to name a few, may themselves cause distortions. Johansen (16, p. 28) points out that it is impossible to preserve tissue in the exact condition in which it existed during life.

Two methods for preparing plant tissue for microscopic study are the histological freeze-dry method which appears to be promising and has been recommended by Harper and Tappel (12, p. 229) and Glick (11, p. 3) and the tertiary-butyl-alcohol method of dehydration described by Johansen (16, p. 130-132).

Histological Freeze-drying Method

In the freeze-drying process, the material which is to be dehydrated is frozen and the water is removed by sublimation (12, p. 172). The temperature is kept below the freezing point of any ice phase (12, p. 172). The material to be dried is kept under vacuum during the entire drying process (12, p. 176). Glick (11, p. 3)
states that the freeze-drying preparation of tissue for microscopic study has many advantages over the usual histological methods which employ fixing and dehydrating solutions. He states "the chief of these advantages are a minimum of chemical change in the tissue, (an almost instantaneous cessation of metabolic activity and no chance for other chemical changes to occur) a minimum of shifting of diffusible constituents, a greater preservation of cytoplasmic inclusions than is possible with the use of fixing solutions, the possibility of direct paraffin infiltration of dehydrated tissue, and the absence of cell shrinkage" (11, p. 3-4). He states that no evidence of distortion has been found due to paraffin infiltration of the dehydrated tissue under vacuum.

Harper and Tappel (12, p. 173) list the advantages of tissue dehydration by freeze-drying as being elimination of shrinkage and migration of dissolved materials and inhibition of chemical reactions. These writers state that "drug and pharmaceutical products can be freeze-dried with no loss in biological activity" (12, p. 173).

Jensen and Kavaljian (15, p. 33) state that plant tissue has been difficult to handle by freeze-drying, so this method is seldom used. "The extremely high water content of the cells, the high solute concentration in the central vacuoles, the massive cell walls, the
heterogeneous composition of the tissues, the areas susceptible to tearing under stress such as the cambium and endodermis are all factors that make uniform and artifact-free freezing impossible and paraffin infiltration difficult. Even in the face of these inherent difficulties in the material, however, preparations can be obtained that are striking for their cytological clarity and histochecanical potentialities" (15, p. 36).

**Johansen's Tertiary-Butyl-Alcohol Method**

Johansen's book on microtechnique is considered to be a standard textbook in the field. From his experience, Johansen (16, p. 130) says that the tertiary-butyl-alcohol method of dehydration is the most satisfactory method for dehydration by means of killing and fixing solutions.
CHAPTER III

EXPERIMENTAL PROCEDURE

Selection of Potatoes

Oregon-grown, Russet Burbank potatoes were obtained at harvest time directly from the fields of farms which were selected at random in the commercial potato-growing areas. Tubers from six farms were included in the study. The specific gravity of each tuber was determined by the salt-density method employed by Clark, Lombard, and Whiteman (4, p. 39).

Tubers of high specific gravity, 1.115, and tubers of low specific gravity, 1.085, were selected from each farm in order to provide a means of determining specific gravity effects.

Storage of Tubers

The tubers were assembled in cardboard boxes and placed in storage at 3.5°C. (38°F.) on October 24, 1958. All tubers remained in this storage until January 5, 1959. At this time, one high-specific-gravity and one low-specific-gravity tuber from each of six farms were taken from cold storage and placed at room temperature, 24°C. (75°F.), to condition for two weeks, before being parfried. The parfries were frozen at temperatures of -18°C. (0°F.)
and -78°C. (-108°F) on dry ice. They were maintained at these temperatures for two weeks. At the time the par- fries were prepared, January 19, 1959, the tubers to be French fried but which were to have no freezing treatment were taken from storage to condition for two weeks. This schedule brought all samples to the taste-testing period simultaneously. Taste testing of all samples occurred the first week in February.

All tubers used for the microscopic studies were processed directly from storage; thus, the conditioning period was eliminated for these tubers.

Methods of French Frying

For this study it was necessary to fry all potatoes at the same temperature for the same length of time. During preliminary investigations, potatoes were fried for different lengths of time and the starch observed by means of polarized light. It was found that all the starch was gelatinized after six and one-half minutes of frying at 177°C (350°F); therefore, regardless of other treatment, all samples were fried for a total of six and one-half minutes at this temperature. Uniform strips for frying were cut from each tuber. Cross sections of strips were one-half inch by one-half inch.
Preparation of Samples for Taste Testing

Four methods of preparation were used to prepare samples for taste testing. The methods are listed below.

1. Single-stage fried. The raw strips were placed in the preheated fat and fried at 177°C. (350°F.) for six and one-half minutes.

2. Duo-stage fried, unfrozen. Raw strips were placed in the preheated fat and fried at 177°C. (350°F.) for five minutes, placed on paper towels to drain, and allowed to stand at room temperature for one hour. The parfried strips were finished by frying at 177°C. (350°F.) for one and one-half minutes.

3. Parfried, frozen at -78°C. (-108°F.), and finish fried. Raw strips were placed in preheated fat and fried at 177°C. (350°F.) for five minutes, then placed on paper towels to drain and left at room temperature until cool, approximately 15 minutes. The parfried strips were placed in plastic freezer bags and placed on dry ice. They were held on dry ice, -78°C. (-108°F.), for two weeks at which time they were finish fried at 177°C. (350°F.) for one and one-half minutes.

4. Parfried, frozen at -18°C. (0°F.) and finish fried. The method employed was the same as that described under three above except that the parfried potato strips were placed in a freezer which maintained a
temperature of \(-18^\circ\text{C. (0^\circ\text{F.})}\), and were held in this storage for two weeks before finish frying.

**Preparation of Samples for Microscopic Studies**

The same French-frying methods and temperatures were used to prepare samples for microscopic study as were used to prepare samples for taste testing. The methods are described under the section "Preparation of Samples for Taste Testing" page 35. In addition to the four methods described under "taste-testing", raw potato was included and samples were taken of parfried tissue as well as of finish-fried material.

**Procedures in Sensory Evaluation**

Tubers from six farms were used for taste testing. One tuber of high specific gravity, 1.115, and one tuber of low specific gravity, 1.085, from each farm were used for the frozen samples, and tubers of these same specific gravities from each farm were used for the unfrozen samples.

The tubers used in any one replication were selected at random. The six high-specific-gravity tubers or the six low-specific-gravity tubers used to prepare the frozen samples were placed together and two were selected at random for one replication; two others were selected
as the second replication and the remaining two tubers were used for the third replication. This same procedure for random selection was employed for the tubers which were used for the unfrozen samples.

The taste-testing panel consisted of four judges. Preliminary trials were carried out to familiarize the judges with the score card, the specific characteristics of the French-fried potatoes to be evaluated, and to standardize the methods of judging.

At each judging session, which constituted one replication, one French-fried sample of high specific gravity and one sample of low specific gravity prepared by each frying method were presented to the judges; thus, each judge had eight samples per replication. The fries were presented in random order four at a time. As soon as the first four were judged, the remaining four samples were presented. Three replications were carried out. The French-fried strips were served while hot.

The fries were judged for characteristics of overall quality, crust crispness, crust tenderness, interior appearance, graininess, moistness, and cohesiveness. Figure I in the appendix shows the score card that was used.
Selection and Preparation of Samples for Microscopic Study

Tubers for microscopic study were selected from two of the same farms that were used for the evaluation of palatability. In order to provide a means for studying specific gravity effects, tubers of high specific gravity, 1.115, and tubers from the same farms of low specific gravity, 1.085, were included in the sample. In order to eliminate as many variables as possible, only two tubers of each specific gravity from each farm were used in the series in which samples were prepared for microscopic study by dehydration and by embedding in tissuemat. All methods of preparation were carried out on strips from these two tubers.

From each of these tubers, the center strips were used for French frying. Samples representing each stage of preparation and each method of French frying were taken for microscopic study.

Each of the following stages and methods of preparation were represented:

1. Raw.
2. Single-stage fried.
3. Parfried, unfrozen.
4. Duo-stage fried, unfrozen.
5. Parfried, and frozen at -78°C. (-108°F.).
6. Parfried, and frozen at -18°C. (0°F.).
7. Parfried, frozen at -78°C. (-108°F.), and finish fried.

8. Parfried, frozen at -18°C. (0°F.) and finish fried.

Methods Used for Microscopic Study

In order to obtain as much information as possible on the structure of French-fried potatoes at various stages of preparation, several procedures were followed. These included studies of (1) treated materials, (a) fixed and dehydrated by Johansen's tertiary-butyl-alcohol method, and (b) tissue prepared by the histological freeze-drying method; (2) untreated materials, (a) fresh or frozen fragments that had not been subjected to fixing or dehydration, and (b) changes in raw and cooked tissue during the freezing process.

Samples for microscopic study were taken from the potato strips directly after frying and after the parfries had been frozen for a two-week period. Small samples were cut and used either for the studies of untreated tissue or placed on dry ice or in a killing and fixing solution as the first step in the respective series for study of treated materials.

Treated Materials

Histological Freeze-drying Method. The frozen, parfried strips were allowed to warm slightly
until thin slices could be cut with a razor blade. A sample of the entire cross section was cut and immediately placed on dry ice. The samples were then placed in metal cassettes which were, in turn, placed in tissue tubes which were one-third full of solid, degassed tissuemat with a melting point of 54 to 56°F. (129 to 133°F.). The tissue-tubes were surrounded with dry ice and connected to a histological freeze-drying apparatus, model FD-11, manufactured by the Scientific Specialties Corporation, Cambridge, Massachusetts. A vacuum equal to 0.01 to 0.001 millimeters of mercury was maintained until dehydration was complete. During dehydration, the dry ice was allowed to evaporate very gradually from around the tissue tubes until at the end of the dehydration period the samples were at room temperature. With this method, the dehydration took place while the samples were still frozen. All the cooked samples were dehydrated for 52 hours; whereas, the raw samples were dehydrated for 76 hours.

When dehydration was complete, the tissuemat in the tissue tubes was melted slowly, and the cassettes containing the samples were allowed to settle into it while still under vacuum. The samples were left in the melted tissuemat under vacuum for two and one-half to three hours. Preliminary investigation indicated that when the slight bubbling which was observed ceased, the infiltration was
complete. This was, therefore, used as an indication of the completion of infiltration. The temperature of the melted tissuemat was kept at 65°C. (149°F.) or below.

When infiltration was complete, the casettes and samples were placed in paper boats. Melted tissuemat at 63°C. (145°F.) was poured over the casette and sample, the casette was removed and the sample arranged in the warm tissuemat. The tissuemat was solidified quickly by placing the boats in ice water as soon as the samples were arranged.

Johansen's Tertiary-Butyl-Alcohol Method.

Samples were cut from the same French fries and from the same raw strips as were used for the freeze-drying method. In fact, the samples were cut at the same time.

Directly after cutting, the samples were placed in vials containing FAA (50 per cent ethyl alcohol, 90 per cent; glacial acetic acid, 5 per cent, and formalin, 5 per cent) killing and fixing solution. All samples remained in this solution for a minimum of 48 hours.

While in this solution, the samples were evacuated for several hours, six hours average, to remove any air or intercellular gas which might have been trapped in the sample. When the gas had been removed, the samples sank to the bottom of the vials. The removal of gas allowed
the solution to penetrate the tissues.

Following fixation, the FAA solution was decanted and the samples were covered with 50 per cent ethyl alcohol. After washing in 50 per cent alcohol, which consisted of two changes of alcohol over a period of two hours, the samples were dehydrated in increasing concentrations of tertiary-butyl-alcohol and then infiltrated with tissuemat. Seven alcohol solutions were used followed by three changes of parowax. Following this the tissue was embedded in tissuemat. The following series of solutions of water, ethyl and tertiary butyl alcohols, and paraffin oil were used. Solutions number one through number six represent increasing concentrations of tertiary-butyl alcohol accompanied by decreasing concentrations of water and, in most cases, ethyl alcohol. In solution number seven, paraffin oil was introduced.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Solution Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distilled water, cc.</td>
<td>200 120 60</td>
</tr>
<tr>
<td>95 per cent ethyl alcohol, cc.</td>
<td>160 200 200 180</td>
</tr>
<tr>
<td>Tertiary butyl alcohol, cc.</td>
<td>40 80 140 220 300 400 200</td>
</tr>
<tr>
<td>100 per cent ethyl alcohol, cc.</td>
<td>100</td>
</tr>
<tr>
<td>Paraffin oil, cc.</td>
<td>200</td>
</tr>
</tbody>
</table>

The above solutions were numbered one to seven. The following schedule was used. Only the minimum times are given.
The dehydrated samples were infiltrated with parowax and tissuemat by the following schedule:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parowax</td>
<td>5 1/4</td>
</tr>
<tr>
<td>Parowax</td>
<td>1 1/2</td>
</tr>
<tr>
<td>Parowax</td>
<td>2 1/2</td>
</tr>
<tr>
<td>Tissuemat</td>
<td>1 1/2</td>
</tr>
<tr>
<td>Tissuemat</td>
<td>2</td>
</tr>
</tbody>
</table>

The parowax was introduced into the series by filling a vial one-third full of melted parowax. The parowax was allowed to cool until a hard surface layer was formed. The potato sample and the tertiary-butyl-alcohol and paraffin-oil solution, number seven, were added to this vial and the vial was placed in a paraffin oven at 60°C (140°F).

When infiltration was complete, the contents of each vial, including sample and melted tissuemat, were poured into a paper boat. The tissuemat was solidified quickly by placing the boats in ice water as soon as the samples were arranged.

All samples from both the freeze-drying and the tertiary-butyl-alcohol methods were removed from the paper
boats. The tissuemat was trimmed until only a small amount surrounded the sample except on the bottom, where more tissuemat was necessary for proper mounting.

Each sample was mounted on a wooden block and microtomed with a rotary microtome until the surface of the sample was exposed. The entire cross section of the potato strip was then available for study. The surface of the section was stained with a one per cent solution of basic fuchsin. The embedded, stained sections were then removed from the wooden microtome blocks. The tissuemat was trimmed from the bottom of the sample until only a very thin layer remained. Photomicrographs were taken of the cross sections prepared in this way.

Untreated Materials

Since it is probably impossible to prepare tissue for microscopic study by the freeze-drying and alcohol-dehydration methods without some distortion occurring, the author felt that it would be of value to study raw and cooked potato tissue without these treatments. This should contribute valuable information concerning the microscopic appearance of the individual potato cells.

Eight potato strips from a high-specific-gravity, 1.115, tuber and eight strips from a low-specific-gravity, 1.085, tuber were used to prepare the samples for this
study. These represented the same stages and methods of preparation as did the samples which were prepared by dehydration followed by infiltration with tissueat.

A small, unstained sample was cut by means of a razor blade and placed on a slide for viewing. Photomicrographs were taken of the sample before and after adding one drop of distilled water. The water tended to disperse the potato cells; especially those from the tuber of 1.115 specific gravity. This dispersion made it much easier to see the individual cells.

The same procedure was used to prepare the samples from the frozen parfries with the exception that the parfries were cut while frozen and placed on a chilled slide. Photomicrographs were taken of the sample after thawing.

Parfries from different tubers but representing the same specific-gravity classes were prepared for a study of the changes during the freezing process. Small samples of the parfried material were cut with a razor blade and placed on slides. For one series, the samples were stained with a dilute iodine solution, followed by washing with distilled water. The samples were viewed during freezing at a magnification of 60 times. The samples were frozen on a Leitz cooling stage, manufactured by E. Leitz, Inc., New York, with which carbon dioxide was
used as the freezing medium. Photomicrographs were made of the cooked potato tissue as freezing took place.

A second series of slides was prepared by the same process as above, but the sample was such that only a few cells clung together. These cells were viewed under high power, 270X, magnification; and photomicrographs were taken during the freezing process.

Another slide was prepared in which the sample consisted of only a few cells, and this sample was stained with basic fuchsin. These cells were observed under high power magnification, 270X, and photomicrographs were taken during the freezing process.

Determinations of Moisture Loss and Fat Absorption

It is of value to know the amount of moisture lost during frying. If different methods of treatment cause a variance in moisture loss, this might help to explain differences in microscopic appearance and palatability scores. The amount of fat absorbed during French frying also influences the palatability; therefore, this information would help interpret the palatability data. Moisture loss and fat absorption were determined as follows:
<table>
<thead>
<tr>
<th></th>
<th>Parfried potato, g.</th>
<th>Finish fried potato, g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Weight of strips, raw, grams</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Weight of strips, cooked, grams</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Loss in weight, grams</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Weight of pan, grams</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Weight of pan plus fat before cooking, grams</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Weight of pan plus fat after cooking, grams</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Loss in weight, grams</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Weight of paper towels, grams</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Weight of paper towels plus fat drained from fries, grams</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Gain in weight, grams</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Loss in weight of pan plus fat after cooking less weight fat on towels, grams</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Weight of moisture loss, grams</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Per cent moisture loss (raw weight basis)</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Per cent fat absorbed (cooked weight basis)</td>
<td></td>
</tr>
</tbody>
</table>

The loss in weight of pan plus fat after cooking less weight fat on towels, number 11, was obtained by subtracting the gain in weight of paper towels, number 10, from loss in weight of the pan, number seven. The weight of moisture loss, number 12, was determined by adding the loss in weight of the strips during cooking, number three, and the loss in weight of pan plus fat after cooking less weight fat on towels, number 11.
The percentage of moisture lost was calculated by dividing the weight of moisture loss, number 12, by the weight of the raw potato strips, number one.

The weight of fat absorbed, number 11, was divided by the cooked weight of the tuber, number two, to obtain the percentage of fat absorbed on the basis of cooked weight.

**Changes in Temperature of Potato Strips During French Frying and Freezing**

Since the rate of freezing influences the size of the ice crystals formed, and this in turn may influence the texture of the product, it is of value to know the rate at which a material is frozen. The temperature at which a potato is fried also influences its texture.

The changes in temperature during frying, freezing, and finish frying were recorded by means of an electronic recording potentiometer, manufactured by the Brown Instrument Company, Philadelphia, Pennsylvania. The instrument used has four thermocouples, each of which makes a temperature recording every two minutes. By means of this instrument it was possible to record the temperatures of each of four potato strips every two minutes. The lowest temperature which could be recorded by this particular instrument was \(-40^\circ C\). (\(-40^\circ F\).)
this reason, information concerning the lowest temperature reached by the samples frozen on dry ice could not be obtained.

Two potato strips of each specific gravity, 1.115 and 1.085 were frozen in a Revco home freezer, model FF-230, manufactured by Revco, Inc., Deerfield, Michigan, at -18°C. (0°F.) and two strips were frozen on dry ice, -78°C. (-108°F.).

Frying and freezing curves were prepared from the information recorded.
Sensory Evaluation of French-Fried Potatoes

Average scores for the characteristics of French-fried potatoes prepared by different methods are shown in Table 1, page 51. By means of the analysis of variance, Table I, Appendix, it was found that over-all quality, crust crispness, crust tenderness, and interior cohesiveness were influenced by treatment. As mentioned under procedure, treatments were: (1) single-stage fried, (2) duo-stage fried, unfrozen, (3) parfried, frozen at \(-18^\circ\text{C. (0°F.)}\) and finish fried, and (4) parfried, frozen at \(-78^\circ\text{C. (-108°F.)}\) and finish fried.

According to the judges' evaluation, the crust of the potato strips which had been parfried, frozen, then finish fried was more tender and crisp, and the interior texture was less cohesive than that of French-fried potatoes that had no freezing treatment. For example, it will be noted in Table 1 that scores for crust tenderness of these potatoes averaged three and six-tenths; whereas, the scores for potatoes having no freezing treatment averaged two and five-tenths on a scale with a score of "four" being the highest and "one" the lowest. Least significant differences between means are shown in
Table 1


<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Single-stage fry</th>
<th>Duo-stage fry</th>
<th>Treatment at -18°C (0°F)</th>
<th>Treatment at -78°C (-108°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S.G.**</td>
<td>S.G.</td>
<td>S.G.</td>
<td>S.G.</td>
</tr>
<tr>
<td>Over-all quality (preference)</td>
<td>1.115</td>
<td>1.085</td>
<td>1.115</td>
<td>1.085</td>
</tr>
<tr>
<td>Crust crispness (crisp vs. lacking crispness)</td>
<td>2.2</td>
<td>2.4</td>
<td>2.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Crust tenderness (tender vs. tough)</td>
<td>1.9</td>
<td>2.7</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Interior appearance (opaque vs. translucent)</td>
<td>3.1</td>
<td>2.3</td>
<td>3.3</td>
<td>2.8</td>
</tr>
<tr>
<td>Interior graininess (granules, abundant vs. non-detectable)</td>
<td>3.3</td>
<td>2.8</td>
<td>3.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Interior moistness (dry vs. soggy)</td>
<td>3.0</td>
<td>2.5</td>
<td>3.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Interior cohesiveness (particles disperse readily vs. cohesive)</td>
<td>2.9</td>
<td>2.7</td>
<td>3.3</td>
<td>2.6</td>
</tr>
</tbody>
</table>

* Each number is the average of 12 scores (4 judges, and 3 replications).

** S.G. - specific gravity of tubers.
Table II, Appendix.

Over-all quality also was judged to be better when the parfried potato strips had a freezing treatment. For over-all quality, which in this case indicated preference, the average score was three for the potatoes which were frozen as an intermediate step in preparation, but was only two and five-tenths for the treatments which did not include freezing. Least significant difference between means are shown in Table II, Appendix.

Because of the higher starch content and larger starch grains reported for high-specific-gravity potatoes (29, p. 559, 563-564), it might be expected that specific gravity would influence the texture. By means of the analysis of variance, Table I, Appendix, it was demonstrated that specific gravity of the tubers did have an influence on some textural characteristics. The French fries prepared from potatoes of high specific gravity had a less tender crust, a more glistening, opaque interior, greater graininess, a drier and fluffier interior and a less cohesive interior than did the French fries prepared from low-specific-gravity tubers. The significance level for differences between means are shown in Table III, Appendix.

Treatment had a greater effect on over-all quality, crust crispness, and crust tenderness than did specific gravity. Specific gravity had a greater effect on
interior appearance, interior graininess and interior
moistness. Both specific gravity and treatment influenced
interior cohesiveness. These data are shown in Table I,
Appendix.

Loss of Moisture and Absorption of Fat During French Frying

According to Benes, Carlin, and Logan (3, p. 6), when
a potato is properly French fried, it will have lost about
20 per cent (variable) of its original moisture content.
In addition, the potato strips will add eight to ten per
cent of their finished weight in absorbed fat. These
authors go on to say that if the French-fried potato ab-
sorbs much more than 10 per cent fat, it will have a poor
texture and appearance (3, p. 6).

The amount of moisture lost during frying could
vary with the method of preparation. Since water must be
present for starch gelatinization, the amount of moisture
lost might influence the texture of the French-fried
potatoes.

Since oiliness of French-fried potatoes is consider-
ed undesirable, it would be of value to determine the
amount of fat absorbed by potatoes prepared in various
ways. It might be expected that two-stage frying would
cause the strips to absorb more fat, but, as mentioned
earlier, judges preferred French fries which were
prepared by two-stage frying with freezing as an intermediate step. It would be of value to know if freezing as a step in preparation influenced the amount of fat absorbed.

The per cent of moisture lost and the per cent of fat absorbed were determined both for the parfries and for the finished potato strips. The percentage loss in moisture, on the basis of the fresh weight, and absorption of fat, on the basis of cooked weight, of French-fried potatoes prepared by various methods are shown in Table 2, page 55.

By means of the analysis of variance, Table IV, Appendix, it was found that the method of preparation influenced both the loss of moisture and the absorption of fat. This difference was not found in the parfries, but only in the finish-fried strips.

The potato strips which were duo-fried without a freezing treatment lost more moisture than did the potato strips which were fried by the single-stage method.

The French-fried potatoes which were frozen as an intermediate step in preparation lost less moisture when finish fried than did the French fries which had not been frozen, the difference being significant at the one per cent level. This difference in moisture loss might be explained by the maximum internal temperatures reached
Table 2

Moisture Loss and Fat Absorption of Russet Burbank Potatoes During French Frying

<table>
<thead>
<tr>
<th>Sample gravity: Treatment</th>
<th>Fat Absorption</th>
<th>Moisture loss, absorption, fresh weight: Finish-fried basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specified gravity:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fat</td>
<td>Finish-fried basis</td>
</tr>
<tr>
<td></td>
<td>Finish</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1.085</th>
<th>Frozen at -18°C (0°F.)</th>
<th>43.56</th>
<th>47.51</th>
<th>5.79</th>
<th>8.10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.085</td>
<td>&quot;</td>
<td>44.20</td>
<td>46.91</td>
<td>7.00</td>
<td>8.51</td>
</tr>
<tr>
<td>2</td>
<td>1.115</td>
<td>&quot;</td>
<td>43.27</td>
<td>46.47</td>
<td>7.33</td>
<td>8.74</td>
</tr>
<tr>
<td>3</td>
<td>1.115</td>
<td>&quot;</td>
<td>41.47</td>
<td>44.26</td>
<td>5.24</td>
<td>7.11</td>
</tr>
<tr>
<td>4</td>
<td>1.085</td>
<td>Frozen at -78°C (-108°F.)</td>
<td>43.86</td>
<td>46.42</td>
<td>6.60</td>
<td>9.89</td>
</tr>
<tr>
<td>5</td>
<td>1.085</td>
<td>&quot;</td>
<td>41.87</td>
<td>44.33</td>
<td>5.60</td>
<td>9.24</td>
</tr>
<tr>
<td>6</td>
<td>1.115</td>
<td>&quot;</td>
<td>44.69</td>
<td>47.07</td>
<td>7.91</td>
<td>10.82</td>
</tr>
<tr>
<td>7</td>
<td>1.115</td>
<td>&quot;</td>
<td>45.43</td>
<td>47.65</td>
<td>7.94</td>
<td>11.66</td>
</tr>
<tr>
<td>8</td>
<td>1.085</td>
<td>Single fried</td>
<td>--</td>
<td>48.45</td>
<td>--</td>
<td>6.49</td>
</tr>
<tr>
<td>9</td>
<td>1.085</td>
<td>&quot;</td>
<td>--</td>
<td>46.52</td>
<td>--</td>
<td>6.82</td>
</tr>
<tr>
<td>10</td>
<td>1.115</td>
<td>&quot;</td>
<td>--</td>
<td>46.45</td>
<td>--</td>
<td>6.05</td>
</tr>
<tr>
<td>11</td>
<td>1.115</td>
<td>&quot;</td>
<td>--</td>
<td>47.59</td>
<td>--</td>
<td>6.43</td>
</tr>
<tr>
<td>12</td>
<td>1.085</td>
<td>Duo-fried</td>
<td>--</td>
<td>50.84</td>
<td>--</td>
<td>9.25</td>
</tr>
<tr>
<td>13</td>
<td>1.085</td>
<td>&quot;</td>
<td>--</td>
<td>50.12</td>
<td>--</td>
<td>8.18</td>
</tr>
<tr>
<td>14</td>
<td>1.115</td>
<td>&quot;</td>
<td>--</td>
<td>49.10</td>
<td>--</td>
<td>8.72</td>
</tr>
<tr>
<td>15</td>
<td>1.115</td>
<td>&quot;</td>
<td>--</td>
<td>48.15</td>
<td>--</td>
<td>7.55</td>
</tr>
</tbody>
</table>
When the frozen parfries were finish fried, they were taken directly from frozen storage and without thawing, immersed in the preheated fat, and allowed to fry for one and one-half minutes. This was sufficiently long to brown the crust and to bring the strips to a hot serving temperature. However, the internal temperature, as shown in Figure 3, page 57, attained a maximum of only 96°C (205°F.). In contrast, the temperature attained by the unfrozen parfries during finish frying was above 100°C (212°F.).

Potato strips that had been frozen absorbed more fat, approximately nine and three-tenths per cent, than did those that had no freezing treatment, approximately seven and seven-tenths per cent. Of the samples which had been frozen, those which were frozen at -78°C (-108°F.) absorbed more fat than did those which were frozen at -18°C (0°F.). The potato strips which were fried by single-stage frying absorbed less fat, approximately seven per cent, than did those which were duo-fried without a freezing treatment which averaged about eight and four-tenths per cent.

In summary, the potato strips which were frozen as an intermediate step in preparation absorbed more fat and lost less moisture than did the French fries which
Figure 3

Temperature Changes in French-Fried Potato Strips During Parfrying, Freezing and Finish Frying.

Key

..... Frozen at -18°C. (0°F.)
--- Frozen at -78°C. (-108°F.)
were not frozen. These French fries were preferred to those that had not been frozen. See Table 1, page 51.

The French-fried potatoes prepared in this study lost approximately 45 per cent of their original weight during frying. This was due to moisture loss. This moisture loss differs from that reported by Benes, Carlin, and Logan (3, p. 6) as being desirable for good French-fried potatoes. The lower moisture loss reported by these authors is probably due to the fact that in commercial frying when large amounts of potatoes are fried at one time a drop in fat temperature is brought about. The interior temperature of the potatoes is, therefore, comparatively low and less moisture is lost. Apparently the degree of moisture loss is not important from a palatability viewpoint, since the judges in this study gave high palatability scores to the French fries.

Rates of Temperature Change During Cooking and Freezing of French-Fried Potatoes

Studies by Gardner (10) have indicated that the rate of freezing fruit or vegetable tissue influences not only the size of the ice crystals formed but the location of the crystals. During freezing, ice crystals form first between cells. If freezing occurs slowly, water is withdrawn from the cells and larger ice crystals are formed
which crush the cells (10, p. 233). If the tissue is frozen rapidly, many small ice crystals are formed within the cells as well as between cells; consequently, there is less tissue damage or textural change and less rupturing of cells.

The judges did not detect a difference between the French fries which had been frozen on dry ice, \(-78^\circ C\) \((-108^\circ F.)\), and those frozen in a home freezer at \(-18^\circ C\) \((0^\circ F.)\). It might be assumed that such differences in the temperatures of the freezing environment would cause differences in the freezing rates of the parfried potatoes. This was not the case. The rates of freezing for these samples were similar. This finding was unexpected in view of the observations on microscopic structure described later.

Temperature changes during parfrying, freezing, and finish frying are shown in Figure 3, page 57. Because of the similarity in the rate of temperature drop, initial ice crystal formation probably took place in much the same way under both conditions of freezing.

The potentiometer used for securing the temperature readings recorded a minimum of \(-40^\circ C\) \((-40^\circ F.)\). For this reason, neither the time needed to reach the lowest temperature nor the final temperature attained were noted for parfried strips placed on dry ice, although it may be assumed that the temperature dropped rapidly to that of
dry ice. The low temperature during storage would have probably inhibited growth of ice crystals in the potato tissue.

It may be concluded that the temperature of freezing, whether it be -18°C. (0°F.) as in a home freezer, or -78°C. (-108°F.) as on dry ice, has no appreciable influence on the rate of freezing, or on palatability scores for texture of French-fried potatoes. Woodroof (34, p. 17) in his studies found that as far as microscopic changes are concerned, the temperature at which starchy vegetables were frozen did not influence texture.

As will be described later, frozen parfried potato tissue, though exhibiting various structural alterations due to freezing, tends to recover some of its original characteristics when finish-fried. This factor, as well as the similarity in rate of freezing may have masked any differences that might have been associated with freezing and storing at different temperatures.

Comparison of Histological Methods for Studying Potato Tissue

As far as the present writer knows, freeze-drying has not been employed previously for the preparation of cooked potato tissue for microscopic study. Since some writers (11, p. 3-4 and 12, p. 173) feel that
dehydration by freeze drying has many advantages, while others (15, p. 33) feel that plant material is difficult to freeze-dry satisfactory, in this study Johansen's tertiary-butyl-alcohol method, a commonly used method for dehydration, was used, as well as the freeze-drying technique. In addition, unfixed tissue was studied.

The number of different lines of investigation followed, in order to determine the effect of various preparation methods on French-fried potatoes, resulted in numerous data. In order to narrow the discussion, a comparison will be made between the two histological methods used for killing, fixing, dehydrating and infiltrating the potato tissue. Tissue treated in these ways will be compared with the untreated tissue. Following this, the microscopic characteristics of tissue from potatoes of high and low specific gravity will be discussed.

Photomicrographs showing the characteristics of potato tissue from unfixed material and material fixed by the two histological methods are shown in Figures 4 and 5, pages 62 and 63.

It would be difficult to say that one method or another was the best for preparing potato tissue for microscopic study.

In raw potato tissue which has not been dehydrated, the starch granules are very prominent and tend to be
Figure 4

Photomicrographs (x 60) of Raw Potato Tissue Treated in Different Ways for Microscopic Study

a. Tissue untreated

b. Tissue dehydrated in alcohols and embedded in paraffin

c. Tissue prepared by histological freeze-drying technique and embedded in paraffin
Figure 5

Photomicrographs (x 60) of Cooked Potato Tissue Treated in Different Ways for Microscopic Study

a. Tissue untreated

b. Tissue dehydrated in alcohols and embedded in paraffin

c. Tissue dehydrated by freeze-drying and embedded in paraffin
dispersed throughout the cells, Figure 4, photomicrograph a. When the tissue has been dehydrated by Johansen's method using tertiary-butyl-alcohol, the starch granules appear to be much smaller and are more concentrated in one area of the cell, Figure 4, photomicrograph b. This sample was easy to section by means of the rotary microtome. The tissue mat had completely infiltrated the tissue.

The starch granules in the raw tissue which was subjected to the freeze-drying technique appeared to be more like the raw, undehydrated tissue, Figure 4, photomicrograph c. This sample was light, and powdery, and could not be sectioned by means of the microtome and appeared not to be completely infiltrated with tissue mat. It was concluded that the freeze-drying technique was not satisfactory for preparing raw potato tissue for microscopic study.

Most confidence might be placed in the appearance of potato cells that were not subjected to any fixing treatment. However, this method would not permit a study of clumps or groups of cells and the adhesion between cells, since the individual cells separated when placed on a slide. Nor would it be possible to make a cross section of these cells, to study the cell contents.

Cooked potato tissue fixed by the freeze-drying technique as compared to that prepared by the Johansen
method showed similarity in shrinking or clumping of the cell contents into irregular masses. In tissue fixed by the freeze-drying method, the spaces between the clumped cell contents were filled with lacy, fragile-looking material; whereas, these spaces appeared to be empty in tissue fixed by the Johansen method. The presence of material in the spaces among the cells suggests that fixation was quicker by the freeze-drying method than by the Johansen method. The presence of large, empty spaces in the tissue prepared by the Johansen method, made it appear that the cell contents had more time in which to migrate together. The cell walls were quite distinct in tissue fixed by the Johansen method, but were indistinct in tissue fixed by the freeze-drying method.

Since tissue prepared by both methods was similar in regard to the shrinkage or clumping of cell contents, and since fixation by the freeze-drying method may have been quicker, the freeze-drying technique appeared to yield as much, if not more, information than the Johansen method. For these reasons, the illustrative material discussed in the section dealing with microscopic appearance of fixed, dehydrated tissue is material prepared by the freeze-drying technique.
Comparison of Tissues from Tubers of High and Low Specific Gravity

In order to determine whether potato tissues from tubers of different specific gravity were influenced in different ways by various cooking or freezing procedures, low, 1.085, and high, 1.115, specific-gravity potatoes were compared. Photomicrographs of cooked tissue from high and low-specific-gravity tubers are shown in Figure 6, page 67.

When prepared by either histological method, the appearance of tissue taken from frozen parfried potatoes appeared to be independent of the specific gravity of the tubers. Therefore, in evaluating the histological changes brought about in potato tissue by various cooking or freezing methods, the microscopic appearance of the tissue is discussed without reference to specific gravity of the tubers.

Changes in Microscopic Appearance of Potato Tissue Due to the Process of Freezing

By studying sections of tissue which had been dehydrated and infiltrated with tissuemat, information was obtained which was not available from studies of the untreated material. By cutting through the fixed material, it was possible to see inside the cells which was an
Figure 6
Photomicrographs (x 60) of Cooked Potato Tissue of High, 1.115, and of Low, 1.085, Specific Gravity
impossibility with the untreated material. In addition, a study of the sections allowed for observation of relationships of the cells and intercellular material as they were affected by cooking and freezing. On the other hand, much additional information was obtained from studying individual cells and unfixed tissues.

**Tissue Prepared by the Histological Freeze-Drying Technique**

The freeze-drying method of tissue preparation for microscopic study was used because it was believed that the low temperatures employed, -78°C. (-108°F.), would minimize changes in the tissue during the process of dehydration. The microscopic appearance of tissue prepared in this way indicates that before dehydration could be completed, some shrinkage of cell contents and distortion of cells occurred.

In spite of this limitation, tissue prepared by the freeze-drying method showed differences due to the cooking or freezing treatment of the parfried and finish-fried potatoes. Photomicrographs of a series of samples prepared by the histological freeze-drying technique are shown in Figures 7 and 8, pages 69, 70, and 71.

Many dark, concentrated-appearing areas within the cells may be seen in the photomicrographs. These areas
Photomicrographs (X 60) of Raw and Cooked Potato Tissue Prepared for Microscopic Study by Histological Freeze-Drying Technique

Identity
1. Raw
2. Parfry unfrozen
3. Single fry
4. Duo-fry, unfrozen
5. Parfry frozen at -18°C. (0°F.)
6. Parfry frozen at -78°C. (-108°F.)
7. Parfry frozen at -18°C. (0°F.) and finish fried
8. Parfry frozen at -78°C. (-108°F.) and finish fried
Figure 8
Photomicrographs (X 270) of Raw and Cooked Potato Tissue Prepared for Microscopic Study by Histological Freeze-Drying Technique

Identity
1. Raw
2. Parfry unfrozen
3. Single fry, unfrozen
4. Duo-fry, unfrozen
Identity

1. Parfry frozen at -18°C. (0°F.)
2. Parfry frozen at -78°C. (-108°F.)
3. Parfry frozen at -18°C. (0°F.) and finish fried
4. Parfry frozen at -78°C. (-108°F.) and finish fried
are irregular in shape and outline. They are probably composed of swollen and gelled starch granules. The size of these concentrated-appearing areas depended on the treatment of the French-fries. Cooked tissue that had no freezing treatment had larger, less distorted-appearing areas.

Tissue from samples which had been held at freezing temperatures for two weeks had similar clumped areas, but they were more compact, while the spaces between the areas were larger, and contained torn or fragmented material. The whole cross section of the interior of some of the frozen parfries had a lacy, fragile appearance when viewed under the microscope, Figure 8.

It appears that as ice-crystal formation occurred, water was withdrawn from the cell contents and the starchy contents were pushed into heaps which appeared as dark concentrated masses.

**Appearance of Unfixed Potato Cells**

As mentioned previously, reports in the literature state that it is impossible to fix and dehydrate vegetable tissue without some distortion occurring. This statement was corroborated by observations on potato tissue here-with reported in the section on comparison of histological methods for studying potato tissue. Studies were,
therefore, carried out on untreated tissue to supplement the information obtained by other histological methods.

Photomicrographs showing the characteristics of potato cells which have been neither dehydrated nor embedded in paraffin are shown in Figure 9, page 74. The cooked, unfrozen, potato cells are plump with a velvety-looking texture. They have a stippled surface appearance.

Potato cells which have been frozen present a different picture. They have lost their velvety-looking texture, and have a characteristic appearance which depends on the temperature at which they were frozen. Cells from parfries which had been frozen at -18°C. (0°F.), but not finish fried, have a very broken and lacy appearance, Figure 9. Cells from parfries which had been frozen at -78°C. (-108°F.) have a surface which is covered with numerous fissures, or minute folds.

The appearance of the cells from tissue frozen at -18°C. (0°F.) indicates that large ice crystals formed which pushed the contents together into small heaps. The crystals were so large that the cell walls were sometimes ruptured. The ice crystals in cells frozen at -78°C. (-108°F.) must have been smaller, since the cells did not show the extensive laciness or breaking noted in cells frozen at -18°C. (-108°F.). The cells do, however, show evidence of strain due to the freezing treatment since many of the
Figure 9

Photomicrographs (X 60) of (1) Raw Potato Tissue and (2) Tissue Prepared by Various Cooking and Freezing Methods. Undehydrated Tissue

Identity

1. Raw
2. Parfry unfrozen
3. Single fry
4. Duo-fry, unfrozen
5. Parfry frozen at -18°C (0°F.)
6. Parfry frozen at -78°C (-108°F.)
7. Parfry frozen at -18°C (0°F.) and finish fried
8. Parfry frozen at -78°C (-108°F.) and finish fried
fissures and striations showing in the walls of these cells are twisted.

When parfried tissue which was frozen at -18°C. (0°F.) was finish fried, and the cells examined under the microscope, it was found that the cooking process had caused the cell contents to plump up and fill out the cells. Breaks in the cell walls caused by ice crystals during freezing tended to disappear when the frozen tissue was finish fried. Since cells from the parfried tissue which was frozen at -78°C. (-108°F.) did not show a lacy structure as did the parfried tissue frozen at -18°C. (0°F.), the plumping or filling out of cells caused by finish frying was not noticed. However, the surfaces of cells that had undergone a freezing treatment before finish frying differed in appearance from those which had not been frozen. Instead of the velvety, stippled appearance of the unfrozen cells, they exhibited many small striations which appeared to be cracks or tiny folds.

Changes Observed in Unfixed, Cooked Tissue During the Process of Freezing and Thawing

Since freezing causes changes in the texture of French-fried potatoes, as noted by the taste-test panel, information as to the kind and extent of tissue change would be of importance when freezing is used to produce
textural changes in such a food.

Data on the sequence of change during the process of freezing and thawing were obtained by placing small bits of freshly prepared, parfried potato tissue on a slide and observing the tissue during freezing. The samples were frozen on a Leitz cooling stage with carbon dioxide gas as the freezing medium. The lowest temperature during the freezing process was \(-20^\circ\text{C.} \ (-4^\circ\text{F.})\). Evidence was found on the following points: (1) the breaking of intercellular cementing material, (2) the distortion and fracturing of cells, (3) the "piling" up of gelatinized starch granules within the cells, and (4) partial recovery during thawing.

The series of photomicrographs made while parfried potato tissue was undergoing freezing are shown in Figures 10, 11, 12, 13, and 14, pages 79, 80, 81, 82 and 83. The first pictures are completely dark, since the bit of tissue was thick enough to prevent transmission of light, Figures 10 and 11. As cooling with carbon dioxide continued, the tissue began to freeze. The first signs of freezing were tiny breaks in the mass of cellular material through which light was transmitted, Figures 10 and 11. These tiny breaks must have been sites of ice crystal formation, for larger and larger breaks occurred at these locations as freezing continued.
When the tissue was completely frozen, very large breaks as well as small ones were found throughout the mass of cells, Figures 10 and 11. In this series of photomicrographs, most of the breaks were found between cells. During the latter stages of freezing, some of the cells, Figure 10, became very lacy in appearance, resembling cells taken from parfried tissue which had been frozen and stored at -18 C. (0 F.), Figure 9, page 74.

The extensive rupturing of intercellular substance during freezing undoubtedly accounts for the "loose", noncohesive texture noted by the taste-test panel in French-fried potatoes that had been frozen as parfries and then finish fried.

In order to gain more information about the changes which occurred in the cells during freezing, a few cells from parfried potato strips were placed on a slide and viewed during the process of freezing. Figures 12, 13, and 14, pages 81, 82, and 83. Extreme distortion of cells took place during freezing, as shown in Figures 12, and 14. This appeared to follow cell separation.

When the tissue was allowed to thaw, as may be seen in the photomicrographs, Figure 13, page 82, some reversal of the freezing changes took place, most
noticeable being a plumping and recovery of shape of the cells. Fractures of intercellular cementing substances could not have been repaired although the spaces between cells became smaller as the cells returned to approximately their former size and shape, Figures 12 and 13, pages 80 and 81.
Figure 10

Series of Photomicrographs (X 60) of Cooked Potato Tissue
During the Process of Freezing, Sample No. 1
Figure 11

Photomicrographs (X 60) of Cooked Potato Tissue During the Process of Freezing, Sample No. 2

Unfrozen, cooked potato tissue

Frozen, cooked potato tissue
Figure 12
Series of Photomicrographs (X 270) of Cooked Potato Cells During the Process of Freezing, Sample No. 1

Unfrozen tissue

Frozen tissue
Figure 13
Photomicrographs (X 270) of Thawed and Refrozen, Cooked Potato Cells.
Microscopic Field Same as that in Figure 12

Thawed tissue

Refrozen tissue
Figure 14

Series of Photomicrographs (X 270) of Cooked Potato Cells
During the Process of Freezing, Sample No. 2
CHAPTER V

SUMMARY AND CONCLUSIONS

Preliminary investigations indicated that French-fried potato strips which were parfried, frozen, and finish fried had a different and seemingly superior texture than did French fries which were not frozen as an intermediate step in preparation.

The purpose of this study was twofold: to obtain palatability data on French-fried potatoes prepared by different methods, and to obtain data on the changes which occur in parfried, potato strips during the process of freezing as contrasted with other methods of preparation. Information as to the changes which occur during freezing and the sequence in which these changes occur would be of importance when freezing a starchy food such as French-fried potatoes in order to control its textural characteristics.

A trained, taste-test panel evaluated French-fried potatoes prepared from tubers of high, 1.115, and low, 1.085, specific gravity for the following characteristics: over-all quality, crust crispness, crust tenderness, interior appearance, interior graininess, interior moistness, and interior cohesiveness.

Tissues from potatoes treated in the following
eight ways were studied: raw; parfried and not frozen; parfried and frozen at $-18^\circ$C. ($0^\circ$F.); parfried and frozen at $-78^\circ$C. ($-108^\circ$F.); single-stage fried and not frozen; duo-stage fried and unfrozen; parfried, frozen at $-18^\circ$C. ($0^\circ$F.) and finish fried; and parfried, frozen at $-78^\circ$C. ($-108^\circ$F.) and finish fried. All parfries were fried for five minutes at $177^\circ$C. ($350^\circ$F.). The potato strips which were fried in one or two stages without freezing treatment and those which were finish fried after freezing had a total frying time of six and one-half minutes at $177^\circ$C. ($350^\circ$F.).

For microscopic study, cross sections of the French fries were dehydrated, embedded in tissue-embedding and stained with basic fuchsin. Photomicrographs were made. In addition, tissues taken directly from the potato strips at various stages of parfrying, freezing, and finish frying were studied without dehydration. Small bits of tissue were placed on slides and photomicrographs taken. For studying individual cells, a drop of water was added which caused the cells to separate.

To observe changes during the freezing process, small samples of undehydrated tissue or individual cells were placed on slides and frozen with carbon dioxide gas. Photomicrographs were taken as freezing took place.

In this study, the judges preferred the
French-fried potatoes which had been parfried, frozen, and finish fried to those which had not been frozen. The French fries prepared from frozen parfries had a more tender, crisp crust and a less cohesive interior than did French fries which had no freezing treatment.

Specific gravity of the tubers had an influence on some textural characteristics. French fries prepared from potatoes of high specific gravity had a less tender crust, a more glistening, opaque interior, greater graininess, a drier and fluffier interior and a less cohesive interior than did French-fried potatoes prepared from low-specific-gravity tubers.

Treatment, such as frying with or without freezing as an intermediate step, had a greater effect on over-all quality, crust crispness, and crust tenderness than did specific gravity. Specific gravity had a greater effect on interior appearance, interior graininess and interior moistness. Both treatment and specific gravity influenced cohesiveness.

The potato strips which were frozen as an intermediate step in preparation absorbed more fat and lost less moisture than did the French fries which were not frozen.

It was found that the temperature of freezing whether \(-18^\circ C. (0^\circ F. )\) as in a home freezer, or \(-78^\circ C.\)
(-108°F.) as on dry ice, had no appreciable influence on the rate of freezing, or on palatability scores for texture.

The microscopic appearance of tissue taken from frozen French-fried potatoes appeared to be unrelated to specific gravity.

Concentration of cell contents and large spaces between these areas were observed in photomicrographs of tissue which had been dehydrated and infiltrated with tissuemat. The concentrated-appearing areas were larger in tissues from French fries which had no freezing treatment. Tissues from frozen parfries had smaller clumped areas and larger spaces containing fragmented material.

The surfaces of cooked, undehydrated, potato cells which had not been frozen were velvety and stippled in appearance. Cells from tissue that had been frozen had a different appearance. Undehydrated potato cells from parfries which had been frozen at -18°C. (0°F.) but not finish fried, had a broken and lacy appearance. This was not observed in the cells which had been frozen at -78°C. (-108°F.). The appearance of the cells from tissue frozen at -18°C. (0°F.) indicates that large ice crystals formed which pushed the contents into small heaps and ruptured the cell walls. The ice crystals
formed when parfries were held at -78°C. (-108°F.) must have been smaller, since the cells did not show the extensive laciness or breaking noted in cells frozen at the higher temperature.

Freezing causes changes in the intercellular cementing material of potatoes which allows the cells to separate. Following cell separation, cell distortion and a concentration of cell contents occurred. The cells tended to recover when thawed. Even though the potato tissue appeared to recover somewhat from the changes which occurred during freezing, the recovery was not complete; therefore, cooked potato tissue which had been frozen was less cohesive than cooked tissue which had not been frozen.

This study indicates that potato strips which are parfried, frozen, and finish fried produce superior French-fried potatoes. The process of freezing causes desirable changes in the texture of the fried potato strips.
BIBLIOGRAPHY


34. Woodroof, J. G. Microscopic studies of frozen fruits and vegetables. Experiment, 1938. 46 p. (Georgia. Experiment Station Bulletin no. 201)

APPENDIX
## Figure I

Score Card for Judging Texture of French-Fried Potatoes

<table>
<thead>
<tr>
<th>Sample Number</th>
</tr>
</thead>
</table>

### OVERALL QUALITY:

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>excellent</td>
</tr>
<tr>
<td>3</td>
<td>good</td>
</tr>
<tr>
<td>2</td>
<td>fair</td>
</tr>
<tr>
<td>1</td>
<td>poor</td>
</tr>
</tbody>
</table>

### CRUST CRISPNESS:

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>crisp</td>
</tr>
<tr>
<td>3</td>
<td>moderately crisp</td>
</tr>
<tr>
<td>2</td>
<td>slightly crisp</td>
</tr>
<tr>
<td>1</td>
<td>lacking crispness</td>
</tr>
</tbody>
</table>

### CRUST TENDERNESS:

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>tender</td>
</tr>
<tr>
<td>3</td>
<td>moderately tender</td>
</tr>
<tr>
<td>2</td>
<td>slightly tender</td>
</tr>
<tr>
<td>1</td>
<td>tough</td>
</tr>
</tbody>
</table>

### INTERIOR: Appearance

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>opaque, white, glistening and crumbly</td>
</tr>
<tr>
<td>3</td>
<td>glistening, some translucency</td>
</tr>
<tr>
<td>2</td>
<td>few glistening particles, moderately translucent</td>
</tr>
<tr>
<td>1</td>
<td>smooth, wet, translucent</td>
</tr>
</tbody>
</table>

### Mouth Feel: Graininess

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>granules abundant</td>
</tr>
<tr>
<td>3</td>
<td>granules moderately abundant</td>
</tr>
<tr>
<td>2</td>
<td>slightly grainy</td>
</tr>
<tr>
<td>1</td>
<td>lacking graininess</td>
</tr>
</tbody>
</table>

### Mouth Feel: Moistness

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>dry, fluffy</td>
</tr>
<tr>
<td>3</td>
<td>somewhat moist and somewhat fluffy</td>
</tr>
<tr>
<td>2</td>
<td>moist and lacking fluffiness</td>
</tr>
<tr>
<td>1</td>
<td>soggy and smooth</td>
</tr>
</tbody>
</table>

### Mouth Feel: Cohesiveness

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>particles disperse readily in mouth</td>
</tr>
<tr>
<td>3</td>
<td>slightly cohesive</td>
</tr>
<tr>
<td>2</td>
<td>moderately cohesive</td>
</tr>
<tr>
<td>1</td>
<td>cohesive</td>
</tr>
</tbody>
</table>
Table I

Analysis of Variance of Palatability Characteristics of French-Fried Potatoes

| Source of variance of palatability characteristics of French-Fried Potatoes | Degrees of freedom | Crust:Quality:
| | | tenderness |
| | | crispness |
| | | appearance |
| | | graininess |
| | | moister |
| | | cohesive |
| Replication | 2 | .54 |
| Treatments (Tr.) | 3 | 14.82* |
| Specific Gravity (SP Gr) | 1 | 5.04 |
| TR X SpGr | 3 | 3.38 |
| Error | 14 | 3.16 |
| Total | 23 | -- |

| Mean Squares |
| 1.54 |
| 16.50* |
| 2.67 |
| 60.17** |
| 3.95 |
| 2.72 |

* Significant at 5% level.
** Significant at 1% level.
### Table II

Average Palatability Scores for French-Fried Potatoes Prepared by Different Methods

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Single-stage fried</th>
<th>Duo-stage fried</th>
<th>Parfried, frozen at -18°C (0°F) and finish fried</th>
<th>Parfried, frozen at -78°C (-108°F) and finish fried</th>
<th>Least significant difference between means (P = .05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over-all quality</td>
<td>2.29</td>
<td>2.71</td>
<td>2.79</td>
<td>3.25</td>
<td>.55</td>
</tr>
<tr>
<td>Crust crispness</td>
<td>2.50</td>
<td>2.96</td>
<td>3.12</td>
<td>3.50</td>
<td>.57</td>
</tr>
<tr>
<td>Crust tenderness</td>
<td>2.29</td>
<td>2.75</td>
<td>3.50</td>
<td>3.71</td>
<td>.62</td>
</tr>
<tr>
<td>Interior appearance</td>
<td>2.67</td>
<td>3.04</td>
<td>2.75</td>
<td>3.04</td>
<td>N.S.</td>
</tr>
<tr>
<td>Interior graininess</td>
<td>3.08</td>
<td>3.21</td>
<td>2.62</td>
<td>3.25</td>
<td>N.S.</td>
</tr>
<tr>
<td>Interior moistness</td>
<td>2.75</td>
<td>2.83</td>
<td>2.62</td>
<td>2.96</td>
<td>N.S.</td>
</tr>
<tr>
<td>Interior cohesiveness</td>
<td>2.79</td>
<td>2.96</td>
<td>3.17</td>
<td>3.46</td>
<td>.26</td>
</tr>
</tbody>
</table>
Table III

Average Palatability Scores for French-Fried Potatoes of Different Specific Gravity

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specific gravity</th>
<th>Significance level</th>
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<tbody>
<tr>
<td></td>
<td>1.115</td>
<td>1.085</td>
</tr>
<tr>
<td>Over-all quality</td>
<td>2.88</td>
<td>2.64</td>
</tr>
<tr>
<td>Crust crispness</td>
<td>3.10</td>
<td>2.94</td>
</tr>
<tr>
<td>Crust tenderness</td>
<td>2.83</td>
<td>3.29</td>
</tr>
<tr>
<td>Interior appearance</td>
<td>3.27</td>
<td>2.48</td>
</tr>
<tr>
<td>Interior graininess</td>
<td>3.40</td>
<td>2.69</td>
</tr>
<tr>
<td>Interior moisture</td>
<td>3.12</td>
<td>2.46</td>
</tr>
<tr>
<td>Interior cohesiveness</td>
<td>3.31</td>
<td>2.88</td>
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Table IV

Analysis of Variance of Moisture Loss and Fat Absorption of Russet Burbank Potatoes During French Frying

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>Mean squares</th>
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<tbody>
<tr>
<td></td>
<td>Moisture loss, per cent</td>
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<tr>
<td></td>
<td>Degrees of freedom</td>
</tr>
<tr>
<td>Specific gravity (S.G.)</td>
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</tr>
<tr>
<td>Treatment (TR)</td>
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</tr>
<tr>
<td>Frozen at -18°C (0°F) vs. Frozen at -78°C (-105°F)</td>
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</tr>
<tr>
<td>Single fry (S) vs. Duo fry (D)</td>
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</tr>
<tr>
<td>Freezing (F) vs. Nonfreezing (N)</td>
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</tr>
<tr>
<td>S.G. X TR</td>
<td>3</td>
</tr>
<tr>
<td>S.G. X F (-18°C) vs. F. (-78°C)</td>
<td>1</td>
</tr>
<tr>
<td>S.G. X S vs. D</td>
<td>1</td>
</tr>
<tr>
<td>S.G. X F vs. N</td>
<td>1</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
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<tr>
<td>Total</td>
<td>15</td>
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* Significant at the 5% level.
** Significant at the 1% level.