MICROSCOPIC STRUCTURE OF POTATO CHIPS[1]

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Although various commercially processed potato products have been microscopically investigated (2, 3, 4, 6), apparently no descriptions of the cellular structure of potatoes fried in deep fat have been published. Certain conditions of deep-fat frying are known to produce blisters in potato chips and these blisters sometimes are filled with oil. The mechanism by which these blisters form has been little understood, but the results of recent preliminary studies suggest that they arise by cell separation in the interior of the slice (1). Likewise, little seems to be known about the manner in which the oil becomes distributed within either chips or French fries, whether it is localized or uniformly distributed throughout the slice.

This communication describes the microscopic structure of chips and French fried potatoes and includes observations on the formation of blisters and the distribution of the oil in potato chips.

Materials and Methods

Both commercial products and those experimentally produced at this Laboratory were used. The experimental samples were fried in cottonseed oil for 2½ minutes beginning at 380° F. and finishing at 320° F. for chips, and at 375° F. for 3 to 4½ minutes for French fries. Slice thickness for chips varied from 1/30 to 1/9 inch. Some samples were removed from the hot oil at different intervals in order to follow the sequence of blister development.

Sections for microscopic study were cut after the samples had been softened by soaking, first in ethyl alcohol and ether solution (2:1 by volume) for about 2 hours, to remove most of the oil, and then either in cold water for several hours or in hot water (about 180° F.) for 20 to 30 minutes. Several changes each were made of the alcohol-ether solution and of water to remove as much of the oil as possible and thus enhance the microscopic appearance of the sections. When sufficiently softened with water, pieces of the chips were placed on the flat surface of a block of paraffin and sectioned free-hand with a safety razor blade. Nearly all sections so cut were slightly wedge-shaped in 2 directions—the thicker portions being about 500 microns thick. This soaking procedure eliminated fracture of the cell walls that would occur with sectioning of the dry, brittle chips. Suitable sections of the blister areas of some of the chips also could be obtained by limiting the time of soaking in water so that the fragile blister walls were not overly softened and did not crumble when the sections were cut. Complete dehydration of these sections then occurred rapidly when they were placed in water for microscopic examination.

Other samples were soaked only in a 0.1 per cent aqueous solution of osmium tetroxide in a closed container to fix and stain their oil for

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microscopic localization. Exceptional care was taken in working with this toxic reagent. Because of extremely intense staining of the tissue by osmium tetroxide, it was necessary to cut wedge-shaped sections and use only the thinner portions of the wedges for microscopic examinations. Other fried samples were partly softened with water, or with a solution of one volume each of glycerine, ethyl alcohol and water, then sectioned and the sections stained with a fat dye such as Sudan IV made up as a 1 per cent solution in 3 parts of 80 per cent alcohol and 1 part glycerine by volume.

Some of the chip samples treated with osmic acid solution were embedded in polyethylene glycol wax according to the method developed by Spurr (5) for plant tissue. The osmium-fixed fats in the chips impeded infiltration of the water-soluble wax and many of the embedded samples crumbled badly when sectioned. When the infiltration schedule was prolonged, intact sections could be obtained from some embedded samples, however, at thicknesses ranging from 10 to 80 microns. These were mounted in a glycerine-gelatin preparation after careful removal of the wax as described by Spurr (5).

All photomicrographs were taken on a pancromatic film at low to medium magnifications.

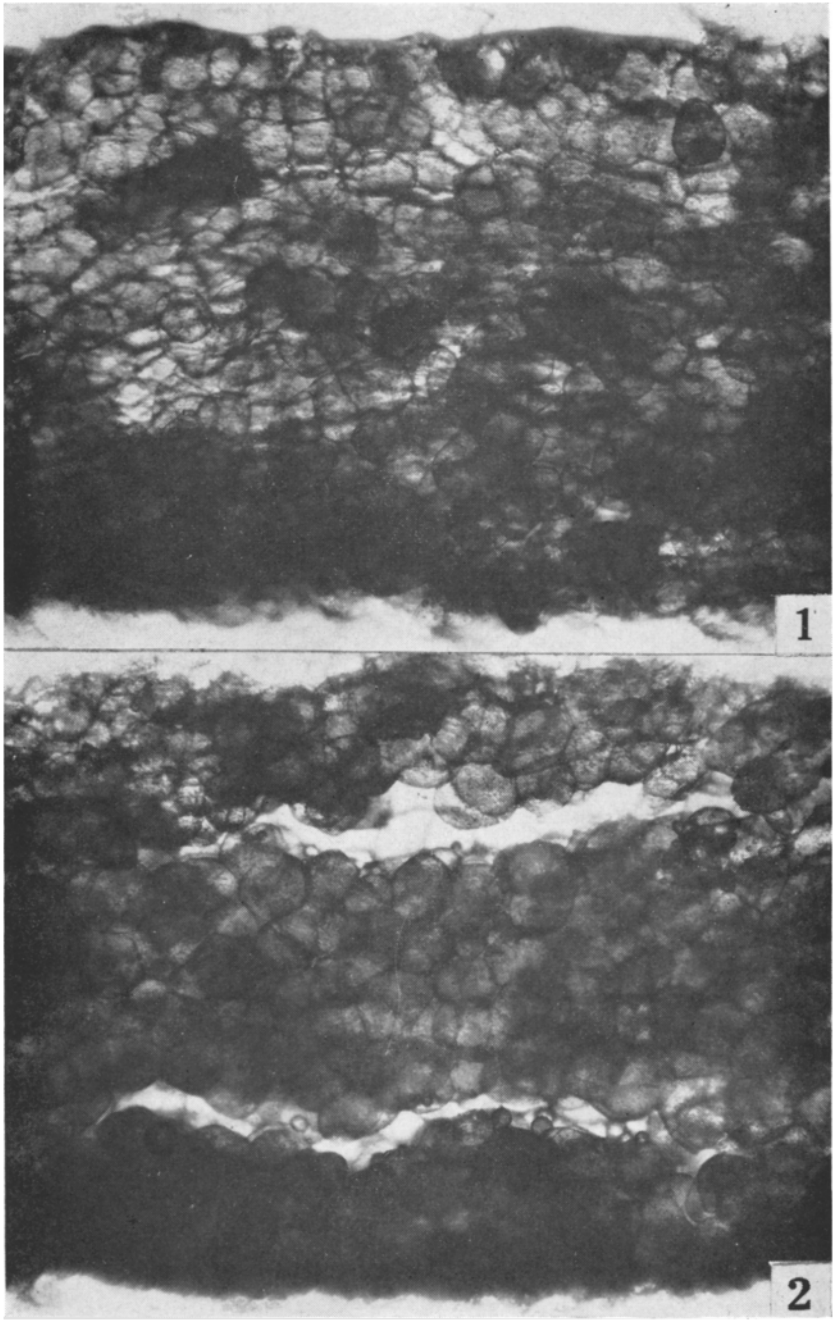
Results

The microscopic structure of rehydrated potato chips is illustrated in Figures 1 to 4. All of the cells inside the original cut surfaces of the slices are intact; their starch content, first gelled and then dehydrated by cooking in hot oil, has been swollen by rehydration so that the cell walls are slightly distended and the cells have a rounded appearance. The tissue structure thus appears similar to that described elsewhere for steam-cooked potatoes (4, 6).

French fried potatoes display essentially the same tissue structure and differ from chips only in the degree of dehydration which the centers of the strips undergo when fried. In chips the slices become dehydrated throughout. The center of French fried strips do not completely dehydrate unless the strips are fried until brittle. The softer strips frequently could be sectioned without soaking treatment.

The microscopic appearence of the dry, brittle chip is the same as that previously described for dehydrated potato cubes which were sectioned after embedding in cellulose nitrate (3). The cells are shrunken and the cellulosic walls are wrinkled and convolute around the dried gelled starch content. In this shrunken condition the walls may appear to be fractured and, in fact, frequently do fracture when sections of chips and dehydrated cubes are cut in the brittle state. However, when the tissue is rehydrated the gelled starch swells and remains within the confines of cell walls. It is thus clearly evident that the walls have not been ruptured by the deep-fat frying process.

Figures 2 and 4 are different magnifications of sections cut through blister areas in chips after oil removal and rehydration as described. The blister area is clearly defined as one of localized cell separation. Figure 2 shows entirely 2 tiny blisters formed at opposite sides of a slice and Figure 3 is a portion of one of these blisters at higher magnification. Figure 4 is a section cut through the edge of a blister which measured over an



FIGURES 1 and 2.—Photomicrographs of unstained sections of rehydrated potato chips. Dark areas are thicker portions of section with some cells out of focus. Figure 2 shows 2 small blister areas formed by simple cell separation. 40X magnification.

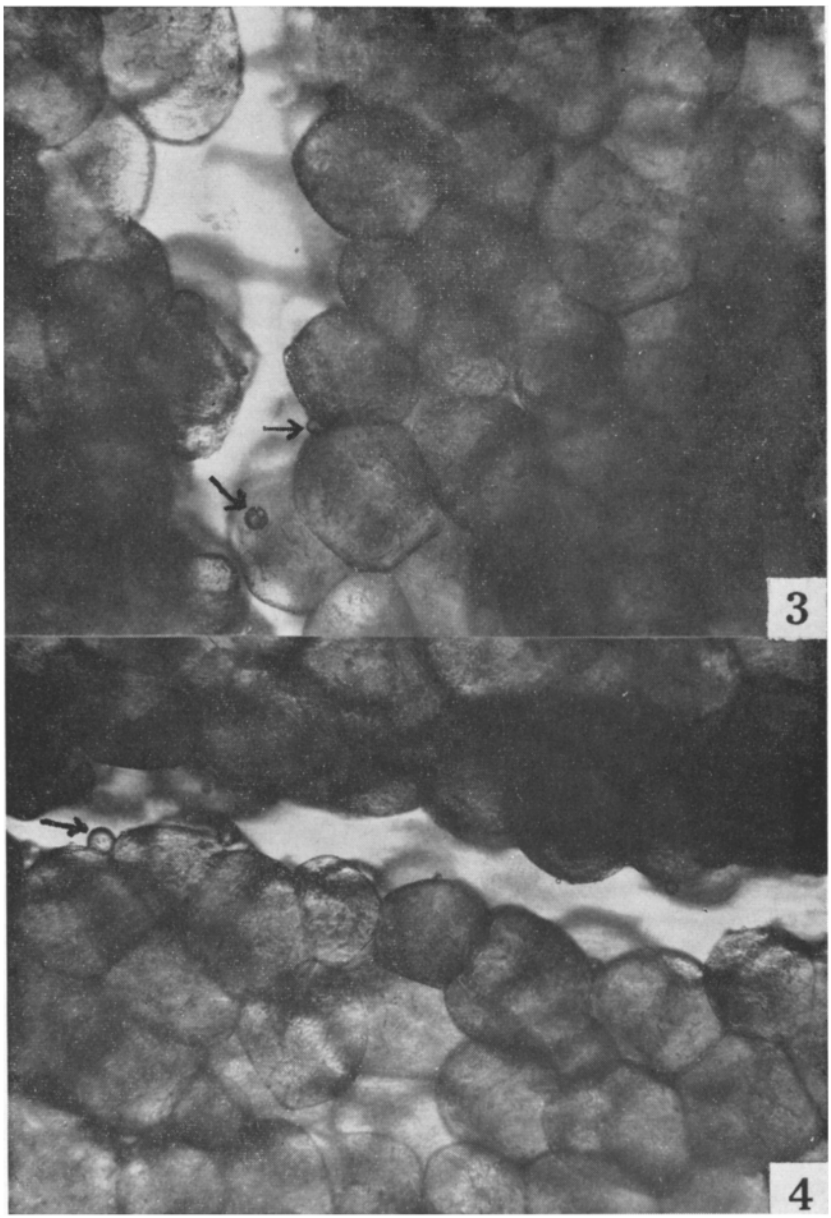
inch in diameter. Search of the inner margins of blisters in a number of sections failed to reveal any evidence of ruptured cells other than those obviously produced by cutting the section.

Blisters were more readily produced in thick than in thin slices of potatoes .Chips produced from slices of 1/23-inch thickness contained no readily observed blisters although sections of these sometimes revealed minute blisters comparable with those in Figure 2. Such thin slices are only about 6 to 8 cell diameters thick. Chips produced from thicker slices increased blistering with increased thickness of slice. Slices of standard thickness (ca 1/18 inch) are about 10 or 12 cells deep. The starch in the outer cells of these and of thicker slices gels and becomes dehydrated more rapidly than that in the centers of the slices. Expanding steam is thus trapped, at first principally in the tiny intercellular spaces. As the middle lamella pectic substances between adjacent cell walls become softened and partially solubilized by the cook treatment, the cells are forced apart. Eventual escape of the steam is sometimes followed by movement of oil into the intercellular pocket thus formed.

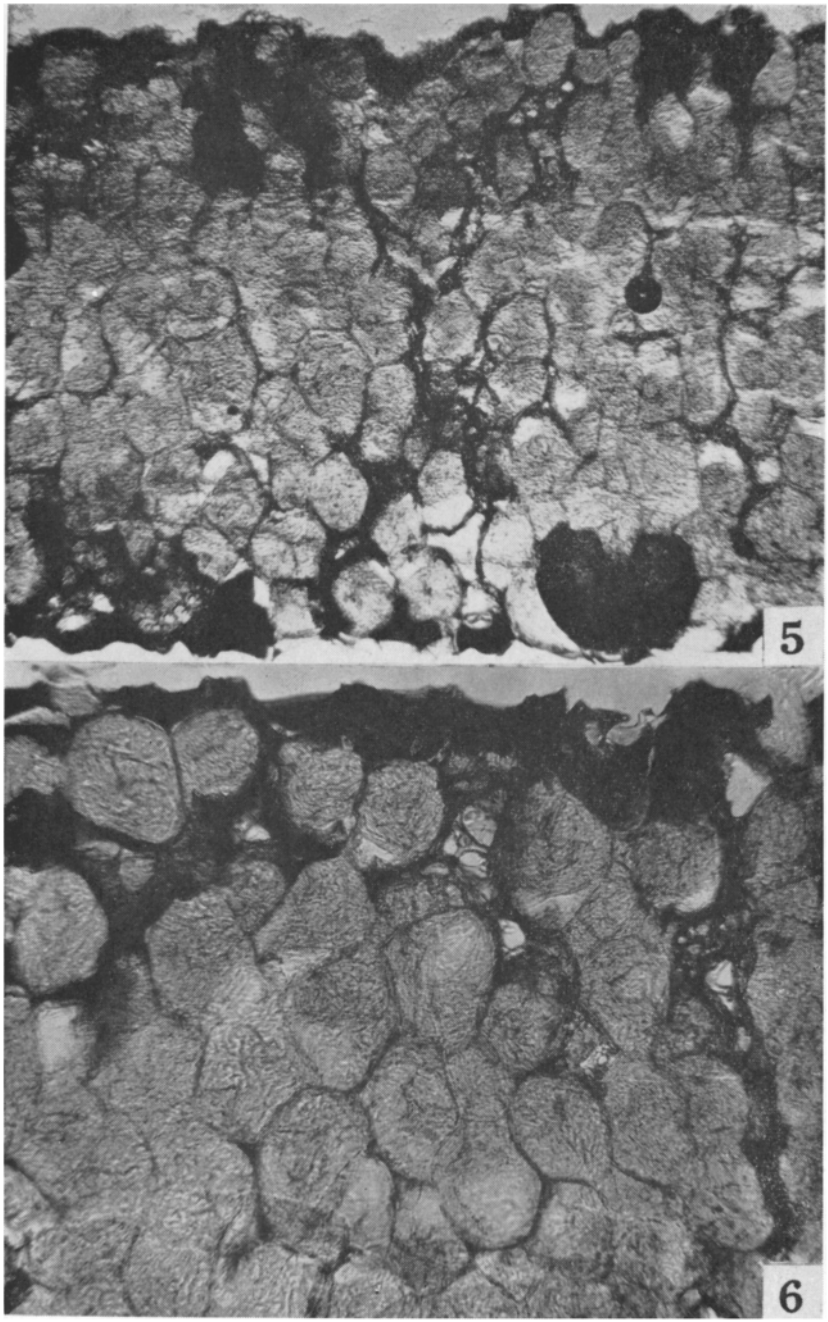
Figures 5 and 6 show sections of chips cut from samples embedded in polyethylene glycol after treatment with osmium tetroxide solution to stain the oil. The black areas are the oil deposits. Very similar, although less pronounced, oil staining was obtained with Sudan IV. With both staining treatments, a considerable amount of the oil is initially lost from the soaked chips before the staining reaction becomes pronounced. However, the osmium tetroxide method very soon produces a black, viscous soap which does not diffuse from its site and thus provides a reliable microscopic localization.

Osmium tetroxide penetrates tissues slowly. It did not blacken the centers of chips until at least 3 or 4 hours' exposure; then the structural detail became completely obscured by the stained oil. With only 2 hours' soak in the osmium tetroxide solution, as in Figures 5 and 6, sufficient of the chip centers remain unstained that differential distribution of the oil is more clearly revealed. Most of the stained oil appears to be in the cell walls and in minute intercellular spaces. The cell walls, in that they rehydrate more rapidly than the gelled starch contents of the cells (3), are also the route of the most rapid penetration of the osmium tetroxide solution.

Some completely blackened cells appear to be stained throughout, such as the 2 in the lower right of Figure 5. However, only some of these were found to contain large amounts of oil. When viewed in thick, free-hand sections in which these cells were intact, it was not possible to distinguish between surface views of stained, oil impregnated cell walls and those intact cells containing stained oil. When these whole cells were crushed, this distinction could be made. The gelled starch contents of many of these crushed cells showed only minute streaks of stained oil. Reexposure of such chrushed cells to osmium tetroxide solution did not result in additional staining and it was thus evident that the original appearance of these was due to stained oil in the cell walls. Similar, although more finely divided staining with osmium tetroxide was obtained by treating crushed cells of freshly cooked potatoes. The cell walls of both raw and freshly cooked potato cells likewise were stained only faintly with the osmium tetroxide



FIGURES 3 and 4.—Photomicrographs of parts of blister areas in sections at higher magnification (100X). Figure 3 is of central part of upper blister in figure 2. Figure 4 is from a section through the edge of a blister about 1 inch in diameter. Note oil droplets (arrows) and cellular intactness.



FIGURES 5 and 6.—Photomicrographs of sections about 60 microns thick cut from chips first treated 2 hours with osmium tetroxide solution to stain the oil and then embedded in water-soluble wax. Black areas are oil deposits; note that they occur principally in cell wall areas and intercellular spaces. Figure 5 = 50X magnification; Figure 6 = 100X magnification.

solution except for the suberized cell walls of the periderm or skin and the lignified xylem walls which stained intensely.

Some intact cells in freehand sections of potato chips, however, did contain large aounts of stained oil. The appearance of such cells in thin sections cut from wax-embedded samples suggested that the initial dehydration effected by hot oil frying was more rapid than the swelling of the gelled starch. Thus, there was sufficient space for the oil to penetrate. Such cells with large amounts of oil were closely associated with the original cut surfaces of the tuber slices where, upon submersion in the hot frying oil, dehydration would be most rapid.

Sections cut through osmium-stained strips of French fries revealed little, if any, absorbed oil in the soft centers while the more dehydrated surfaces of the strips showed stained oil distribution comparable with that of the chips. It appears from these observations that oil distribution in both chips and French fries is not uniform, that the oil penetrates as water is removed, and that it is most abundant in the cellulosic walls and intercellular spaces. Presumably the gelled starch becomes relatively impervious to the oil as it dehydrates during the deep fat frying process, but some oil is able to penetrate a few surface cells between gelled starch granules before they swell and completely fill the cells.

Discussion

The effect of deep fat frying on the cellular structure of potato tissue may be directly compared with the changes which have been previously described for cooking and dehydration processing (2, 3, 4). Potato starch granules gel readily at 65° to 70° C. At cooking temperatures the granules rapidly hydrate and swell excessively. Rapid dehydration during cooking, as occurs with deep fat frying, curtails this swelling process so that the cell walls do not become ruptured as sometimes occurs with the ordinary cooking of potatoes. As the gelled starch shrinks, water is partly replaced with oil in the frying process and the tissue becomes brittle. The shrunken cells of the finished chip are intact and similar in appearance to those of dehydrated potato products. Thicker pieces of potato tissue, as in French fries, have an outer shell of more completely dehydrated cell layers surrounding the cooked, less shrunken cells of the central, more moist tissue.

Although it might appear that the extreme conditions of deep fat frying would result in a considerable number of ruptured cells, no evidence could be found of any ruptured cells resulting from this process. It remains possible, however, that a very few cells might be ruptured in the initial contacts of the raw slices with the hot oil since even ordinary cooking to doneness ruptures some cells (sometimes about 2 to 3 per cent) as a result of swelling of the gelled starch content (4). Further, fully fried chips could not be sectioned after softening in water, as accomplished here, were there any appreciable frequency of ruptured cells. In fact, large numbers of ruptured cells in potato chips would probably cause the soaked chips to disintegrate into a pasty sediment. The demonstration that blistering in potato chips is a result of separation of intact cells is conclusive evidence that cell rupturing rarely occurs, if at all, with this process.

Blister formation in potato chips is similar to certain phenomena which have been described for dehydrated potato products. For example, when potato cubes are blanched prior to drying, the middle lamella pectins are

softened. A certain amount of "case hardening" sometimes occurs during hot air dehydration of the blanched cubes so that steam is trapped internally and its expansion results in cell separation and the formation of porous, opaque areas—the "popcorn" effect described elsewhere (4). Simple cooking induces cell separation in potato tissues and cell separation may be induced by excessive cooking in other vegetables and fruits without causing a physical breakdown of their cellulosic walls. In the case of potato and other high starch tissues, the swelling and hydration of the cooked, gelled starch may be sufficient to rupture some cell walls. Other evidence of broken cells in cooked fruits and vegetables, however, are traceable to artifacts of techniques in preparation for microscopic examination (3, 4, 6).

Excessive blistering is undesirable because chips break too readily to be suitable for "dips" and also because some blisters may contain large amounts of oil which impair chip flavor and render the product greasy when the blisters are broken in the package. Chips prepared from very thin slices which do not blister also are too fragile. Thicker slices, cut in corrugated form, do not blister because the central tissues of the slice are close to cut surfaces and the expanding steam can readily escape before the surfaces are sealed. The textural qualities of potato chips and French fries are thus influenced by readily observed effects of processing on cellular structure and can be manipulated. More needs to be learned about the practical limits of manipulation in relation to its influence on other characteristics of these products.

Summary

Microscopic examination of potato chips and French fries has provided conclusive demonstration that the cellular structure remains intact and that the cell walls rarely, if ever, rupture during the deep-fat frying process. Blistering of chips is a result of simple cell separation due to expansion of steam trapped within the slices when the surface become dehydrated and sealed. Deep-fat frying is essentially a cooking and dehydration process during which the starch content of the cells is gelled and dehydrated and and some of the water in the tissue is replaced with oil. Most of the oil in finished chips is distributed in the cell walls, inter-cellular spaces and blister areas. Apparently much less of the oil present in chips is held between the gelled starch granules within the cells although oil penetrates some intact cells at the original surface of the slices.

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