The Popping of Corn.

Paul Weatherwax.

The ability of the grains of some varieties of Indian corn to "pop" when heated lends a unique interest to this otherwise unusually interesting plant, and a number of popular notions and more or less scientific theories have attempted complete or partial explanations of the phenomenon.

Kraemer's detailed histological studies lead him to the belief that the popping of corn is due to peculiarities in the minute structure of the starch grain.

Wilbert showed, in 1903, that the "pop" was due to the expansion of moisture in the grain, and that corn too dry to pop well could be improved by soaking in water and then partially drying. He also found that the hull of the grain plays no essential part, and that the pop starts in the densest pheripheral portion of the grain.

Attacking some old ideas as to the popping process, Storer found, in 1904, that the expansive medium responsible for popping was not a volatile oil. He also found that the hull of the grain was not necessary, since pieces of grains would pop the same as whole grains.

A year ago at the meeting of this Academy, Carr and Ripley revived the problem by inquiring into "What puts pop in popcorn?" Disposing of the history of the question with the statement that it is often "joked about but seems never to have been considered seriously enough to lead to any investigation", they discuss certain observations and experiments on a number of varieties of popcorn. They state that the expansive medium causing the pop is steam generated within the starch grain, and that between a wide range of extremes the moisture content is immaterial. In explaining how the pressure is confined for a time and then suddenly released, they state (p. 264): "The cellular starch wall is very elastic, permitting of wide distention, and a loss of some cell granules, without breaking. Other corn grains split open without much cell elasticity being shown." Although this terminology cannot readily be translated into standard terms as applied to cell structure, it is taken to mean that the cell wall is the structure responsible for the peculiarity, and that popcorns differ from other varieties with respect to this structure. They emphasize the important point that successful popping requires the dextrinization of most of the starch, and this requires that the heat be applied at an optimum rate.

In the light of significant results coming from recent investigations, this seems an appropriate time to collect and evaluate the data afforded from all sources and to generalize on the subject.

Nature of the Process.—The popping process is in reality a miniature explosion caused by the slow application of heat, and resulting in a disruption in which the endosperm increases greatly in volume, often turning the grain inside out. Physical examination shows a profound change in the texture of the endosperm, the cell walls being destroyed, the starch grains exploded, and other characteristics of organic structure obliterated; and chemical analysis indicates hydrolysis of most of the starch and a considerable loss of moisture.

Two factors here present themselves for explanation: (1) the expansive medium acted upon by the heat; and (2) the structure which gives force to the explosion by confining the accumulating pressure until a limit is reached.

Most of the investigators of the subject up to the present have been physicists and chemists, and they have satisfactorily solved the problem involved in the first of these factors, the expansive medium. But they have failed to locate the confining structure, because here the clue is afforded by the difference between popcorn and kinds of corn that do not pop; and this falls within the field of plant morphology.

The Expansive Medium.—An old idea, that the expansive medium, acting as a vehicle for the disruptive force, was a small volume of air imprisoned in the middle of the grain, seems long ago to have been abandoned for want of evidence. And the more recent one, attributing the explosion to a volatile oil, has gone by the same route. The significant changes that occur in popping indicate that the disruptive force is distributed throughout the endosperm, while analysis shows that the oil content is limited to the embryo of the grain.

The occurrence of maximum and minimum moisture contents for good popping—although the range is wide—and the visible escape of steam during popping, indicate that water contained in the very hygroscopic starch grains themselves is the substance that expands and causes the explosion. At least a partial hydrolysis of the starch is necessary for best results, and this necessitates slow enough application of the heat to permit dextrinization before the explosion occurs. Experience has shown that best results are obtained when the popping temperature, which is 175° to 200° C., is reached in two to three minutes from the initial application of heat.

The Confining Structure.—The confinement of the increasing pressure until the instant of explosion was long attributed to the pericarp of the grain, but experiments do not bear out this idea. Pieces of grains will pop, as will also grains with holes drilled in them, and grains with the pericarp removed.

A microscopic examination of the endosperm of maize shows the contents of each cell to consist of numerous starch grains embedded in a mass of desiccated colloidal material, the protoplasm of the cell. This colloidal material is the seat of all the protein of the endosperm except that in the aleurone layer. The flinty or soft texture of the endosperm depends upon how completely the colloidal material fills the interstices between the starch grains. The moisture in the starch grain is changed to steam during the heating process, but the starch is held intact by the colloidal matrix until the limit of its capacity is reached. Then the explosion of the starch grains of a few cells at the surface, where the tissue is flintiest, releases the external pressure on underlying units, and the whole ten million grains let go simultaneously. The cell wall is a comparatively fragile structure, incapable of holding any great pressure, and playing no significant part in the process. In the softer varieties of corn the steam generated during the application of the heat tends to leak out through the more porous matrix of colloidal material so that the explosion, when it finally occurs, is much less violent; and it comes at a lower pressure than in good popping varieties because the confining structure is not strong enough to hold a greater pressure.

All kinds of corn pop more or less, and the process is also characteristic of the seeds of many other species of grasses. But it is only in the small-seeded flint varieties known as popcorns, and in some of the sorghums, that the grain undergoes so great a change as is generally indicated in the popular term *popping*. The necessary structure for successful popping is a flinty endosperm. The range of moisture permissible is much wider than is generally supposed.

Popping and Protein Content.—Since the hardness of the endosperm is determined by the degree to which the interstices between the starch grains are filled with the colloid rich in protein, a close correlation might be expected between the popping quality and the protein content of the grain. A general correlation does occur, but analyses such as those given by Carr and Ripley (p. 262) show that it is not so close as might be expected.

It may be remarked in passing that the ordinary analysis of the whole grain of corn is scarcely more than useless in the solution of a problem like the one here at hand. A grain of corn consists of three separate and distinct parts—pericarp, endosperm, and embryo—members of three different morphological generations of the plant, and possessed of three distinct genetic possibilities, and capable of having three uncorrelated chemical compositions.

The protein concerned in the popping process is located in the interstices between the starch grains of the endosperm, that in other parts of the grain playing only a passive part. An analysis of the whole grain will indicate feeding qualities and many other things, but to take such an analysis as an index to popping qualities, or, as some have done, to the hereditary constitution of the embryo, is exactly as scientific as carrying out a nitrogen determination after spilling an unknown quantity of a substance of unknown composition into the digestion flask.

Analyses of endosperms carefully separated from the rest of the grains show a much closer correlation between protein content and popping qualities. But even here too much must not be expected. Protein content is only a matter of relativity after all. Starch grains vary much in size and in shape, and there is consequent variation in the amount of protein-bearing colloid necessary to fill all the spaces sufficiently to produce flinty translucency. The endosperm of the flintiest type the author has ever analyzed had only a little more than 6% protein, while that of a relatively soft, floury variety had more than 12%. Although the former had large enough a grain to be classified among the flints, it popped well; the latter merely split open when heated. But microscopic examination showed the one to have large, hexagonal, closely-arranged starch grains, only a small amount of colloid being necessary to fill the interstices completely; the latter had small, rounded, loosely-arranged starch grains, and the relatively large amount of protein-bearing material was not sufficient to fill the spaces and produce a flinty texture. The difference between the two conditions is not wholly one of heredity, the weather conditions attendant upon maturity, and doubtless the chemical constitution of the soil, being determining factors.

Structure of the Starch Grain.—Kraemer's theory that the ability to pop is dependent upon the minute structure of the starch grain, is not readily substantiated. The extremes that he notes between popping and non-popping varieties in this respect can all be found in good popping varieties if enough samples are examined.

The "Puffed" Cereals.—Contrary to the opinion expressed by Carr and Ripley (p. 261), there is good evidence that in the manufacture of the "puffed" cereals exactly the same principle is involved as in the popping of corn, man having provided what nature omitted. The grain, containing a proper amount of moisture, is enclosed in an air-tight metal drum and heated until the optimum temperature and pressure have been reached. Then, by suddenly opening the drum, the pressure outside each grain of the cereal is released, and each starch grain explodes because of the internal pressure of the steam.

Summary.

The popping of a grain of corn is an explosion due to the expansion, under pressure, of moisture contained in the starch grains. Until the instant of the explosion, this force is confined by the colloidal matrix in which the starch grains are embedded. Neither air nor any volatile oil is in any way concerned with the process as the expansive medium.

As a result of popping, there is hydrolysis of much of the starch, a loss of moisture, and the obliteration of all cellular structure in the endosperm.

Except to aid slightly in confining the pressure, neither the embryo nor the hull (pericarp) of the grain plays any part in the process.

Maximum, minimum, and optimum moisture contents are indicated, but the range is wide.

The flinty texture of the endosperm is an accurate index to popping qualities. Hardness of the endosperm is due to nitrogenous material filling the interstices between the starch grains; but, because of variation in the size, shape, and proximity of the starch grains,—and consequent variation in the relative amount of material necessary to fill the interstices,—popping quality is not in direct proportion to protein content.

The difference between popping and non-popping varieties is wholly one of hardness of endosperm. Popping is not in any way dependent upon the minute structure of the starch grain. Non-popping varieties may be made to pop if they are heated to the proper temperature under pressure and the pressure suddenly released.

For successful popping, the heat must be applied rapidly enough to generate steam faster than it escapes, but slowly enough to permit hydrolysis of most of the starch before the explosion occurs. Best results are obtained when the heat is so applied that a temperature of 175° to 200° C. is reached in 2.5 to 3 minutes.

Indiana University.

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