Starch "Swelling Pressure" of Cooked Potatoes

The literature on cooked potato texture contains numerous references to an intracellular pressure being exerted by the swelling starch granules when potato tuber tissue is heated beyond the gelation temperature of the starch. This pressure has been assumed to cause rupture of the cell wall or a rounding-off of the cell surface with resulting cell separation. The existence of such a "swelling pressure" is disputed and an alternate interpretation of cell separation and rupture is presented.

Reeve (1972) objects to certain passages in our paper on potato firming (Bartolome and Hoff, 1972). These passages are presumed to "negate the role of physical characteristics of gelatinized starch in the textural qualities of potato products." Such was not our intention. Our dispute is with the interpretation of cell rupture and cell separation during heating of potato tuber tissue. The common interpretation of these phenomena and their presumed cause is the exertion of a swelling pressure produced by the cellular starch granules when they undergo gelation. This hypothesis has been cited in the literature on potato texture at least since 1895 (Atwater, 1895) and has since been thoroughly entrenched to the extent that it appears as a solidly established fact in books (Fraser, 1910; Gilbert, 1920; Talburt and Smith, 1959) and in reviews and research articles (Reeve, 1954, 1967; Whittenberger, 1951); Bretzloff (1970) has, on the other hand, disputed its existence.

There has to our knowledge been no experimental verification of the starch swelling pressure. In the absence of direct verification of the events occurring within a cell during cooking, circumstantial reasoning would tend to predict that such a pressure does not always exist. When a closed system consisting of water and suspended starch is heated to bring about starch gelation and then brought back to the original temperature, there is no observable increase in volume of the system. The intermittent change in volume when the system undergoes a temperature change is fully ascribable to its thermal expansion coefficient. A cell in the interior of a tuber, fully surrounded by other cells, is analogous to this situation. No net mass transfer takes place and therefore no change in density of the cell *in toto* can take place except for the rather insignificant change in water density resulting from its existence as "free water" to in part "bound water" as the starch undergoes hydration. The contribution of this factor would lead to a contraction rather than an expansion. The situation here is different from that of an open system such as the surface layer of tuber tissue exposed to cooking water, or a suspension of cells or a slice of potato tissue immersed in water on a microscopic slide. In the latter circumstance, mass transfer may take place through the cell wall and the cell may increase in volume when the starch absorbs water during gelation. However, Bretzloff (1970) was unable to detect any changes in linear dimensions of cells of an intact tissue slice observed on a heated microscope stage.

Rathsack (1935) suggested that sloughing (Zerkochungsgrad) was due to the expansion of tubers during cooking because of the mere increase in temperature. Using Rathsack's reasoning one may describe the events during cooking in the following manner. In being heated from room temperature to the boiling point, a tuber, which consists mostly of water, will increase approximately 4% in volume. It seems reasonable to believe that considerable shear stresses, both radial and tangential, will, as a result, be generated in the tuber interior depending on the module of elasticity and the tensile strength of the cell wall, and on the turgor pressure that existed when heating was initiated. Under certain circumstances the limit of elasticity (which varies with temperature) of the weakest point will be exceeded. In a mealy potato this weakest point is evidently the middle lamella and the result is cell separation. In a nonmealy potato the weakest point is evidently the cell wall proper, which results in cell rupture. Alternatively the elasticity limit is not exceeded and neither cell separation nor cell rupture occurs. Viewed in this manner, the problem of cooked potato texture is reduced to a consideration of the factors that influence the strength of the cell wall and the middle lamella. A number of these factors have been recognized in numerous publications. A theory of any validity will have to consider the effect of calcium (Personius and Sharp, 1939; Whittenberger and Nutting, 1950), the generally recognized highly significant correlations between mealiness and starch content, specific gravity, and total solids (Barrios *et al.*, 1961; Bettelheim and Sterling, 1955; Le Tourneau and Zaehringer, 1965), the effects of cell size, (Barrios *et al.*, 1963), the influence of organic acids (Schwartz *et al.*, 1961; Wager, 1963), age and storage time of the tuber (Barrios *et al.*, 1961a), the effect of different amylose–amylopectin ratios, rate and extent of starch retrogradation (Barrios *et al.*, 1961b; Reeve, 1954; Unrau and Nylund, 1957), and the rate of diffusion of amylose into the cell wall (Linehan and Hughes, 1969).

Calcium. Addition of calcium to cooking water or its presence during a precook soaking treatment has the effect of toughening cooked potato tissue, reducing sloughing, and rendering the tissue less mealy. The simplest explanation for this behavior is interaction of calcium with the pectin substances of the cell wall and formation of calcium bridges.

Organic Acids. Addition in a similar manner of salts of organic acids, particularly citrate, results in increased sloughing and cell separation. The known ability of these ions to form complexes with calcium suggests that they compete with the pectic substances for calcium and, when present, have the effect of reducing the amount of calcium available for interaction with the cell wall constitutents. The net effect is a weakened middle lamella and an increased tendency to develop cell separation during cooking. This concept is supported by the observation that mealy potatoes tend to contain relatively high concentrations of these acids (Schwartz *et al.*, 1961).

Cell Size. Mealy potatoes tend to contain larger cells than nonmealy potatoes. For a given relative volumetric expansion the stresses in any one direction in the cell wall will be proportional to the original diameter of the cell. This is to say that the stresses in the middle lamella of a 200-mμ cell will be twice as large as the stresses developing in a 100-mμ cell. Maximum shear will develop between adjacent layers of small cells (vascular bundle region) and large cells (cortical region), and it is precisely here that the most severe sloughing takes place.

Starch Content. A major portion of the total calcium of the potato tuber is present in the starch granules (Bartolome and Hoff, 1972). It seems reasonable to believe that high starch

content would, as suggested by Bretzloff (1970), make less calcium available to the cell wall. A high starch content could therefore be expected to result in mealiness. Since total solids and specific gravity are almost uniquely dependent on the starch content, similar positive correlations between these factors and mealiness would follow as a matter of course.

Age and Storage Time. The changes that occur in potato tubers during storage are complex and incompletely understood. But perhaps most significant are the reduction in turgor due to dehydration and loss of starch due to respiration. The first factor would be expected to result in a relaxation of shear stresses in the cell surface and an ability to tolerate thermal expansion without exceeding the elasticity limit. Loss of starch would result in release of calcium, which now becomes available for reinforcement of the cell wall constituents. Both of these factors would therefore be expected to result in loss of mealiness which is, in fact, the common experience.

Starch Retrogradation. Gel formation and retrogradation of the gel has been shown to influence texture in products subject to chilling or extended cooling periods. The extent to which retrogradation takes place is evidently a function of the nature of the starch, particularly the amylose–amylopectin ratio.

Diffusion of amylose has been postulated to strengthen intercellular adhesion, and releasable amylose was observed to be particularly prominent in low-starch tubers (Reeve, 1954). The latter two effects will tend to obscure or alter the overall effect of the cell wall-related factors discussed earlier.

Texture of the cooked potato is obviously influenced by numerous factors, and no attempt has here been made to treat this subject exhaustively. The purpose of this communication is rather to focus on those factors that appear to be of major importance and to try to interpret experimental results in terms of a coherent concept. In that context, the starch gelation pressure should only be thought to exist when there is a net influx of mass to the tissue and not as phenomenon that inevitably takes place when gelation of the starch grains occurs.

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Johan E. Hoff

Department of Horticulture
Purdue University
Lafayette, Indiana 47907

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Effect of DDT on Rumen Fermentation

The effect of DDT, DDD, other metabolites and analogs of DDT, chlordane, dieldrin, aldrin, and DDVP on *in vitro* fermentation and methane production by rumen microbes was studied. DDT inhibited methane production only at very high levels (240 ppm) in contrast to chloral hydrate, which is a potent methane inhibitor at 12 ppm. DDT and other pesticides studied had no effect on fermentation gases or volatile fatty acid metabolites at 120 ppm.

Trei *et al.* (1971a,b, 1972) have shown that when sheep and cattle are given certain compounds in the diet which inhibit methane production in the rumen, an improvement in growth rate and efficiency of utilization of feedstuffs results. The performance response is at least partially due to inhibition of rumen methane production. A recent report (McBride, 1970; McBride and Wolfe, 1971b) that DDT is a potent inhibitor of methanogenesis by certain methanogenic bacteria prompts us to report our observations of the effect of DDT, some of its metabolites and analogs, and five other polychlorinated insecticides on fermentation and methane production by rumen microbes.

In vitro fermentations were carried out as described in a previous report (Trei *et al.*, 1971b). Strained rumen fluid (75 ml) obtained from a fistulated steer was incubated with a grain substrate (2.4 g) and the chemical additives for 3 hr. The resulting gaseous and liquid metabolites are shown in Table I.

When compared with other polyhalogenated compounds which inhibit methane production at concentrations of 1–10 ppm [*e.g.*, chloroform (Trei and Olson, 1969), bromochloromethane (Trei *et al.*, 1970), and some haloacetic acids and derivatives (Trei *et al.*, 1971b)] both pure and technical grade DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane] have little antimethanogenic activity in rumen fluid. When added to rumen fluid at 240 ppm, DDT inhibited methane production only to the extent of 20% (experiment 4). At 120 ppm DDT had no effect on the fermentation as measured by pro-