V—The "saturation" of the rich oil is considered.

VI—Experimental data are given of the rates of gain in weight of absorbing vessels filled with wash oil when illuminating gas was passed through them.

VII—The extraction of toluene from gases is discussed and suggestion made for a more efficient scheme of washing in order to increase the yield of pure toluene.

VIII—The possibility of obtaining better washing media, through research, is suggested.

DEPARTMENT OF CHEMISTRY
UNIVERSITY OF MANITOBA
WINNIPEG, CANADA

THE EFFECT OF FROST AND DECAY UPON THE STARCH IN POTATOES

By H. A. EDSON

Received June 18, 1918

Severely chilled, frosted, and decayed potatoes are regarded by the trade, the grower, and the general public as worthless. On theoretical grounds, however, such material would seem to possess a potential value for starch production nearly or quite equal to that of sound stock. It is a matter of common knowledge among potato pathologists that the starch granules of frozen potatoes, and of most decayed stock as well, present a normal appearance under the microscope.

Decay in potatoes is initiated in most cases either by frost or by fungi, followed of course by bacteria, but often the bacteria play a relatively unimportant part in the process, except perhaps in the final stages. Southern bacterial rot, black-leg decay, and bacterial decay following flooding accompanied by high temperatures, constitute the most important exceptions to this general rule. The total amount of destruction from these three last-mentioned causes, however, is relatively small. In New York and New England, and in a few other regions, late blight decay is quite destructive certain seasons on stock from unsprayed or improperly sprayed fields. In these cases the destruction is accomplished largely through the action of so-called secondary organisms to which the *Phytophthora* gives entrance. Among these secondary invaders, *Fusaria* of various species are frequently encountered. Powdery dry rot, jelly-end rot, numerous types of dry rot as well as several soft or wet rots are caused by one or another species of *Fusaria*. Potato leak in California is caused by *Pythium*. Taking the country as a whole, parasitic *Fusaria*, and frost in field, storage, or transit, combined with the parasitic and saprophytic *Fusaria* which usually follow frost, are responsible for the destruction of enormous amounts of potatoes. Shippers have expressed the opinion that frost is the most important single cause of loss encountered after the crop is harvested.

Since much of this injury seems more or less inevitable and is likely to continue, the question of possible salvage is worthy of consideration and one who is not primarily concerned with problems of potato utilization may be permitted to bring to the attention of those interested certain facts regarding this neglected source of starch supply with which he has become familiar during the prosecution of his duties as a potato pathologist. As already stated, the micro-

scope indicates that the starch in frozen and in most decaying stock is normal. The action of frost and the results of invasion by organisms of decay appear to be exercised upon the lamellae of the walls and the protoplasmic contents of the cells rather than upon the starch. Such physiological studies as have been conducted upon the organisms under consideration indicate that most of them are either entirely incapable of cleaving starch or that their amylolytic power is weak. This is especially true of the filamentous fungi involved, but it also applies to many of the bacterial species associated in the decay of potatoes. This explains why the starch granules often remain free from corrosion even in cases of advanced decomposition.

With these facts in mind, preliminary trials were undertaken to further establish the action of decay-producing organisms upon potato starch, and the possibility of its recovery from frozen and from decayed material. The first tests were conducted upon frosted and decayed potatoes obtained during routine examination in connection with the service of the Bureau of Markets for inspection at destinations. Four types of material were included:

- 1—Frozen potatoes which had not been allowed to thaw.
- 2—Frozen potatoes subsequently thawed and softened, but not materially decayed.
- 3—*Fusarium* decayed stock in which the indications were that slight field frost undetected at the shipping point probably predisposed the material to decay.
- 4—Decayed portions only of the material described in 3.

The potatoes were pulped by grinding in a small hand corn mill and the starch recovered by repeated, successive shakings with 10 or 15 volumes of water, sedimenting the pulp, and decanting the supernatant liquid. For the final purification only 1 or 2 volumes of water were used.

Since the original weight of the samples before injury could be determined only for 1, the percentage yields could not be calculated, but they appeared to be normal in amount and they were certainly of good quality and free from odors. That from 4 (decayed portions only), while a good white starch, was not so clear as that from the other three classes of material. This was due in part to the fact that the sample was not washed before pulping and particles of earth sedimented with the starch. The microscope revealed also a considerable number of free, unbroken cells with their starch content intact embedded in the pure material. The brownish cellulose walls of these cells doubtless contributed to the discoloration.

In another series of experiments Green Mountain potatoes from the same sack were employed. Eleven samples of equal weight were washed and treated as indicated below:

- 1—Normal; extracted at once for a control.
- 2—Frozen solidly; thawed and extracted after an interval of one day.

3—Frozen solidly; thawed, heavily inoculated with a mixed spore suspension of potato-destroying *Fusaria*, held in the laboratory 4 days at about 70° F., and extracted.

4—Same treatment as 3, but held for 16 days.

5—Same treatment as 3, but held for 20 days.

6—Normal; extracted at close of experiment as control.

7—Inoculated with *Fusarium oxysporum* and held in a moist incubator at 25° C. until completely decayed.

8—Inoculated with *Fusarium radiciola* and held in a moist incubator at 30° C. until the greater portion of each of the tubers decayed. The rot obtained was in some cases dry, in others wet.

9—Inoculated with *Fusarium radiciola* and held in a moist incubator at 30° C. with abundant aeration until completely decayed. The rot obtained was altogether very wet and soft.

10—Inoculated with *Rhizopus* and held in a moist chamber in the laboratory until most of the tissue was involved in decay. The rot was dry and apparently due in part to *Rhizopus* and in part to other fungi and bacteria present.

11—Inoculated with *Pythium debarayanum* and held at room temperature, approximately 70° F., until decay resulted.

The results are briefly presented in tabular form below:

TABLE I—YIELDS OF STARCH FROM DECAYED POTATOES

No.	Treatment	Yield Per cent	Grade
1	Control.....	10.29	1
2	Frozen, held 1 day.....	10.30	2
3	Frozen, inoculated, held 4 days.....	9.93	2
4	Frozen, inoculated, held 16 days.....	9.53	1
5	Frozen, inoculated, held 20 days.....	6.83	4
6	Control.....	12.13	1
7	Decayed by <i>F. oxysporum</i>	11.43	3
8	Decayed by <i>F. radiciola</i>	9.19	3
9	Decayed by <i>F. radiciola</i>	12.88	1
10	Decayed by <i>Rhizopus</i>	6.04	3
11	Decayed by <i>Pythium debarayanum</i>	5.76	2

Microscopic examination of the starch from these samples revealed no indications of injury to the grains from any of the treatments employed except in the case of *Pythium*, which exerted a solvent action on the granules. Macroscopically all were of good quality. The washed samples were free from the odor of decay. According to color they could be separated into four grades as indicated in the table but the difference in clarity between Grade 1, the lightest, and Grade 4, the darkest, was by no means striking. Under the microscope it could be determined that the degree of variation from pure white was proportional to the quantity of free, unbroken, starch-laden cells in the sample. This in turn seemed to depend upon the type and degree of decay. The low yields from Sample 11 appear to be due in part to the solvent action of the organism on the starch, but the outcome in the case of Samples 5 and 10 was not the result of starch destruction during decay but of excessive loss during recovery. At least the examinations made of the discarded pulp and the recovered starch point to that conclusion. The mechanical condition of the

pulp obtained on grinding the samples varied materially according to the type of decomposition. In some, the middle lamellae of the cells were quite completely dissolved, leaving the cellulose lamellae intact and the cells detached. Many such free starch-bearing cells were not ruptured during the process of pulping and more or less difficulty was experienced in separating them from the free starch. As already indicated they discolored the samples more or less when they were retained; and as they were filled with starch, the yield was lowered when they were washed away. The difficulty of complete separation was considerably increased in Samples 5 and 10 where practically all the tissue was involved in a dry rot. The pulp contained many free cells and many small aggregates of cells surrounded by a mat of radiating mycelial strands by which they became entangled in sedimentation.

The highest yield was obtained from Sample 9 which underwent very complete wet decay involving the cellulose lamellae of the walls as well as the middle lamella. The semifluid obtained on breaking the skins of the potatoes of this lot consisted of free starch grains floating in a matrix of residual material. Much of the tissue was sufficiently disintegrated to pass readily through cheesecloth without pressure or the use of additional water. Two-thirds of the entire yield secured came from washing this portion without grinding and the balance from the remainder after it was pulped. The behavior of this sample suggests the possibility of employing *Fusarium radiciola* for the destruction of the pulp in the preparation of special potato starch for use in biological work where a high degree of purity is essential. Before a practical method of this sort could be established it would of course be necessary to standardize the procedure so as to secure the condition of temperature, humidity, and aeration affording a maximum cellulose destruction.

Frosted and decayed potatoes have been found in these trials to be entirely capable of producing acceptable and frequently normal yields of clean, white starch of good quality. Much of this material appears to possess a potential value for the production of sizing starch approximating that of the stock at present used for this purpose. The mechanical difficulties in recovery from decayed pulp are sometimes greater and sometimes less than from normal. Modified procedure better adapted to these abnormal pulps could doubtless be devised, but there seems to be no reason why the present methods might not be applied profitably in the meantime in the production of sizing starch in factories at the large shipping centers installed to utilize the great quantities of frozen and decayed potatoes arriving during the fall and winter. This would turn to profitable account large supplies at present without value, but which are a serious burden of expense, since to their cost of production must be added transportation and dumping charges.