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POWDERY SCAB (SPONGOSPORA SUBTERRANEA) OF POTATOES.[1]

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INTRODUCTION.

The comparatively recent discovery of *Spongospora subterranea* in the United States makes it necessary to introduce to the potato grower, importer, and pathologist a new potato disease. This disease is commonly known as powdery scab, and mild attacks of it resemble superficially the common Oospora scab. Its prevalence in many European countries and the Dominion of Canada has prompted the Secretary of Agriculture to extend, for a time at least, the present quarantine on foreign potatoes.

Although powdery scab has probably been known to exist in Europe since 1841, it was not until within the last decade that it assumed an important rôle in pathological literature. It has been most extensively studied by pathologists in the British Isles, where powdery scab is said to be very common.

In February, 1913, Spongospora was reported for the first time in North America. It was collected in several provinces of Canada by the Dominion Botanist, Dr. H. T. Güssow (1913),[2] who has expressed the opinion that the first introduction into Canada must have been at least seven years previous. Dr. W. J. Morse (1913), of the Maine Agricultural Experiment Station, and the writer (1913) obtained evidence during the summer of 1913 showing that this disease exists in the United States. It seems probable that it was introduced with the heavy shipments of foreign potatoes in 1911 before the quarantine law against the wart disease went into effect. Sufficient evidence is at hand to show that powdery scab will make inroads on the potato industry unless proper precautions are taken, and it is the

[1] This paper will be of interest to plant pathologists and to potato growers in the northern and southern potato-growing sections.

[2] The dates in parentheses refer to the bibliography printed at the end of this bulletin.

object of this bulletin to call attention to this fact and ask the concerted effort of all interested in the potato industry to prevent the spread of this malady.

COMMON NAME OF THE DISEASE CAUSED BY SPONGOSPORA.

Spongospora, like many other fungi, has been given a variety of common names. In Germany it was early known as "Kartoffelräude" (Wallroth, 1842*b*) among the farmers. By Wallroth (1842*a*), who first recorded its occurrence and who considered it a smut, it was given the common name "Knollenbrand." According to Brunchorst it is called "Skorv" in Norway, and is identical with the disease known as "Schorf" or "Grind" in Germany. In the British Isles, where it has been most intensively studied, it has been called corky end, corky scab (Johnson, 1908), powdery scab, Spongospora scab, and potato canker. The name powdery scab, which was first applied to it by Johnson, of Ireland, is in most common use at the present time. This name has reference to a characteristic symptom of the mature spot, or sorus, as it appears when the infected tuber is dug from the ground.

SCIENTIFIC NAME OF POWDERY SCAB.

The scientific name of Spongospora has been changed even more often than its common name. This has probably been due (1) to the imperfect understanding of the life history of the fungus and (2) to the superficial resemblance of the spore balls of Spongospora to those of the smuts. Wallroth (1842*b*), who first collected Spongospora in 1841, named it *Erysibe subterranea*. It was described and figured by Martius (1842) as *Protomyces tuberum solani*. In 1844 Rabenhorst concluded it was not a species of Erysibe and described it in a new genus, *Rhyzosporium solani*. That Berkeley (1846) was familiar with the fungus and knew that it had been reported previously is apparent from a short note in one of his articles on the potato murrain published in 1846. He mentions Martius's Protomyces and figures the spore balls, choosing, however, to call it *Tuburcinia scabies* (Berkeley, 1850). The name of the organism was again changed in 1877 by Fischer von Waldheim, who placed it in another genus and called it *Sorosporium scabies* Berk.

It was not until 1886, when Brunchorst found Spongospora on potatoes in Norway, that it was shifted into the correct group, namely the Myxomycetes. Why Brunchorst failed to recognize or mention any of the earlier descriptions of Spongospora is not explained in his paper. That he was aware of the fact that the same disease existed in Germany and perhaps in England is evident from the following sentence:

Was das Vorkommen des Spongospora betrifft, ist derselbe hier in Norwegen äusserst verbreitet; wenn es sich bestätigen sollte, was ich sicher glaube, dass der

Pilz die Ursache der in Deutschland "Schorf" genannten Krankheit ist, und vielleicht auch der "Scab" der Englander, würde auch sonst die Verbreitung eine ganz ansehnliche sein.

Nevertheless he described it anew as *Spongospora solani*, and this name was in general use until 1908, when Massee (1908 and 1910) described it as *Spongospora scabies*, combining Brunchorst's generic name and Berkeley's specific name, a combination which is referred to by Pethybridge (1913*a*) as not necessary and untenable. Johnson, of Ireland, used the name applied by Brunchorst until 1909, when he found evidence to show that Brunchorst's *Spongospora solani* was identical with Wallroth's *Erysibe subterranea*. In an article published in 1911, Horne is unable to confirm Johnson and questions whether the organism described and figured by Wallroth, Martius, and Berkeley really is the same fungus described by Brunchorst. In view of this fact he adheres to Brunchorst's *Spongospora solani*.

In a very recent article Pethybridge (1913*a*) brings forth still more evidence to establish the identity of Wallroth's *Erysibe subterranea* and the organism now known as Spongospora. He also emphasizes the fact "that the question of identity does not rest merely upon the degree of accuracy with which the spore balls are figured, but some regard must also be paid to the very full description given by Wallroth of the development and fate of the warts, which agrees fully with what we know of the behavior of Spongospora and which does not apply to any other organism known at present." Judging from the evidence now available as to the specific name of Spongospora, it seems clear to the writer that it should be that first used by Johnson, namely, *Spongospora subterranea* (Wallr.) Johnson.

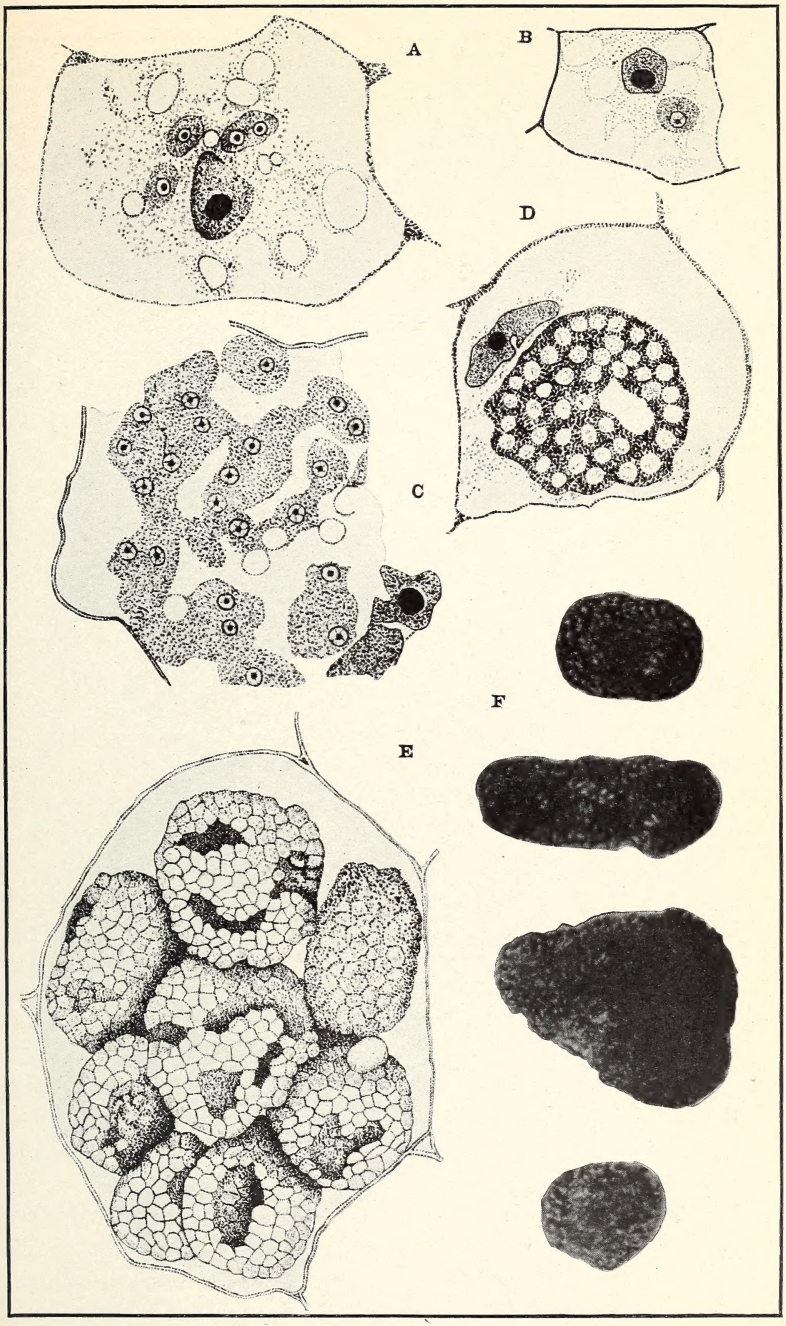
DESCRIPTION OF THE DISEASE.

This disease, so far as is known, never attacks the aboveground portions of the potato plant. It is primarily a disease of the young tubers, which develops as they mature in the ground. The earliest stages of infection, according to Osborn (1911), "are visible on young tubers not larger than hazelnuts. The disease is apparent by small slightly raised pimples and a slight discoloration of the surface. When cut open, the infected areas appear faintly purplish and extend from approximately the outermost cells of the tuber toward the deeper layers. Actual infection of the potato tuber by Spongospora has not been seen, nor have infection experiments been successful. The earliest stage in the life history that has been observed is that of a single uninucleate amœba in a young potato cell near the eye." Once in the tissues these naked masses of cytoplasm consume the cell content and multiply rapidly, as shown in Plate I, *A*, and at the same time stimulate the host cells to further growth and division.

It seems established that the amœbæ pass from one cell to another when cell division takes place, although it is claimed by Massee (1908) that the amœbæ invade new cells by boring through the cell walls. On the other hand, Osborn (1911), who has made an extensive cytological study of this organism, holds that "on the division of the host cell * * * it is a purely fortuitous circumstance whether each resulting cell shall contain an amœba, and so be infected or not. * * * I have never seen any signs of the migration of an amœba to a neighboring cell nor any continuity of protoplasm, such as Massee has described." Osborn's contention as to the method of migration of the amœbæ has been confirmed by Horne (1911). The abnormal local increase of cells causes a swelling and a faint discoloration of the skin, which latter becomes a wartlike outgrowth. The fungus present in this tissue consumes largely the contents of the cells (Pl. I, *C, D*), after which the amœbæ coalesce (Pl. I, *C, D*) and form one or more large spongy masses in each cell, known as plasmodia (Pl. I, *D*). These latter divide into many small spores, each of which takes on a heavy yellowish brown wall (Pl. I, *E*). Instead of these spores separating, they remain attached, forming a "spongelike body," according to Johnson (1908), and not a hollow sphere, as reported by Berkeley(1846) and Massee (1910).

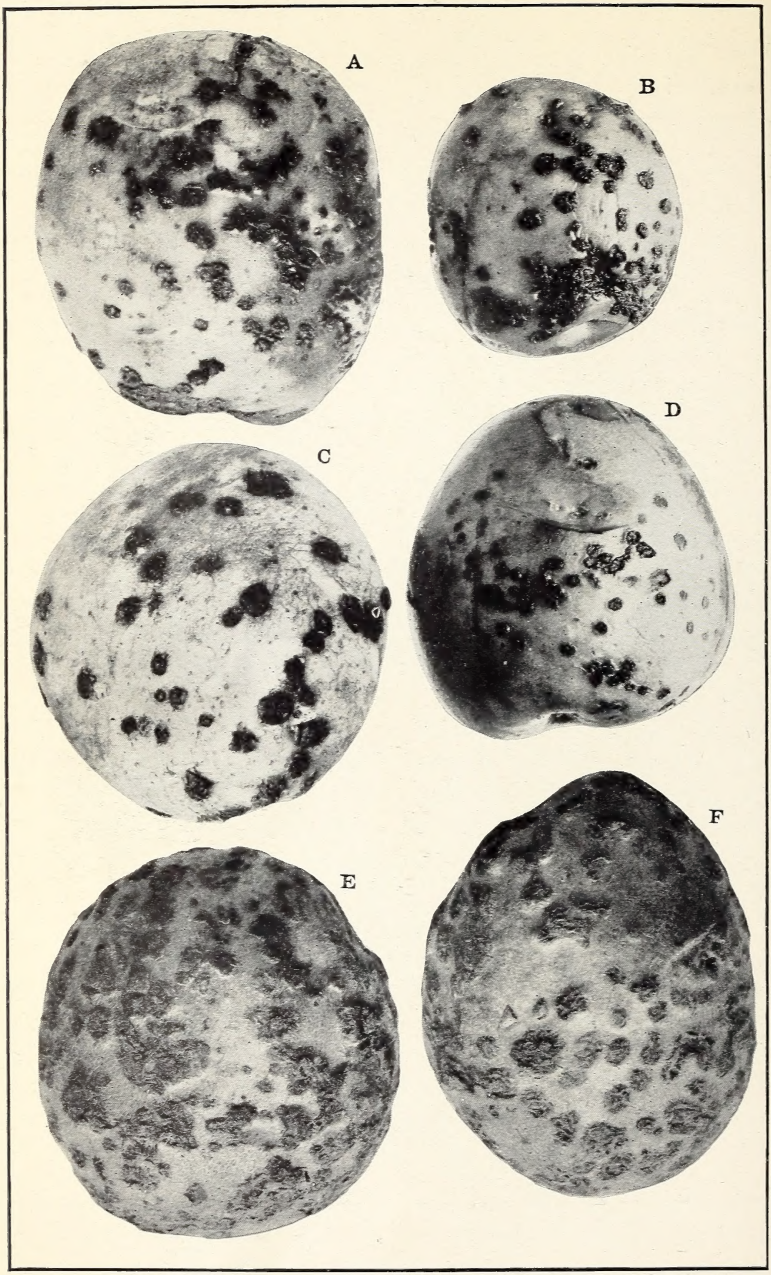
Since the contents of the attacked host cells are used up in forming spore balls, the infected area becomes a pit filled with a yellowish brown dust consisting chiefly of spore balls (Pl. II, *C*). These pits, or sori, at maturity are bordered by the torn skin of the tuber. The torn skin standing up on the periphery of the sorus is one of the characteristics of powdery scab, which often enables one to distinguish it from the Oospora scab macroscopically. The powdery contents of the sori in this stage of the disease doubtless suggested to Johnson the name "powdery scab," as has already been noted. It has been observed that in storage shriveling and shrinkage take place about these pits, or sori. How generally this shriveling occurs and its significance are not known up to the present writing, nor have these matters been emphasized in the literature, to the writer's knowledge. The cause of this shrinkage is not known, but it may possibly be due to insufficient cork deposition in the bottom of the sori which afford an avenue for storage rots to attack the infected tuber.

When conditions are highly favorable for the fungus, it may eat large cavities in the immature tubers. Besides consuming part of the tubers, it stunts their further growth and produces malformed tubers, such as are shown in Plate III. The nature and extent of the depressions caused are shown in Plate III, *C*. This stage of the disease has been called the cankerous stage (Horne, 1911) and is the one that causes the greatest loss.



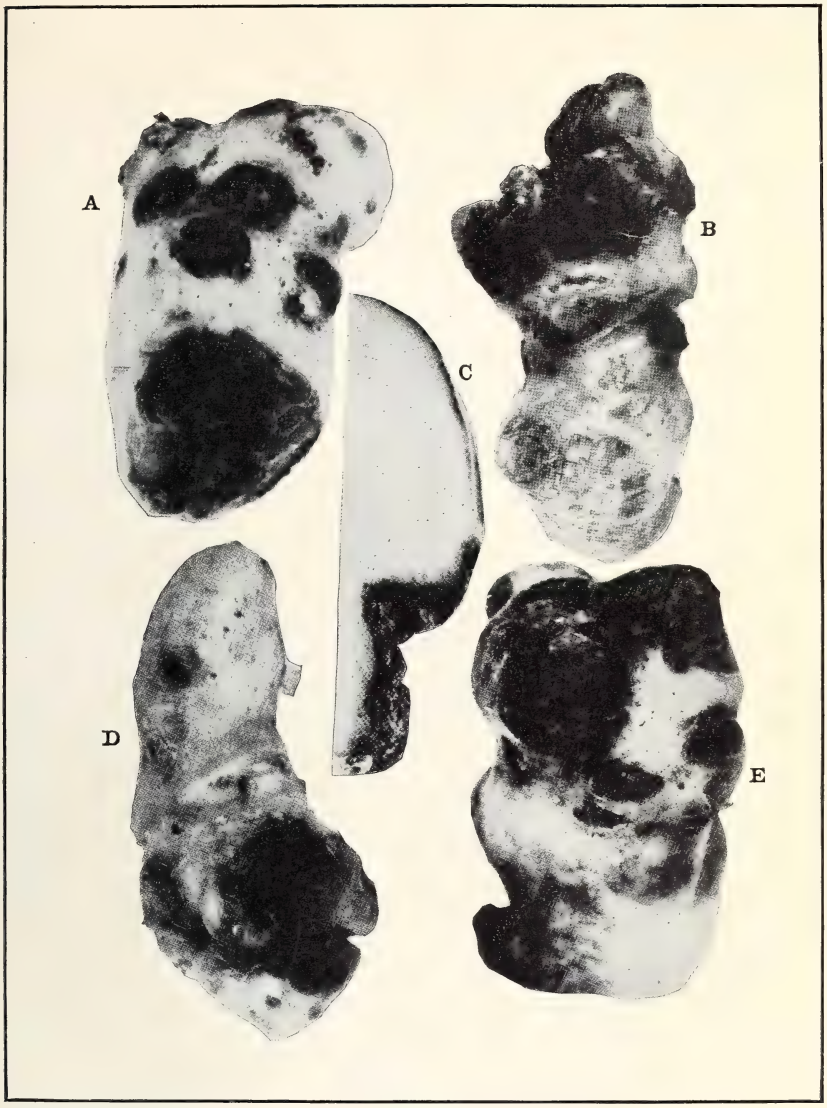
VARIOUS STAGES IN THE LIFE HISTORY OF THE FUNGUS WHICH CAUSES POWDERY SCAB.

A, A large host cell in which there are three amœbæ of Spongospora. *B*, A young host cell in the early stages of infection. The amœba lies just below the nucleus. *C*, The amœbæ are coalescing to form the plasmodium. *D*, The plasmodial stage. *E*, Mature spore balls in an enlarged host cell. (*A* to *E*, after Osborn.) *F*, The isolated spore balls photographed. Note the variation. (Original.)



FOUR TUBERS (*A*, *B*, *C*, AND *D*) INFECTED WITH SPONGOSPORA SUBTERRANEA COLLECTED IN NEW BRUNSWICK, DOMINION OF CANADA, ON OCTOBER 1, 1913.

They represent the scabby stage of the disease. The sori may be either isolated or grouped, as shown in *A* and *B*. The variation in size and general appearance of the sori is brought out in *C* and *D*. In the tuber marked *D* the sori are only about half as large and more superficial than in *C*. Two tubers infected with Oospora scab are shown as *E* and *F*.



THE CANKEROUS STAGE OF SPONGOSPORA.

It is this stage that is most destructive to the potato tuber. The cavities and large pustules combine to cause malformation of the tubers. In *C* is shown a section through a tuber badly infected with Spongospora. (*A*, *B*, *D*, and *E* are after Horne, *C* after Güssow.)

GEOGRAPHICAL DISTRIBUTION OF POWDERY SCAB.

Spongospora seems to be quite generally distributed in northern Europe. As early as 1841 it was recorded as existing in Germany, and that it had existed for some time before this is suggested by the fact that among farmers the disease had come to be known by a common name (Kartoffelräude). Frank more recently (1897) has mentioned its existence in Germany, but he does not think it is generally distributed. That it does exist to some extent, and possibly more than Frank's report indicates, is suggested by the following facts:

In the spring of 1913 the Bureau of Plant Industry purchased 22 different varieties of seed potatoes from two dealers in Germany. When these were received and examined by the inspecting pathologist, four of the lots were condemned, being infected with Spongospora.

In 1846 powdery scab was discovered in England by Berkeley in connection with his studies of the potato murrain, the disease which is now known as *Phytophthora infestans*. The little careful study that was given to Spongospora by the pathologists of Berkeley's day may well have been due to the intensive study given to the Phytophthora disease, which at that time threatened to destroy the potato industry of northern Europe. The general distribution of Spongospora in England and Scotland at the present time can readily be seen from the following statement of the Board of Insect and Fungous Pests for 1909:

> It has been reported to the board from many parts of Great Britain, chiefly, however, from those parts where wart disease is also present, or where it has been suspected. Cases have been reported from Peebles, Stornoway, Forfar, Fife, Lanark, Aberdeenshire, Stirlingshire, Lancashire, Cumberland, Shropshire, Rorks, W. W., Staffordshire, Wales, Hereford, Somerset, and Worcester. In Scotland, therefore, the disease seems fairly widely distributed, but in England, as might be expected, it appears to be confined to the west, where the rainfall is higher. It is not, however, to be supposed for a moment that anything like all affected localities are here recorded.

In the spring of the current year the United States Department of Agriculture imported 18 different varieties of potatoes from Scotland for seed purposes, all of which were found to be infected with Spongospora and were condemned by the inspecting pathologist. Nine different varieties were imported from England for similar purposes and were not allowed to pass, owing to Spongospora infection.

On October 31, 1913, Mr. W. W. Gilbert, of the Bureau of Plant Industry, collected specimens of powdery scab on potatoes imported into this country from the Netherlands. On November 20 the writer likewise collected Spongospora at New York City on two different shipments from the Netherlands. The following day specimens were taken by Mr. O. A. Pratt and the writer from a shipment coming from Belgium. More recently the disease has been found several times

in considerable quantity on potatoes coming from the Netherlands and Belgium. As already stated, the disease has been in Norway since 1886 and has since been found in Sweden.

It is also interesting in this connection to note that Spongospora occurs in South America, probably the native habitat of the potato. It was collected in 1891 at Quito, Ecuador, by Lagerheim, who reports that the disease is well known to the natives. This suggests two possibilities: (1) That the disease has always existed there or (2) that it was introduced into South America on European varieties.

PRESENCE OF POWDERY SCAB IN CANADA.

More recently powdery scab has gained a foothold in North America, and early in the spring of 1913 it was reported in several Provinces of Canada by Güssow. The writer has been able to confirm Güssow's reports by personally visiting the potato-growing sections in three of the Provinces of Canada, namely, New Brunswick, Prince Edward Island, and Nova Scotia. It was found that powdery scab was quite generally distributed in the lower St. John River valley, New Brunswick, and on Prince Edward Island.

POWDERY SCAB IN THE UNITED STATES.

That Spongospora exists also in the United States has been definitely established. In the spring of 1913 Morse, of the Maine Agricultural Experiment Station, obtained some evidence that the disease exists in Nebraska and Massachusetts. No further cases have been reported from these States. In June, 1913, the writer collected 84 tubers infected with Spongospora from four barrels of the Green Mountain variety purchased for experimental purposes at Presque Isle, Me. These had been grown in the vicinity of the village during the season of 1912.

Spongospora was collected at Washburn, Me., on February 9, 1914, and at Frenchville on the following day. Later it was found at stations farther south in Aroostook County.

A thorough survey of northern Maine is now being made by the State department of agriculture, with the cooperation of this department. The survey to date indicates that powdery scab is more common in the northern half of Aroostook County. Several cases were found where the growers at some time during the last three or four years had secured seed from the neighboring infested sections of New Brunswick, which may well account for the introduction of the disease. The results secured up to the time this bulletin goes to press indicate that there is considerable powdery-scab infection in Aroostook County. The active measures that are now being taken to discover and delimit the infected areas and to prevent the shipment of diseased potatoes for seed purposes should result in checking the spread of powdery scab.

DAMAGE TO THE POTATO CROP.

The scabby stage of Spongospora, like the common Oospora scab, is a skin disease confined to the tubers, marring their appearance and thereby decreasing their market value. The cankerous stage, as shown in Plate III, completely destroys the tubers for both food and seed purposes. This observation is confirmed by the following quotation from Pethybridge (1911, p. 442):

> As was pointed out last year, Spongospora scab presents two forms of attack, in the one case that of small spots on the surface of the tubers, and in the other the form of a "canker" or eating away of the tuber. This latter is, of course, the most serious one, but there are all degrees of transition between it and the spot form.

Pethybridge is inclined to classify the effect on the potato as producing "scab spots" and "cankers," the former doing little harm to the tuber, while the latter, as shown by his illustrations, completely deform and dwarf its growth, so as to make the tubers worthless.

Osborn (1911) holds that the soil moisture determines to a great extent the damage done by the disease and says—

> Under dry conditions of the soil the external appearance is limited to small circular patches about 5 mm. across. Under wet conditions the damage is more serious and the scabs may be as large as 3–4 cm. in diameter and as much as 2 cm. in depth. This is the only external appearance; there is no sign of hypertrophy or any distortion other than that caused by the pitting.

The presence of the fungus in the cells stimulates the host to lay down a new layer of cork cells surrounding the sorus, if the soil is not too wet, which checks its growth.

By Güssow (1913), who has, as already stated, found powdery scab in Canada, the disease is not considered trifling. He says—

> The disease should by no means be regarded lightly. Severe attacks occur when potatoes are planted year after year on infected land. Where this is practiced the result will be potatoes hardly superior in quality to those badly affected with canker. This fact is worthy of notice, especially since, as in the case of canker, no preventive measures have proved of much value.

In a very recent publication, Pethybridge (1913*b*, p. 459) refers to the damage done by Spongospora in his experimental plats, as follows:

> They were particularly disastrous on those portions of the land which for special purposes have now been cropped for four successive seasons with potatoes, the cankerous form of the disease being extremely common. In one or two plats nearly two-thirds of the total crop were practically ruined by it, while the general average loss in the plats on the old land due to it would be about one-third of the crop.

EFFECT ON SEED POTATOES.

Besides injuring the potato for market purposes and decreasing the yield, as already noted, powdery scab also depreciates the value

of the potato for seed purposes. Its harmful effect on the seed has been emphasized by Johnson (1908, p. 453), as follows:

> Such tubers are not only much reduced in market value for eating purposes, but must provide also poor seed for the next year's crop. Yet I was constantly told that this was the kind of seed regularly planted from year to year; and that the people used this seed because they had, and could get, no other. * * * I have no doubt myself that this Spongospora scab has a good deal to do with the miserable average yield per acre of potatoes in the west of Ireland. * * * It is in some districts of Ireland as injurious to potatoes as finger-and-toe is to turnips.

The following sentence from Pethybridge's report in 1911 (p. 442) shows more strikingly the relation of the disease to the seed potato:

> It was found during the past season that the crop resulting from the planting of the "canker" form of disease in clean land gave 67.1 per cent of affected tubers, while the spot form produced only 54.1 per cent.

That other countries are not considering Spongospora scab lightly is apparent from a farmers' bulletin, No. 110, of the Transvaal Department of Agriculture, issued by Evans in 1910, warning the grower against the use of infected seed potatoes. Evans says—

> Corky scab has caused a considerable amount of damage to the potato crop in Great Britain, Ireland, and Norway. It also occurs in Germany, and is particularly prevalent in the west of Ireland. * * * Diseased tubers should on no account be used for seed purposes, for not only will the resulting crop be scabbed, but the ground will also be infected with the germs of the parasites.

It must also be remembered that not only does powdery scab injure the crop, but the soil becomes contaminated and clean seed planted on this land for several years afterwards becomes infested. Just how long the organism can remain alive in the soil is not known, but that it is resistant and may live for several years is suggested by the structure of the spores and experiments by Pethybridge (1911) showing that the spore balls can pass through an animal without losing their capacity for renewing the disease. Contamination of clean seed may take place, it is claimed, by simply being in contact with diseased potatoes. If such is the case, and there is good reason to believe it possible, clean seed may become infected through the use of old bags and machinery. Indeed, it is even possible for one field to become infested from another by the spore balls being carried by the wind, water, and other agencies.

IS POWDERY SCAB A DANGEROUS MALADY?

In considering whether powdery scab is or is not a dangerous disease it is well to keep in mind that any inciting agent, regardless of its origin or nature, that mars or defaces the tuber depreciates its value and ultimately its productiveness. The degree of danger presented by this intruder is problematical, but all American plant pathologists who have expressed an opinion upon this point are agreed that powdery scab is a disease possessing characteristics that

might make it a serious enemy of the potato in the United States, at least as bad as the common scab caused by *Oospora scabies*, and probably worse.

The effect of the milder form of Spongospora upon the tuber resembles that of the common scab in that it disfigures the potato and thereby reduces the market price, even though the food value may not be materially impaired. It differs from Oospora scab in that the advanced or cankerous stage ruins the tuber for both table and seed purposes.

In this connection it should be remembered that any kind of scab or other injury that mars or defaces the potato tuber is a more serious handicap in the American markets than in those of some European countries, due to the fact that consumers abroad offer fewer objections to scabby potatoes than consumers in the United States. There is even a belief prevalent abroad that scabbiness is an indication of superior quality. In the United States, when potatoes are put on the market, scabby potatoes must be sorted out, and therefore are of no use except for stock feed or the manufacture of starch. In Maine the price of scabby potatoes in the autumn of 1913 was 50 cents per barrel, while clean stock brought $1.50 per barrel. In the country as a whole, hundreds of thousands of bushels of potatoes are left in the fields because they are too scabby to market. There are frequent instances in the New York markets, according to potato dealers, where carload consignments are rejected because of the presence of numerous scabby potatoes. When the soil becomes infested with scab its value as potato land materially depreciates. This is especially true in sections where potatoes constitute the chief crop.

The character and relationship of the parasite should also be taken into consideration in judging the danger which powdery scab presents. This is a case of dealing with a slime mold, a relative of the serious disease of cabbage, turnips, and related plants, known as clubroot.

If powdery scab should prove no more troublesome in the United States than it has been up to the present in Europe, it would be rated as a disease of secondary importance as compared with late-blight or with Fusarium wilt. But there are reasons for fearing that it may become more prevalent here. It seems to be a fact that common scab is less troublesome in Europe than in America, and the same condition might be the case with powdery scab. It quite often occurs that introduced parasites are more destructive in a new habitat than in their native environment. Likewise, it is not impossible that Spongospora may find the American varieties of potatoes more susceptible than the European sorts. There is also no means of predicting the behavior of Spongospora under the varied climatic and soil conditions of the several States. The parasite has only recently

been found on the American Continent, and the brief experience with it in eastern Canada gives no hint of what its behavior would be in the southern trucking districts, the central West, or the irrigated sections. The common scab is much worse in many parts of the West than in the East.

Another reason for grave concern in the United States is that the disease exists in that portion of Canada adjoining the State of Maine, which is the chief source of seed potatoes for the Central Atlantic and Southern States. If powdery scab becomes generally distributed in Maine, only the most extraordinary efforts can check its spread to nearly every State in the Union.

MACROSCOPIC DIFFERENCES BETWEEN SPONGOSPORA AND OOSPORA SCAB.

It should be made clear in discussing the similarity of and differences between Spongospora and Oospora scab that the symptoms and ultimate effect on the tuber vary markedly in the case of both diseases, depending upon external influences. In spite of the wide variation of powdery scab, two characteristic stages of the disease may be recognized, namely, the scabby and the cankerous stages, shown in Plates II and III, respectively. It is only the former of these that can be easily confused with the Oospora scab, and therefore the latter stage needs no further consideration in this connection.

As pointed out by Horne, the early stages of Spongospora resemble markedly the beginning stages of the wart disease caused by *Chrysophlyctis endobiotica*, in that wartlike excrescences appear on the tuber. Such symptoms are in no way like those of the early stages of Oospora scab, and this naturally leaves for comparison only the characteristics of the two diseases as found on the mature tuber at harvest time and shortly thereafter.

The scabby stage of Spongospora on the mature tuber, as illustrated in Plate II, usually differs essentially from Oospora scab in three ways:

(1) The sori are more often circular and not usually as great in diameter as those of Oospora scab.

(2) The periphery of each sorus is bordered by the upraised outer epidermal layer of the tuber, so that virtually small cups or pits are formed, as shown in Plate II, *B* and *C*.

(3) These pits are usually deeper than those of common scab and are always filled at maturity with a brownish colored semicompacted dust or sediment, as shown in Plate II, *C*. The sori of Oospora are usually shallow and composed of corky material of a compact and interwoven nature.

It should be remembered that it is extremely difficult, if not impossible, to define the difference between two diseases varying so

markedly under diverse environmental conditions. In fact, many cases have come to the attention of the writer where the macroscopic characteristics mentioned were not in evidence, and yet the typical spore balls were found in the sorus upon making microscopic examination. It should be especially emphasized that the three differential characteristics pointed out may be totally absent after the infected tuber has been harvested and roughly handled through shipment.

In Plate II are illustrated what may be called common cases of Spongospora and Oospora scab. The upper four potatoes are infected with powdery scab and the lower two with common, or Oospora, scab.

FUNCTION OF THE SPORE BALLS AND METHODS OF INFECTION.

The potato crop probably becomes infected by the spore balls present in the soil or on the sets when planted. Just how infection takes place is not known. Infection studies are made difficult because no one has been able to germinate the spore balls in abundance at will. Massee (1908) claims that the content of each spore is liberated as a whole in the form of irregularly globose bodies with a few small projections. These bodies show a slow, sluggish movement for some time and then come to rest. Each amœboid body is about 3 μ in diameter and uninucleate. Johnson (1908) saw motile bodies resembling swarm spores in his cultures which he believed were the swarm spores of Spongospora, but he states that he never saw them escape from the spore. Instead of being uninucleate, he found them to have from one to eight nuclei, like the swarm spores of Ceratiomyx. Both Osborn (1911) and Horne (1911) have attempted to germinate the spore balls without being able to confirm either Massee or Johnson. It may be that their germination is seasonal, like the spores of a goodly number of other fungi, or that some special stimulus in the soil is necessary to cause them to become active. That they function can not be doubted, because clean seed planted in soil infested with Spongospora spore balls becomes infected with the disease, as shown by Horne's experiments.

It has also been proposed by Massee (1910) that the plasmodia may become encysted during the winter and resume their activity when the tubers begin to sprout, and Johnson (1909) holds that the plasmodium may migrate from the diseased parent tuber into the stem and stolons of the young plant and ultimately infect the young tubers. As suggested by Horne, neither of these investigators has proved experimentally that the plasmodium ever assumes such a rôle. It can not help but become obvious that more information as to the method of functioning of the spore balls and the method of infesting

the soil under field conditions is much needed in order to understand clearly this disease. Such studies are also necessary before control measures can be intelligently worked out.

SEED TREATMENT.

Powdery scab has received little attention from the standpoint of control measures except in Ireland, and the results obtained are not fully convincing. Johnson (1908) states that soaking infected tubers 18 to 24 hours in 2 per cent Bordeaux mixture, or 1 per cent corrosive sublimate for 1½ hours, or 4 per cent formaldehyde solution for 2 hours, is effective in killing the spore balls. It has already been emphasized that very little is known regarding the germination of the spores.

Pethybridge (1911, p. 443) has also studied to some extent the control of Spongospora. His results are shown in Table I.

TABLE I.—*Yield of diseased potatoes when seed was untreated and following various treatments for powdery scab.*

No. of plat.	Treatment of seed potatoes, if any.	Yield of diseased tubers.
		Per cent.
3	No treatment; seed only slightly affected	54.1
4	No treatment; seed badly affected	67.1
7	Soaked in formalin solution (1: 600) for 3 hours	2.6
8	Soaked in copper-sulphate solution (1 per cent) for 3 hours	0
9	Soaked in copper-sulphate solution followed by rolling in slaked lime	4.4
10	Soaked in and covered with precipitate of Burgundy mixture for 3 hours	2.9
11	Surface wetted and rolled in flowers of sulphur	1.03

Regarding these experiments, Pethybridge says—

> From the table it will be seen that in all cases the treatment of the seed tubers resulted in a most satisfactory checking of the disease. With regard to plats 8, 9, and 10, where copper salts were used, the total yield of tubers was, however, quite considerably reduced. The best yield was given with the formalin treatment, and the next best with sulphur. Of these two, perhaps, the sulphur treatment would be the easier to put in practice.

The results obtained by Johnson and Pethybridge are very interesting, but are of a preliminary nature, requiring further study before they can be recommended for practice.

SOIL TREATMENT.

Soil treatment with fungicides for Spongospora scab, as would naturally be expected, has given experimenters but little encouragement. This matter has been most extensively studied for the past three years in Ireland by Pethybridge (1913*b*, p. 460), whose most recent results follow.

TABLE II.—*Yield of diseased potatoes when soil was untreated and following various treatments for powdery scab.*

No. of plat.	Treatment of land, if any.	Total yield per square perch.	Yield of diseased tubers.
		Pounds.	*Per cent.*
5	Extra superphosphate added, 4 hundredweight to statute acre	99	30.3
6	Each tuber planted in a handful of wet sawdust	74	34
7	Extra sulphate of potash added, 1 hundredweight to statute acre	102.5	38
8	No treatment	100	51
9	....do	97	52.5
10	Extra muriate of potash added, 1 hundredweight to statute acre	94	52.1
11	Flowers of sulphur applied, 6½ hundredweight to statute acre	106	23.6

Pethybridge writes as follows regarding these experiments:

With the exception of the muriate of potash, it will be seen that considerable diminution in the weight of diseased tubers produced has been effected by the methods of treatment used, although the use of sawdust has reduced the total yield. The yields given in the above table are pounds per square perch.

The best results were obtained with sulphur, where not only was the amount of disease reduced to less than one-half of that in the untreated plats, but the total yield was higher than in any other case. This result confirms previous experiments carried out at Clifden, which have always shown that sulphur added to the soil increases the yield of potatoes and diminishes the attack of scab. * * *

Substantial as are the reductions in the amount of scab due to the methods of soil treatment above indicated, they can not be looked upon from the practical standpoint as sufficient, and a suitable, cheap soil disinfectant is still a great desideratum for this, as well as for other purposes.

Liming the soil, as is practiced for clubroot of cabbage, a parasite related to Spongospora, has proved an aid to the fungus rather than a check to its development. This makes it clear that it does not behave like clubroot of cabbage, as suggested by Massee. The effect of lime on the development of Spongospora has been pointed out by Horne (1911) and Pethybridge (1911).

It is, of course, obvious, as Pethybridge suggests, that there is as yet no method of controlling this disease when it once gets into the soil. In view of this fact, it is plain that potatoes should not be grown for some years on a piece of land that has produced a crop infected with Spongospora scab. Just how many years the fungus is able to remain alive in the soil is not known and is a question that merits investigation. The nature of the spore balls suggests that the disease may well be able to live in the soil for several years. It should be said also in this connection that if more was known as to the germination of the spore balls, it might be possible to predict their longevity.

SACKS AND BARRELS AS AGENTS IN SPREADING POWDERY SCAB.

It is well known that secondhand sacks, barrels, and boxes are often used in marketing potatoes.

Seed potatoes shipped from the Northern States to be grown in the South are put up either in sacks or barrels. European potatoes coming to this country are shipped in 168-pound gunny sacks. In some of the Western States similar sacks, but holding only 120 to 150 pounds, are used. These sacks cost from 12 to 16 cents each, depending upon their quality and whether they are new or secondhand. Sacks of good quality can be used many times, and this has come to be common practice. In both New York and Boston there are firms that act as clearing houses for potato sacks, buying secondhand sacks from anyone who may wish to sell them and shipping them to potato dealers either north or south. It may happen, therefore, that sacks that have previously contained diseased tubers coming from Europe or elsewhere will be used for shipping select seed from the North to the South. It is not improbable, and, indeed, very possible, that spores of Spongospora, Spondylocladium, Fusarium, Phytophthora, etc., may be communicated to healthy potatoes through secondhand sacks. The same thing may take place through using secondhand barrels, but this is not so often done. There is, however, considerable chance of potato diseases being spread by means of old sacks.

The question arises as to how this spreading of disease can be prevented and, of course, the solution is a simple one—by using only new sacks. But this would increase to some extent the cost of potatoes and bring about the accumulation of large quantities of old sacks. It seems very likely that some means of sterilizing old sacks could be put into practice which would make them fully as harmless as agents in disseminating diseases as new sacks. This could probably best be carried out by firms dealing in sacks. It seems probable that subjecting the sacks to steam sterilization for several hours at a pressure of 15 to 20 pounds would render them free from noxious diseases without increasing their cost to any appreciable extent.

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