UNIVERSITY OF MAINE

The Maine Agricultural Experiment Station

ORONO, MAINE

BULLETIN 482 MAY, 1950

Factors Affecting Potato Blackleg and Seed-Piece Decay

Reiner Bonde

Poor Stand Resulting from Exposing Freshly-cut Seed Pieces to Dry Air and Sunlight for Several hours.

CONTENTS

SUMMARY

One of the important problems of potato growers is to obtain a good vigorous stand by the prevention of seed-piece decay and the control of blackleg disease. This study was made to determine methods of controlling these problems as applied to the conditions in Maine and other northern states, and to some extent in the South where large quantities of seed potatoes are used.

Epidemics of seed-piece decay and of blackleg are often attributed to the presence of the disease in the seed tubers. Other sources of infection, however, may be more important.

The blackleg and other bacterial pathogens are generally present and were isolated in Maine from the fungus lesions of "buttonhole rot," powdery scab, and dry rot caused by the late blight fungus. They were also isolated from the soil, both in Maine and in South Carolina.

The soft rot infection that is present in the fungus lesions may be disseminated by the knife in the seed cutting operation or by coming in contact with freshly cut seed pieces in the process of handling.

The blackleg epidemics that sometimes occur in Aroostook County are definitely associated with long-time storage of the cut seed under unfavorable conditions. Seed that is planted immediately or soon after being cut rarely produces the disease in northern Maine. Seed pieces that were stored under cool well ventilated conditions also seldom developed decay.

Blackleg is often associated with "heating" of the cut seed prior to being planted. Tubers with blackheart readily produced plants having blackleg.

Blackleg was associated with freezing of the cut seed prior to being planted. Seed stocks injured by freezing produced high percentages of blackleg.

Disinfecting the seed stock has controlled seed-piece decay but often has not controlled blackleg satisfactorily.

Roguing and other seed plot practices have not given satisfactory control of blackleg in Maine.

The seed-corn maggot and the potato maggot may help to produce seed-piece decay and blackleg. These insects under Maine conditions enter through bacterial or contaminated fungus lesions developed on the seed pieces before they are planted.

In South Carolina the maggots enter through primary lesions resulting from soil infection. Suberizing the cut seed prevents the formation of these primary lesions and thus eliminates the injury caused by the insects in South Carolina.

Blackleg rarely occurs in Maine in fields planted immediately after being cut. Proper storage of cut seed before it is planted also prevents the occurrence of blackleg and seed-piece decay.

BULLETIN 482

FACTORS AFFECTING POTATO BLACKLEG AND SEED PIECE DECAY

Reiner Bonde

Plant Pathologist

INTRODUCTION

The control of blackleg and seed-piece decay is one of the chief problems in potato production. Blackleg has been reported from practically all countries in the world and probably is present wherever the potato is grown. The disease is important to Maine growers because it reduces the yield of the crop and also because it greatly affects the value of seed potatoes that are sold. State potato seed certification officials discriminate against the presence of blackleg and many buyers refuse to purchase seed stocks known to have even a small percentage of the disease. The problem of preventing seed-piece decay and missing hills in the fields also is an important problem which may be closely associated with the control of blackleg. A good stand of healthy plants is essential for high yields and for the economical production of the crop.

Potato growers and seed buyers have considered that blackleg and seed-piece decay result from the infection being borne systemically in the seed tubers and have bought their stock for seed purposes on this basis. Many states have conducted extensive tests to demonstrate that the source of the seed stock is extremely important regarding the prevalence of blackleg and uneven stands. Often it has been concluded from these tests that the great differences in the amount of these diseases that occur have resulted because of certain inherent differences in the stocks. Many buyers have purchased their supply of seed potatoes on the basis of information derived from such tests. The writer is of the opinion that these differences very often are due to certain local environmental factors and not due to the fact that the seed stock contained a systemic infection of the blackleg organism.

This bulletin deals with some of the factors which influence blackleg and seed-piece decay as well as the methods by which these diseases can be controlled. It supplements previous summaries by Bonde (*1* to *7*),[1] Morse (*17* to *20*), and Schultz et al. (*26*) concerning the blackleg and seed-piece decay problem in Maine. A brief statement regarding the control of seed-piece decay and blackleg in the South also is presented.

---

[1] Numbers in Italics refer to Literature Cited.

SYMPTOMS OF BLACKLEG

Blackleg has been described by a number of workers and the symptoms are known by most potato growers. This report presents some of the symptoms as they appear in Aroostook County, Maine.

Blackleg is a bacterial disease of the stem and the tuber of the potato. The disease is characterized in its typical form by a blackening and soft rot of the basal part of the plant. (See Figure 1.) However, the infected plants often show signs of the disease before the stems have

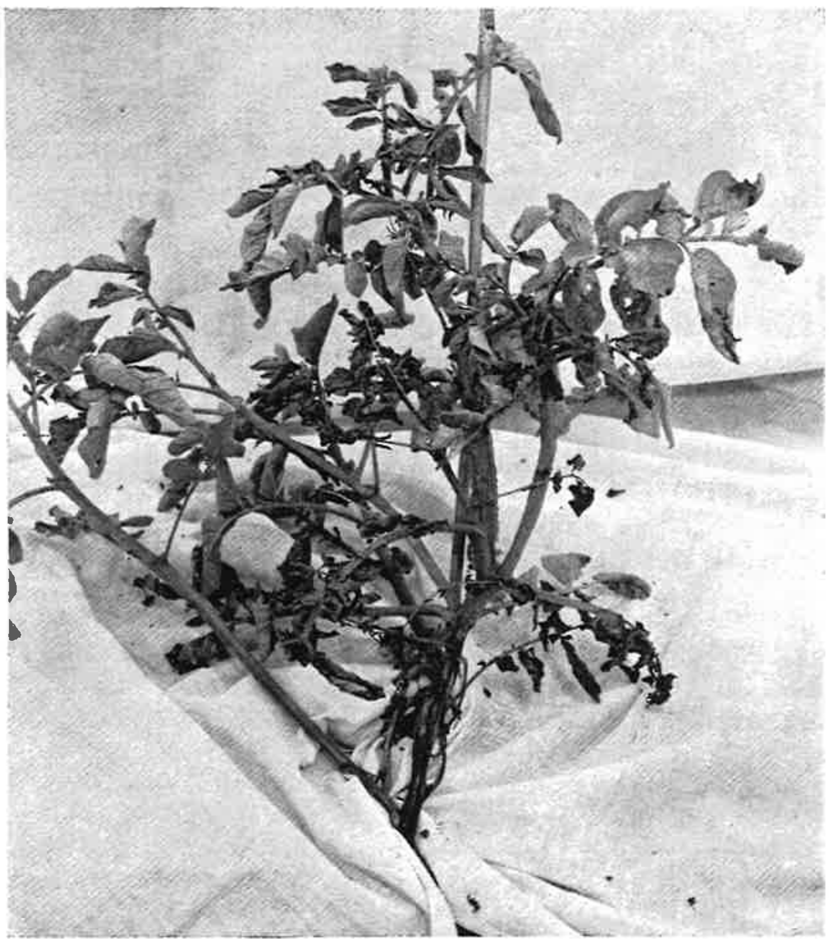

FIGURE 1. A Potato Plant Affected with Blackleg in an Advanced Stage. The plant is yellow, the leaves are curled and the basal part of the stem has a black soft slimy rot.

become blackened and rotted. In the early stages of the disease the plants tend to become erect and the young leaves curled. Later the leaves turn light green or yellow and the plant dies. The disease may progress rapidly under moist conditions and the plant may suddenly fall over with but few of the previously described signs.

The symptoms of blackleg generally become evident during early July when the plants are 10 to 12 inches high but may do so later when they have reached maturity. Sometimes the diseased plants are only 2 or 3 inches high or fail to emerge above the ground level. These latter symptoms often are not recognized by farmers as resulting from the blackleg disease.

The blackleg bacteria may progress into the stolons and infect the young tubers, causing a virulent soft rot. When the infection occurs late in the season, the bacteria may cause a shallow rotted sunken stem end. (See Figure 2.) The bacteria also invade the vessels of the mature tubers causing a discolored vascular ring. This type of infection is considered by many to be directly or indirectly responsible for the propagation and spread of most of the disease.

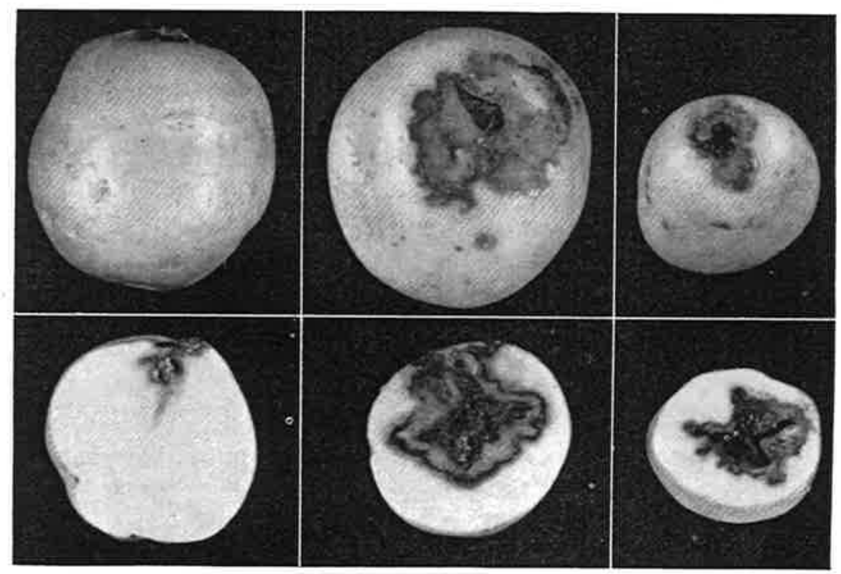

FIGURE 2. Upper: Tubers Produced by Plants that Developed Blackleg Late in the Season.

The bacteria have caused a soft rot at the stem end of the tubers. Such tubers often, but not always, produce blackleg plants.

Lower: Decay Inside of the Tubers often Associated with the Blackleg Disease.

SOURCES OF INFECTION BY BLACKLEG

The prevalence of blackleg varies greatly from season to season. During some years blackleg may be relatively scarce while during other years the disease may vary from one to 20 per cent. The variation is often very great within the different parts of the same field. It is not uncommon to find one part of a field with relatively little blackleg and other parts of the same field and even adjacent rows, planted with the same seed stock, with a high percentage of blackleg and a very uneven stand. This great variation obtained with the same seed stock suggests that the amount of blackleg and seed-piece decay may be dependent more on such factors as the handling of the cut seed prior to planting than on the amount of infection originally present in the seed stock.

The sporadic occurrence of blackleg often raises the question as to the source of infection. Morse, who first studied the blackleg problem in Maine, was of the opinion that the disease was largely borne in the potato tubers and was perpetuated by infected seed (*17,* p. 314 and *20,* p. 91).

The assumption that blackleg is largely perpetuated in the seed tubers from diseased plants has been generally accepted by potato growers and research workers. However, some others who have made a careful study of the problem, have realized that other factors not so apparent were very important in the initiation of blackleg epidemics.

PLANTING SEED HARVESTED FROM DISEASED PLANTS

When these studies were started, it was assumed that high percentages of blackleg plants would result when the tubers from diseased plants were planted. However, in 1926 only one per cent of blackleg resulted from planting tubers selected from diseased hills the previous year.

These results stimulated a further test of the amount of blackleg that would result from planting diseased tubers. Seed tubers were selected from blackleg hills for the 10-year period 1926-1935 inclusive and 1949. These tubers from diseased hills were placed in commercial storage and planted the following year under field conditions. The diseased seed stocks for some years were planted not only in Maine, but in Florida, New York, South Carolina, and New Jersey. In some cases the tubers were separated according to the amount of vascular discoloration and other supposed signs of blackleg infection and the different lots selected on these bases were planted and recorded separately. The lots of seed were in most cases relatively large and the data secured from the test should be fairly reliable. The results are recorded in Table 1.

TABLE 1

*Percentage of Blackleg Resulting from Planting Seed Harvested from Diseased Hills**

Year	Variety	Extent of infection** and type of selection	Where planted	No. seed pieces planted	Per cent blackleg
1926	Spaulding Rose	Bulk. Not selected	Presque Isle, Me.	200	1.0
1926	" "	" " "	Hastings, Fla.	Bushel	1.0
1927	Irish Cobbler	" " "	Presque Isle, Me.	400	4.0
1928	" "	" " "	" " "	200	5.0
1929	" "	Tubers showing vascular discoloration	" " "	330	3.2
1929	" "	Tubers not discolored	" " "	520	2.5
1929	" "	Bulk. Not selected	Charleston, S. C.	100	0
1930	" "	" " "	Presque Isle, Me. (High land Caribou loam)	125	0
1930	" "	Tubers with vascular discoloration	Presque Isle, Me. (Low land Washburn loam. On same farm as Caribou loam above)	300	8.5
1930	" "	Tubers showing decay	"	200	10.0
1930	" "	Tubers not showing vascular discoloration and decay	"	400	1.0
1930	" "	Tubers planted whole	"	200	10.0
1930	" "	Tubers showing vascular discoloration	Charleston, S. C.	100	3.0
1930	" "	Tubers not showing vascular discoloration	" "	100	0
1930	" "	Tubers with internal decay	Long Island, N. Y.	100	2.0
1930	" "	Tubers with vascular discoloration	" " "	200	5.8
1930	" "	Tubers not showing vascular discoloration	" " "	600	0.2
1931	" "	Bulk. Not selected	Presque Isle, Me.	200	0
1932	" "	" " "	" " "	800	2.2
1933	" "	" " "	" " "	500	3.0
1934	" "	" " "	" " "	521	5.1
1935	" "	" " "	" " "	1000	1.0
1949	Katahdin	" " "	" " "	400	1.5
1949	" †	" " "	" " "	400	0
1949	Sebago	" " "	" " "	400	9.6
1949	" †	" " "	" " "	400	1.6
1949	Irish Cobbler	" " "	" " "	400	5.6
1949	" " †	" " "	" " " and New Brunswick, N. J.	400	0.8
1949	" "	" " "	New Brunswick, N. J.	2 bushels	0

* The seed tubers used in these tests were harvested by hand from hills showing blackleg in commercial fields in the vicinity of Presque Isle, Maine.
** In some cases as indicated in the Table the individual lots were sorted according to the amount of vascular discoloration and decay present and the lots selected on this basis were planted separately.
† Controls.

The amount of blackleg resulting from planting tubers from 100 per cent diseased hills varied from none to 10 per cent. The amount of disease from this source would have been negligible in fields planted from field-run seed stock containing a relatively small number of infected tubers. Clayton (*9*) working at Long Island, New York; Gratz (*10*) in Hastings, Florida; and Campbell in New Brunswick, New

Jersey (unpublished data obtained by correspondence) obtained similar results from planting seed stock harvested from blackleg plants.[2]

In contrast with these experiments it is a common experience to obtain much higher losses from blackleg when seed stocks considered to be disease free were planted (*26*).

LESIONS CAUSED BY *Phoma tuberosa* AS AVENUES OF INFECTION

Melhus et al. (*16*) have described a dry rot found prevalent on potatoes from Maine storage houses. The fungus *Phoma tuberosa* Melhus et al. is responsible for this "buttonhole" rot which causes a considerable amount of loss in some seasons when from 10 to 30 per cent of the tubers in some storage bins may be affected. Maine studies have shown that this fungus may also be responsible for a considerable amount of seed-piece spotting and decay. The trouble is characterized by shallow black or dark brown circular spots and sunken areas on the cut surfaces of the seed pieces. Figure 3 shows the fungus on tubers and on seed pieces.

Pycnidia are abundant during early spring on the surface of the fungus mats on the uncut tubers. Experiments have shown that pycnidiospores, which are liberated in great numbers, are disseminated to the freshly cut seed pieces and there initiate the lesions. Studies in Maine have shown also that this fungus, as well as other pathogenic organisms, are disseminated by the knife in the seed cutting operation.

The spotting caused by *Phoma tuberosa* is of interest in relation to these studies because it is associated with bacterial decay and the blackleg disease. Preliminary isolations from rotted and discolored seed pieces from several sources yielded bacteria that were highly pathogenic and capable of causing blackleg by artificial inoculation into potato stems.[3]

Spotting was prevalent in 1927 and 1928 in Aroostook County. Practically every lot of cut seed that had been kept in storage prior to planting was affected to some extent and the economic loss caused by poor stands which resulted when this spotted seed was planted was in many cases very great. In some fields the stand of hills was reduced as much as 28 to 30 per cent because of seed-piece decay. The infection also was serious in 1927 in certain lots of seed which had been produced on an experimental seed plot that had been free from blackleg for several previous years. The spotted and discolored seed pieces when planted germinated poorly and gave only a 65 to 70 per cent stand. It is significant that from 10 to 12 per cent blackleg developed in the remaining plants. Clean and bright seed pieces selected from the same lots of seed germinated well and produced plants with only a trace of blackleg.

Studies were made which prove further that soft rot or blackleg bacteria were present in the seed pieces affected with *Phoma tuberosa*. The discolored and rotted seed pieces were used to inoculate freshly cut seed pieces. The freshly cut surfaces were merely touched with the diseased material and removed to moist chambers. One lot of inoculated seed was stored in the laboratory at 69° F. and another lot was stored in a cool basement maintained at approximately 50° F. Bacterial decay

[2] It is of interest that the diseased tubers used by Clayton, Gratz, and Campbell in these experiments were harvested by hand from diseased plants grown in the vicinity of Presque Isle, Maine.

[3] The blackleg organism was secured from fungus lesions occurring on seed pieces from 5 different farms in the vicinity of Presque Isle, Maine, in 1927.

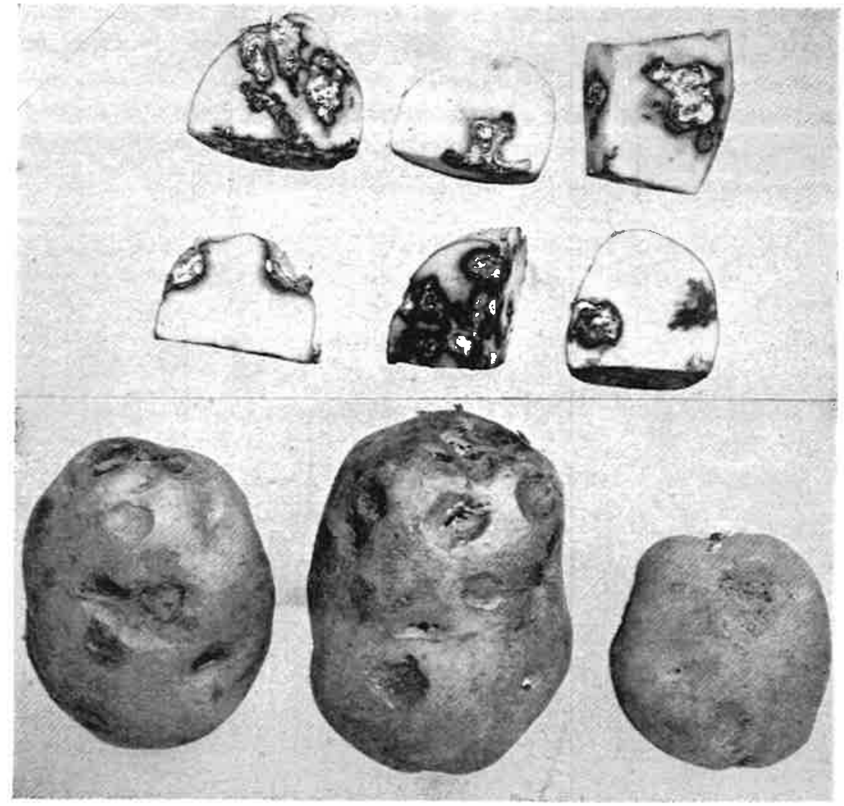

FIGURE 3. Infection by *Phoma tuberosa* on Potato Tubers and Seed Pieces.
The upper seed pieces show the fungus lesions on the cut surfaces. Such infection occurs in the process of cutting the seed pieces. Note the pycnidia on the surface of the fungus mats of the lower right tuber. The pycnospores (fungus spores) also cause infection on the freshly-cut surfaces of the seed pieces.

was rapid and extensive at the higher temperature. The seed pieces stored in the cool basement in contrast became brown and discolored with no active decay. These symptoms were similar to those commonly observed on affected seed pieces occurring in commercial storage when the temperature generally is relatively cool. Figure 4 shows such discolored seed pieces affected with pathogenic bacteria.

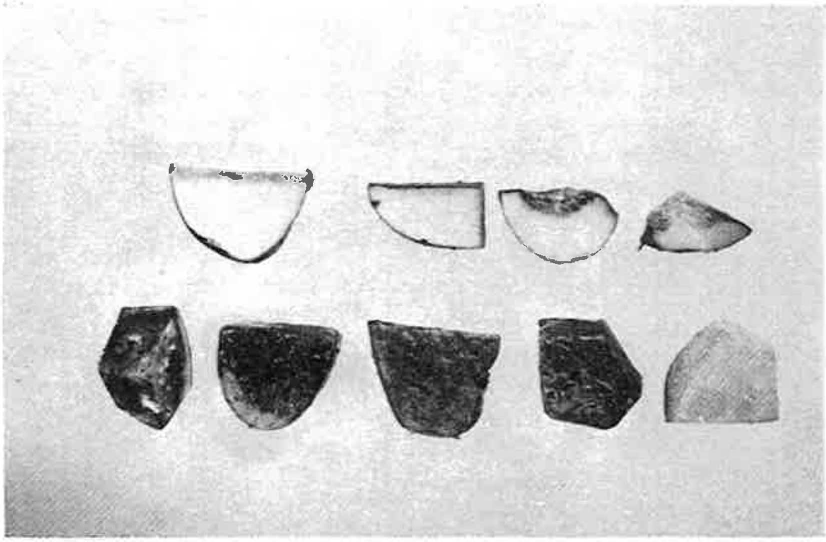

FIGURE 4. Bacterial Decay in Seed Pieces in Commercial Seed Stocks.
Lower: Infected seed pieces as taken from storage showing surface discoloration; except for seed piece in lower right which is healthy.
Upper: Seed pieces cut to show shallow decay.
Such infection resulted when freshly-cut seed pieces came in contact with infected seed tubers or by contamination by the seed cutting knife. The decay was rapid and extensive when the storage conditions were warm and moist. When cool the decay was absent or the seed pieces merely became dark colored with slight decay.

In a similar way the transmission of seed-piece decay by the cutting knife was studied. The knife was used to cut a diseased seed piece just previous to cutting each healthy seed piece. The seed pieces inoculated in this manner were stored at 50 and 69° F. in moist chambers.

Bacterial infection developed rapidly at 69° F. in practically all of the seed pieces inoculated. Those stored at the lower temperature either remained healthy or developed a shallow surface browning, and in no case did extensive decay occur.

Two hundred seed pieces from this knife and seed-piece contact

experiment were planted in the field. Two per cent of the diseased seed pieces gave small foot rotted plants. Such small plants, with black stem bases, have been brought in for identification by farmers, agricultural teachers, and State potato certification inspectors. These people do not generally consider such plants as being "true blackleg," although they really are blackleg. Fifteen per cent of the seed pieces produced typical blackleg which continued to develop until September.

Leach (*12, 14* and *15*) working in Minnesota reported very little blackleg from planting inoculated seed pieces provided they were planted under conditions suitable for the formation of wound periderm.

In another experiment, the bacterial soft rot material was taken from seed pieces affected with *Phoma tuberosa* lesions and introduced with sterilized needles into healthy stems of young potato plants. Thirty plants were inoculated in this manner, 17 of which produced typical blackleg symptoms. Figure 5 shows the blackleg disease produced in a healthy plant by inoculation from soft rot bacteria isolated from seed pieces affected with *Phoma tuberosa*.

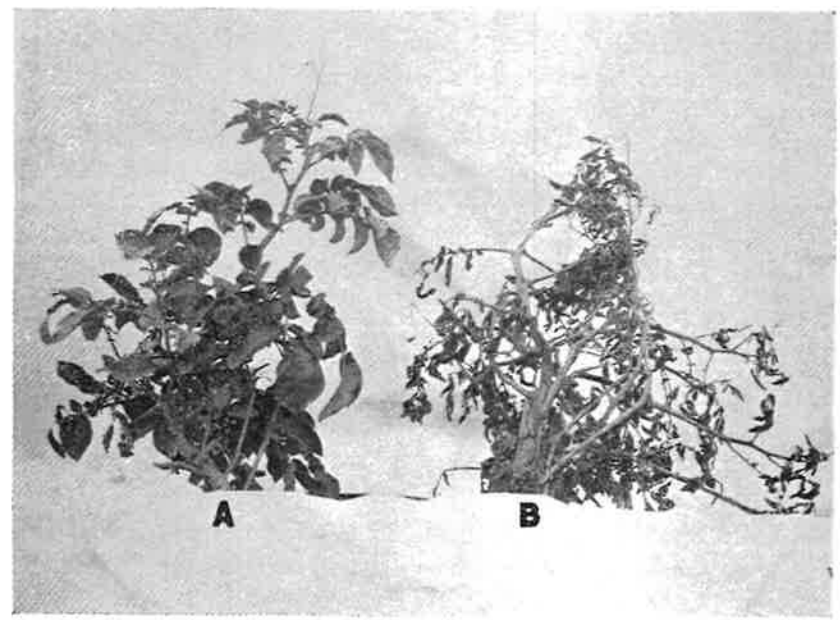

FIGURE 5. Blackleg Produced in a Healthy Plant by Inoculation with Soft Rot Bacteria Isolated from Seed Pieces Affected with *Phoma tuberosa*. A. Healthy uninoculated plant from seed piece from same seed tuber as B. B. Plant with blackleg produced by inoculation.

The seed-piece discoloration and the spotting which were prevalent on Aroostook Farm and in many potato cellars in 1927 and 1928 were bacterial in nature and the infection was readily transmitted by contact of diseased seed pieces and by the cutting knife. Similar spotting and seed piece decay frequently occur during the seasons which are unfavorable for field planting so that it becomes necessary to store the cut seed for long periods under unfavorable conditions. Contact of freshly cut seed with neighboring seed pieces that were diseased probably was one method by which the disease was spread. Infected seed pieces decayed rapidly provided the temperature was high, but merely became brown and discolored when the temperature was low.

Nielsen (*21*) found a relationship between Fusarium seed-piece decay and blackleg. He was of the opinion that the bacteria gain entrance through Fusarium-decay wounds on the cut surfaces with the assistance of the seed-corn maggot larvae or moisture. The studies of Nielsen support the evidence presented here that the blackleg disease often is associated with fungus infection of the cut seed pieces.

LESIONS OF POWDERY SCAB AS AVENUES OF INFECTION

The prevalence of bacterial decay in potato bins made it seem that the pathogen may be quite generally distributed and not necessarily systemically borne in infected tubers, as was commonly believed. The fact that pathogenic bacteria were found associated with *Phoma tuberosa* lesions on cut potato seed pieces, led to studies attempting to locate the source of this infection. *Phoma tuberosa* was often found by Kunkel (*11*) as a secondary organism following infection by the powdery scab organism. During the spring of 1928 the writer made isolations from beneath the lesions caused by *Phoma tuberosa* following the primary infection caused by the powdery scab organism *Spongospora subterranea* (Wallr.) Lagerh. These isolations yielded two types of pathogenic bacteria. One of these was a fluorescent organism capable of causing a relatively slow and yellow decay on potato slices. The other organism caused a rather rapid white decay such as is commonly produced by the soft rot group of bacteria.

In 1928, 1929, and 1930, isolations also were made from powdery scab lesions not affected by secondary fungus invaders. In these studies both the fluorescent and the soft rot bacteria were isolated in pure culture. The data indicate that pathogenic bacteria are quite commonly present as secondary organisms following infection by *Spongospora subterranea.*

Kunkel (*11*, p. 276) states that there is some evidence that certain bacteria and fungi aid in the growth of the powdery scab plasmodium. According to Smith (*29*) and Chupp (*8*, p. 443) Pinoy considered that a true symbiotic relationship exists between certain Myxomycetes and bacteria, and that these bacteria are necessary for the germination of the spores.

Chupp (*8*, p. 445) also reported the presence of rod-shaped bacteria in the club-root galls that were capable of causing a soft rot on cabbage tissue.

Evidently soft rot organisms are quite generally distributed and this fact has a bearing on epidemics of seed-piece decay and blackleg in the potato.

LESIONS OF LATE BLIGHT TUBER ROT AS AVENUES OF INFECTION

Morse (*17*, p. 321 and *20*, p. 89) concluded that the blackleg pathogen was not associated with tuber rot caused by the late blight fungus *Phytophthora infestans.* He apparently attempted unsuccessfully to isolate pathogenic bacteria from newly infected tubers. The writer also had difficulty in obtaining pathogenic bacteria from late blight tubers shortly after they had been affected but made a series of positive isolations from dry rot tubers found in potato bins in the spring after the crop had been in storage. These isolations have yielded bacteria ranging through all degrees of pathogenicity when tested on potato slices.

Seed-piece spotting and decay, and the prevalence of blackleg are more general following years when late blight has been present. This is because the seed cutters spread the fungus and bacterial contamination on their cutting knives. Often they do not discard the diseased tubers which serve as a source of further contamination to the freshly cut seed pieces.

OCCURRENCE OF THE BLACKLEG PATHOGEN IN THE SOIL

Morse (*17* and *20*) expressed the opinion that the seed tubers, already infected at planting time, were responsible for the blackleg disease. The fact that Rosenbaum and Ramsey (*25*) and Ramsey (*23*) concluded that the blackleg organism does not survive in the soil supported the prevalent viewpoint of Morse that infected seed was the chief source of infection. In contrast to this Patel in 1929 (*22*) working in Iowa and Leach in 1930 (*12* and *13*) working in Minnesota were able to demonstrate that the blackleg organism is able to survive in the soil over a comparatively long period of time. In view of the results secured by these workers, an attempt was made to isolate bacterial soft rot organisms from the potato soils both of Aroostook County, Maine, and from the trucking area in the vicinity of Charleston, South Carolina.

Contamination from the soil might explain to some extent the blackleg and seed-piece rot epidemics that sometimes occur.

Pathogenic microorganisms were isolated from the potato soil by the method used by Leach (*12*). Cultures capable of rotting potato slices were isolated from 4 of 10 lots of Aroostook soils obtained in the vicinity of Presque Isle, Maine. The bacterial cultures were for the most part but weakly pathogenic. Several pathogenic cultures of the fluorescent type produced a yellow slow decay. Only one virulent culture of the white rot type was obtained. Single colony isolations were made on agar plates from this culture which were tested further on young potato plants and found capable of rotting potato stems and tubers.

Isolations were made from lots of soil from four different fields in the vicinity of Charleston, South Carolina. No difficulty was experienced in securing bacterial cultures that were pathogenic to the potato from the four soils used in these studies.

The physiological and morphological characteristics of some of the pathogenic cultures isolated from the southern potato soils were determined. These studies revealed that two types of organisms are responsible for much of the seed-piece decay that occurs in the southern soils. One of these organisms is very virulent and causes a white rot on potato slices. It also produced the blackleg disease when inoculated to potato plants.

The other organism that was studied and found to be prevalent in the southern potato soil, causes a rather slow yellow rot on potato seed pieces and apparently does not affect the stem of the plant. This organism does not belong to the soft rot bacteria.

These studies indicate that bacterial organisms of the soft rot group as well as other pathogenic bacteria may survive the winter in the soil of Charleston, South Carolina, and of Aroostook County, Maine. The writer, however, is not convinced that the blackleg epidemics which occur in Maine have their origin from soil contamination. The potato soils of Aroostook County, Maine, were found to have relatively few pathogenic bacteria during the planting season, probably because of the cool climate. Seed pieces frequently are infected in the bin before being planted. In the Charleston, South Carolina, area, on the other hand, much of the seed-piece decay may result from infection originating in the soil which contains great numbers of pathogenic bacteria.

INFLUENCE OF STORAGE OF CUT SEED ON BLACKLEG AND SEED-PIECE DECAY

Much time was devoted to making observations and collecting data on the factors which might influence the prevalence of blackleg and seed-piece decay in Aroostook County, Maine. In 1927, rather careful counts revealed that many fields in the vicinity of the concentrated potato region about Presque Isle, Caribou, and Limestone had from 15 to 50 per cent missing hills. Blackleg was also very general.

One grower had kept an accurate record of his potato operations. He had bought certified seed potatoes from Prince Edward Island which were considered to be free of disease. This seed was cut a few days previous to May 22. Approximately one barrel was planted immediately after being cut and the resulting plants developed no blackleg. Seventeen barrels of this stock were planted within four days after being cut and the plants had from a trace to less than one per cent blackleg for the entire season. Thirty-three barrels of seed cut at the same time were removed to an open shed and were not planted until 10 days after being cut, because of a delay due to rainy weather. This seed emerged very unevenly with approximately 20 per cent missing hills. In June the grower removed three per cent blackleg hills from this part of the field and several weeks later three per cent more of the plants were rogued out because of having the disease. Blackleg continued to develop in this portion of the field until killing frosts occurred.

The information gained from these observations was very valuable because it seemed to throw some light on the problem of potato seed-piece decay and blackleg. The data indicated that the trouble was in some manner associated with the length of time the cut seed had been stored before being planted.

The experiences of this grower led to a rather extensive study of the practices of handling cut seed by the growers of Aroostook County. Data were secured regarding the various factors that appeared to have a bearing on the problem of blackleg and seed-piece decay, such as the source of seed, the seed treatment employed, and the length of time the cut seed remained in storage before being planted. The results of this survey are summarized in Table 2.

Table 2 summarizes the results from 22 different stocks of potato seed planted in 64 different fields under different conditions. The data show that practically no blackleg developed where the seed had been planted immediately after being cut. In 16 fields planted with freshly cut seed only one field developed a trace of blackleg and the percentage of germination was practically perfect in all cases.

Eighteen lots of seed were planted from 1 to 5 days after being cut. The amount of blackleg in these lots varied from none to 4 per cent. In all excepting 2 fields, no more than 1 per cent of the disease appeared. Although more blackleg resulted here than where freshly cut seed was planted, the amount of disease that occurred was not excessive.

TABLE 2

The Effect of Duration of Storage of Cut Seed on the Amount of Blackleg in 1927 for 22 Stocks of Potatoes with Different Seed Treatment

Stock No.	Variety and treatment of each stock	Number of sublots and per cent blackleg by time of storing cut seed			
		0 days	1-5 days	6-15 days	Over 15 days
	Green Mountain				
1	No treatment	—	(1)* 1	—	—
2	Hot formaldehyde	(4) 0	(1) Trace	(3) 2, 3, 18	—
3	Hot corrosive sublimate	(3) 0	(2) 3, 4	(1) 12	—
4	Cold " "	(1) 0	(1) .5	—	(1) 6
5	" " "	—	(1) 1	—	(1) 7
6	" " "	(1) 0	—	(1) 5	(1) 12
7	" " "	(1) 0	—	(1) 5	—
8	" " "	—	(1) Trace	—	(1) 7
	Irish Cobbler				
9	No treatment	(1) Trace	(1) .5	—	—
10	" "	(1) 0	—	—	(1) 4
11	" "	--	(1) 0	—	(1) 4
12	" "	—	(1) .5	—	(1) 11
13	" "	—	—	(1) 12	—
14	Cold corrosive sublimate	—	—	(2) .5, .5	—
15	" " "	—	(1) Trace	(1) 3	—
16	" " "	(1) 0	—	(2) 2, Trace	—
17	" " "	(1) 0	(1) Trace	(1) 7	—
18	" " "	(1) 0	(2) 1, Trace	—	(2) 12, 13
19	" " "	—	(2) .5, 1	(1) 2	(1) 12
20	" " "	—	(2) .1, Trace	(2) 2, 10	(1) 10
21	Semesan	—	—	—	(1) 11
	Spaulding Rose				
22	Cold corrosive sublimate	(1) 0	—	—	(2) 12, 17

* Each number in parentheses is the number of sublots stored for the period indicated.

The important fact revealed by this survey was that the amount of blackleg was increased in those fields where the growers had stored their cut seed for more than six days before planting. Sixteen fields were planted with seed pieces cut from 6 to 15 days before being planted. Seven of these fields showed blackleg in amounts from 5 to 18 per cent. Only 3 fields had less than 1 per cent of this disease.

Blackleg was present in all of the fields where the cut seed had been stored for more than 15 days. As is shown in Table 2 the extent of the disease was quite large in all cases and varied in amount from 4 to 17 per cent.

The results in Table 2 are especially interesting when it is considered that all of the stocks included in the studies had been certified or grown in a seed plot the previous year and were considered to be relatively free from blackleg. The Green Mountain seed stock treated with hot formaldehyde had been on an experimental tuber unit seed plot for several years previously and had never shown a trace of blackleg. Also the Spaulding Rose seed stock had been grown in a tuber unit seed plot under the supervision of the plant pathologists on Aroostook Farm for a period of four years before the occurrence of the epidemic here reported. During this period no blackleg had been noted. It was indeed quite contrary to expectations when both of these stocks developed a high percentage of blackleg when planted under commercial field conditions. It is significant, however, that these stocks remained disease free when the seed was planted immediately after being cut.

The correlation of long-time storage of cut seed with a high percentage of blackleg is not limited to the season of 1927. Every year since 1927 many examples have been found where freshly cut seed potatoes have produced a healthy crop, in contrast to a high percentage of blackleg in similar seed stocks which had been allowed to stand before being planted.

Probably long standing in itself is not the cause of all blackleg epidemics. It is, however, certain that most of the observed epidemics of blackleg during the past 24 years have occurred where the cut seed had stood for some time before being planted. The writer has never observed more than a trace of blackleg in Maine where the seed was planted immediately, or soon, after being cut. Also experimental seed plots planted with freshly cut seed stocks have been free of apparent blackleg for 25 consecutive years.

The effect of factors other than the length of time elapsing between the cutting and the planting operations is shown by an experiment conducted at Presque Isle, Maine, in 1927. Irish Cobbler and Spaulding Rose tubers were selected from disease-free stock grown in a seed plot and stored in different ways before planting. The results of this experiment are given in Table 3. Seven sublots of Irish Cobblers were cut at 10-day intervals from April 1 to June 4 and were all planted on June 4. Each sublot consisted of 4 replications of 125 seed pieces each, or a total of 500 hills. The seed was cut in a heated room and then removed to a cool bin with the other lots included in the experiment. In spite of the fact that the 7 sublots of seed were cut on 7 different dates and stored for periods of time ranging from none to 65 days no blackleg resulted.

An eighth sublot of Irish Cobblers of the same stock was treated in a different manner by a commercial grower. The cut seed was placed in barrels instead of in crates, and was stored at a somewhat higher temperature for 10 or 11 days in an open barn, with some being exposed, in the field for a day. This seed which had been stored in a cut condition for only 11 days developed from 8 to 12 per cent blackleg and had from 20 to 30 per cent vacant hills after planting. The remaining plants were also uneven and unthrifty.

An additional sublot of 30,000 plants of the same Irish Cobbler stock, which was cut and planted by the tuber unit method without being

TABLE 3

The Effect of Time and Condition of Storing Cut Seed on the Percentage of Blackleg

Variety	No. days cut before planting	Storage conditions	Extent of planting	Percentage blackleg
Irish Cobbler	65	Cut in warm room. Placed in crates and taken immediately to cool cellar.	500 plants	None
	55	"	" "	"
	45	"	" "	"
	35	"	" "	"
	25	"	" "	"
	15	"	" "	"
	0	No storage	" "	"
	11	Cut in barrels and stored in barn. Some stood in field one day.	10 acres	8 to 12
	0	No storage. Cut in field and planted by the tuber unit method.	2 acres	None
Spaulding Rose	15	Tubers quartered and put in separate paper bags and stored in cool basement until planted.	1600 plants	None
	0	No storage	8000 plants	"
	14	Cut into barrels, dusted with sulphur and dumped in pile on concrete floor.	10 acres	12
	20	"	22 acres	15

stored, developed no disease. This seed was planted in an adjoining field simultaneously with the previous sublot and all conditions excepting the storage of the seed stock were similar.

The results from Spaulding Rose stock in this experiment are equally interesting. The grower had maintained a rogued seed plot for 4 years previously and his seed stock was rated as being superior and disease free. He selected 400 tubers which were cut into quarters and stored in separate paper bags in a cool cellar. The seed was stored in this manner for 15 days before being planted. Only one diseased stalk was observed for the entire season from 1600 hills. Also, no blackleg disease was found in 8000 additional hills that were planted directly in the field immediately after being cut, by the tuber unit method.

The most striking results occurred with two other sublots of similar Spaulding Rose seed which were cut and stored for 4 days in barrels, then stored in a large pile for 10 and 16 additional days respectively before being planted. These lots of seed developed 12 and 15 per cent blackleg respectively when planted.

This experiment, conducted in a year which was characterized by a great deal of blackleg, demonstrated that conditions of storage as well as the period of time between the cutting and the planting operations may influence the amount of blackleg that occurs. The lots in this experiment

which produced plants with much blackleg and many missing hills were injured from exposure to dry air or by suffocation caused by being stored in the tight barrels. See cover page.

RELATION OF BLACKHEART AND "HEATING" IN STORAGE TO THE OCCURRENCE OF BLACKLEG

The question naturally arises as to the reason why cut seed pieces when kept in storage before being planted may develop a high percentage of blackleg. Experiences of some potato growers indicate that blackleg and seed-piece decay occur only when the cut seed has heated in storage. This opinion is so generally accepted by the growers that the theory seems to be based on evidence. Morse (*20*, p. 90) expressed the opinion that the germs of blackleg are spread by means of the cutting knife and that "heating" of the seed while in storage increased the amount of infection. Regarding this he makes the following statement (*18*, p. 205), "If the cut seed tubers are allowed to 'heat' a little before planting, on account of being barreled up too long, this danger of transference of the disease to healthy seed pieces is greatly increased." He cites (*18*, p. 223-224) a striking example in which the heating of seed caused a high percentage of blackleg. In this particular case several barrels of cut seed were covered and allowed to stand in the field for several days. During this period of time "heating" and some decay occurred. This heating of the seed, according to Morse, caused 20 per cent of the hills to be either missing or attacked by blackleg. Tubers from the same seed stock planted immediately after being cut produced only a trace of blackleg with no missing hills. The writer's observations and experimental data support the conclusions of Morse and show that "heating" of cut seed is closely associated with the presence of blackleg and seed-piece decay.

In 1936 some interesting results were secured that throw some light on the relationship of blackleg to the storage conditions of the seed potatoes. Tubers were dug in 1935 from an experimental seed plot that was free from the disease. Part of these tubers were stored in a cool bin on the Aroostook Experimental Farm and the other part was stored in a farmer's cellar close to his furnace. Both of these lots were cut on the same day and planted by the tuber unit method in the same seed plot. The lot stored in the farmer's bin near the heat from his furnace developed 6 per cent blackleg in contrast to none in the lot stored on Aroostook Farm.

The fact that blackleg has occurred often in seed stock said to have been injured by "heating" in storage led to experiments in which it was attempted to produce a similar condition in the laboratory. Healthy

Irish Cobbler and Green Mountain tubers were selected for this study from stocks considered to be free from blackleg.

Seed pieces from these tubers were cut in the usual manner and subjected to a warm temperature (103° F.) for lengths of time varying from 4 hours to 2 days. Approximately 500 seed pieces were treated in this manner with no blackleg resulting. There was, however, some loss from bacterial decay.

The results were different when whole tubers were treated in a similar manner. Whole tubers from the same seed stock were placed in small cloth sacks and closed containers at a temperature of about 120° F. for 2 days. This treatment resulted in the production of blackheart in some of the tubers.

The tubers were cut and the seed pieces showing blackheart symptoms were planted separately in the field in comparison with those not affected. The results of this test are summarized in Table 4.

TABLE 4

Effect of Blackheart in Seed Tubers on the Incidence of Blackleg

Variety*	Percentage of blackleg resulting**	
	Seed pieces with blackheart	Seed pieces with no blackheart
Irish Cobbler		
Sublot 1	0	0
Sublot 2	30	0
Green Mountain	0	0

* Two lots of Irish Cobblers from the same seed stock were used at different dates.
** Each lot consisted of 100 seed pieces.

It may be noted that blackleg resulted to a high degree in one lot of Irish Cobblers affected with blackheart. The reason the disease did not appear in the other lot of Irish Cobblers is not known, although it is possible that the temperature was somewhat lower and less injury occurred. Blackleg also was not evident in plants from the Green Mountain seed stock. It is significant that the disease was present only in plants from seed pieces that showed blackheart.

EFFECT OF FREEZING INJURY ON THE OCCURRENCE OF BLACKLEG

The effect of freezing the potato seed on the amount of blackleg was observed while in Florida during the planting season of 1938. The major part of a commercial field was planted in the course of one day with a certified seed stock. A four-row strip, however, was left unplanted until the following day. The seed stock for these remaining rows was from the same source but was left unprotected in bags in the field. A heavy frost (22° F.) occurred and the unprotected seed potatoes that had been exposed in the field were injured by freezing.

The frozen seed developed a considerable amount of seed-piece decay, resulted in a 26 per cent reduction in stand, and also developed 8 per cent blackleg. The seed that was not frozen gave nearly a perfect stand and only an occasional plant had blackleg. The fact that the same original seed stock was planted in both cases with the same equipment makes it appear that freezing was a factor in causing the appearance of blackleg.

The effect of freezing on the occurrence of the blackleg disease was tested further in an experiment conducted on Aroostook Farm in 1938. Green Mountain tubers from a healthy seed stock were frozen by artificial refrigeration. Seed pieces from the injured tubers were planted in the field and the amount of the blackleg disease that developed was noted. The results of this test are given in Table 5. It should be observed that much blackleg occurred in one lot of seed potatoes that had been frozen. The other lots on the other hand developed no blackleg.

TABLE 5

The Effect of Freezing Injury on the Amount of Blackleg Occurring in a Disease-Free Green Mountain Seed Stock

Treatment of seed stock	No. seed pieces planted	Per cent blackleg resulting
Tubers frozen artificially		
Sublot 1	39	None
Sublot 2	95	19.0
Unfrozen controls	100	None

Blackleg and seed-piece decay also occur in plants from seed stocks affected with mahogany browning which is an internal tuber necrosis and discoloration resulting in some varieties as a result of prolonged exposure to cold storage conditions. Furthermore, seed tubers taken directly from cold storage to a warm room and cut also may develop a high percentage of seed-piece decay and uneven stands in the field.

These results, although not extensive enough to give conclusive data, do indicate that injury of the seed stock by freezing and by low temperatures in storage may be important factors in the production of the blackleg disease and missing hills in the field.

SEED TREATMENT IN THE CONTROL OF BLACKLEG

Although many field trials have been made to test the various treatment methods for the control of this disease, the results in many cases have not been very convincing. The appearance of blackleg is so sporadic that it has often been difficult to plan definite experiments testing out the efficiency of the different treatments recommended. Clayton (*9*) and Gratz (*10*) were unable to develop blackleg epidemics for their seed treatment experiments in spite of the fact they planted seed selected from diseased plants the previous year. The writer has had similar experiences in attempting to create blackleg epidemics by planting seed from diseased tubers.

Tucker (*30, 31*) and Tucker and Harber (*32*) studied the efficiency of the seed treatment methods in controlling blackleg, and Tucker states: "No reflection on seed treatment is intended, for apart from blackleg, it may have considerable value in controlling or reducing other diseases; but rather my aim is to point out that treatments as practiced at present on a large number of farms reduce but do not control blackleg to the extent that appears to be generally expected."

It will be noted in the data summarized in Table 2 that blackleg occurred in many instances in spite of seed treatment and that the occurrence of this depended to a large extent on the length of time the cut

TABLE 6

The Amount of Blackleg Associated with the Use of Different Seed Treatment Methods Applied to Seed Stock Harvested from Diseased Hills in 1929

Kind of seed stock*	Method of treatment	No. seed pieces	Per cent blackleg
Bulk not examined for vascular discoloration	Formaldehyde	76	2.5
"	"	52	5.7
"	" . Planted immediately after being cut	58	0
"	Organic mercury dip	48	0
"	None	67	4.4
"	Mercuric chloride 1½ hour soak	100	3.0
Tubers showing vascular discoloration	Formaldehyde	63	0
"	" . Treated different date than above	371	2.8
"	Organic mercury dip. Planted immediately after being cut	62	0
"	Organic mercury dip	32	3.1
Tubers showing no vascular discoloration	Formaldehyde	569	1.7
"	Organic mercury dip	450	0.6
"	Mercuric chloride 1½ hour soak	400	2.0
"	None	371	3.5

* Hills showing blackleg were harvested by hand in 1928. The following spring part of the tubers were sorted into two lots—tubers that showed vascular discoloration and tubers that appeared to be free from this discoloration.

seed was allowed to stand before being planted. In some cases listed in Table 2 it appears that seed treatment reduced the amount of blackleg to a considerable extent, as with Irish Cobbler stock No. 14 where the treated seed produced less than one per cent blackleg and that which was not treated (Stock 13) yielded 12 per cent disease. However, for stocks No. 1 and No. 3, the reverse is true. Observations made for other years in Aroostook County, Maine, have indicated that losses due to blackleg occur whether the seed tubers have been disinfected or not. In the majority of cases where the writer has observed serious losses from blackleg, the seed had been treated before being planted.

In 1929, seed pieces from tubers harvested the previous year from diseased hills were treated with several of the most commonly recommended disinfectants. The results of these tests are shown in Table 6.

Blackleg in all cases occurred in relatively small amounts, although the seed was from diseased hills the previous season. The data indicate that seed treatment did not reduce the amount of the disease appreciably. The highest percentage of diseased hills, where 5.7 per cent blackleg was found, was treated with formaldehyde. However, in the other groups also treated with formaldehyde, no blackleg was found. The

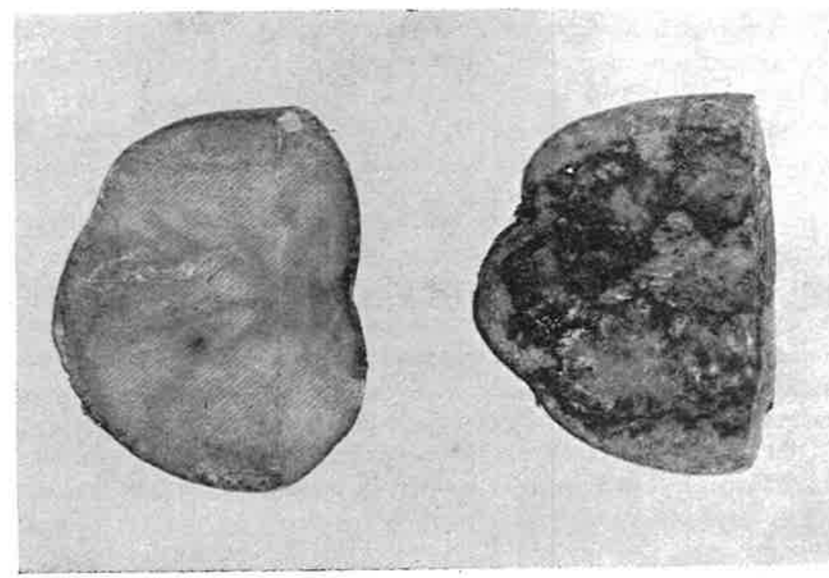

FIGURE 6. Contrast in the Amount of Bacterial Infection on Seed Pieces from Treated and Untreated Tubers.

The bacterial infection resulted from contamination by contact with tubers that had decayed in storage. This spotting on the cut surface of the seed piece shown at the right was caused by the soft-rot bacteria.

other data for the treatments included in this experiment are so variable that it is difficult to draw any definite conclusions. There are, however, some seasons in which the practice of seed treatment greatly reduces the losses due to seed-piece decay occurring in the field, as was shown by studies conducted in Maine by Schultz *et al.* (*27* and *28*).

Studies by the writer show that seed treatment may greatly reduce the amount of spotting that results from contamination by the cutting knife and from bacteria and fungi borne on the surface of the tubers. This is especially true if the contaminating material is bacterial soft rot. Figure 6 shows the contrast, in the amount of surface infection that occurred, between treated and untreated seed that had become contaminated with pathogenic bacteria in storage. Other tests have shown, however, that seed pieces spotted with the blackleg organism may produce a relatively small amount of blackleg (seldom more than 3 per cent in field tests). However, if this seed stock becomes injured by some environmental factor such as heating or excessive drying, the percentage of the disease that results will be greatly increased.

ROGUING OF INFECTED PLANTS IN THE CONTROL OF BLACKLEG

Roguing the seed plot of diseased hills is a generally recommended practice for growers of certified seed potatoes. However, observations in Maine indicate that neither seed treatment nor roguing is very effective in controlling blackleg in some seasons. Blackleg has occurred in epidemic proportions in seed stock harvested from tuber-unit and disease-free seed plots that had been treated.

In Table 2 stocks 2, 3, 7, 10, 16, and 20 had been grown in a rogued seed plot the previous season. All of the other lots were from seed stocks that had passed certification the previous year. In all these lots, although grown from seed that had been rogued, a considerable amount of blackleg occurred when the cut seed was allowed to stand. These experiments as well as many field observations indicate that this disease has not been controlled or eliminated by rigid roguing practices even when accompanied by recommended methods of seed treatment.

The practice of roguing and the growing of seed stock in carefully rogued seed plots, however, is valuable in the control of other diseases and may under some conditions help to reduce the amount of blackleg.

INSECTS IN THE DISSEMINATION OF BLACKLEG AND SEED-PIECE DECAY

Certain insects are commonly associated with blackleg and seed-piece decay in Maine (*2, 6,* and *7*). Some of these insects are merely scavengers and feed on the decayed vegetable matter. Among the insects belonging to this group are the common housefly *Musca domestica,* the false cranefly *Trichocera* sp., a fungus gnat *Sciara tribentala,* and two fruit flies *Drosophila funebris* and *D. bruschii.* The larder beetle *Dermestis lardarius* is commonly associated with decayed potato material and in a few cases the larvae have been seen penetrating healthy potato tissue. The wireworm *Cryptohypnus abbreviatus* often attacks healthy potato seed pieces but this injury does not appear to be responsible for decay. None of the above insects appear to be factors in the dissemination of blackleg and the decay of seed pieces.

A certain Staphylinid insect appeared capable of causing the destruction of potato seed pieces. The larvae of this insect are very active and burrow deeply and beyond the decayed areas, thereby hastening the destruction of the seed pieces.

The seed-corn maggot *Hylemyia cilicrura* Rond. and the potato maggot *H. (Phorbia) trichodactyla* Rond. were found to be commonly associated with decayed seed pieces and blackleg disease. Figure *7* depicts the different stages in the life cycle of the seed-corn maggot. Blackleg was produced by inoculation with the larvae of these insects under controlled laboratory conditions. The soft rot organism, as well as other pathogenic bacteria, were isolated from the adult insect, the puparia, and the surface of the eggs of the seed-corn maggot. Certain soil bacteria appear to be essential for the development of the larvae to the adult stage. It is of significance that the soft rot organism was reisolated from the pupae of the seed-corn maggot that had been reared in the laboratory and overwintered in soil in the field exposed to the rigorously cold climate of northern Maine.

Although these insects may aid in producing this disease, they do not normally attack potato seed pieces that are healthy and free from decay. They generally enter through lesions that are present on the cut surfaces of the potato seed pieces. In South Carolina these primary lesions commonly occur in abundance when freshly cut seed pieces are planted in moist warm soil. (See Figure 8.) The seed-corn maggots may be attracted to these lesions and enter in great numbers and by their burrowing and the introduction of pathogenic bacteria destroy the seed pieces. An active decay does not take place in the infested seed pieces unless the moisture of the soil content is relatively high. In South Carolina seed-piece spotting from soil contamination and the accompanying injury caused by the seed-corn maggot can be prevented by allowing the seed pieces to suberize before they are planted (*6* and *24*).

In Aroostook County the conditions are somewhat different. In this region both the seed-corn maggot and the potato maggot attack

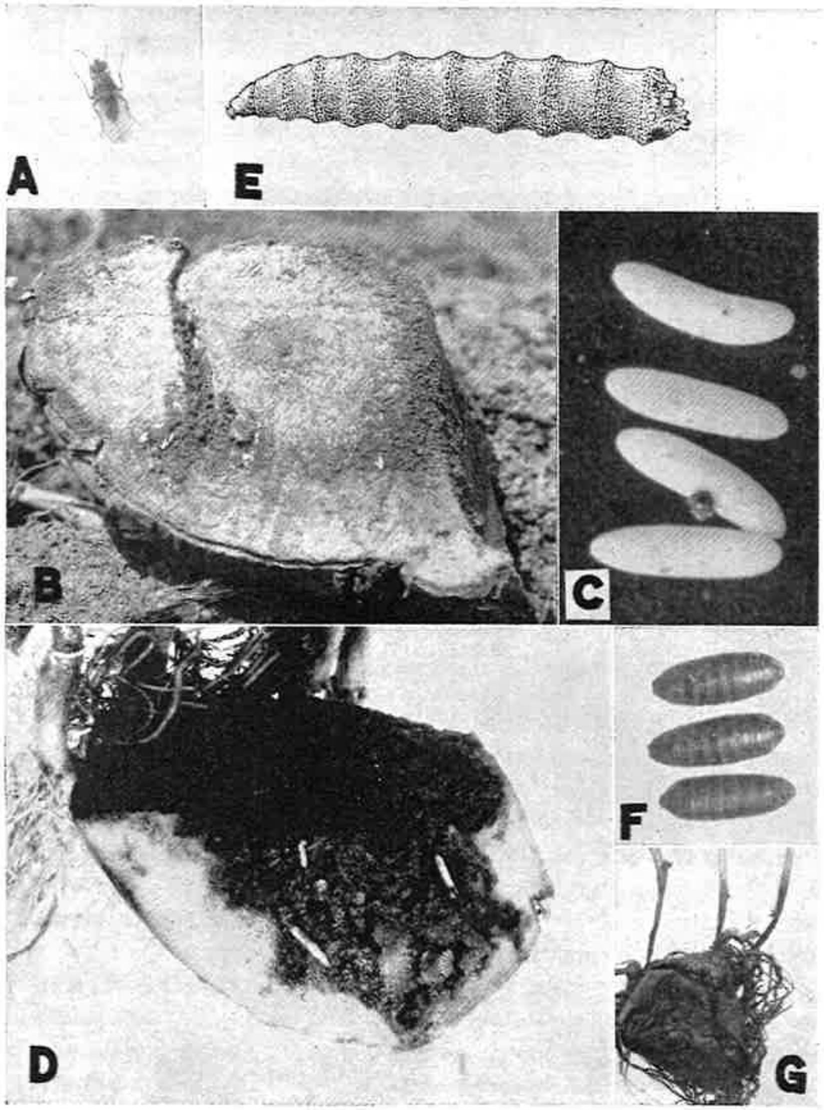

FIGURE 7. Stages of the Life Cycle of the Seed-corn Maggot (*Hylemyia cilicrura* Rond.)

A. Adult female fly, approximately 1½X.
B. Eggs of the seed-corn maggot deposited on the surface of a seed piece planted in the soil.
C. Four eggs, approximately 50X.
D. Seed piece showing 3 maggots and type of injury caused by their feeding.
E. Larva greatly enlarged.
F. Three puparia, approximately 3X.
G. Blackleg plant resulting from seed piece infested with maggots in the laboratory.

A, B, C, and F were made available through the courtesy of Dr. J. G. Leach

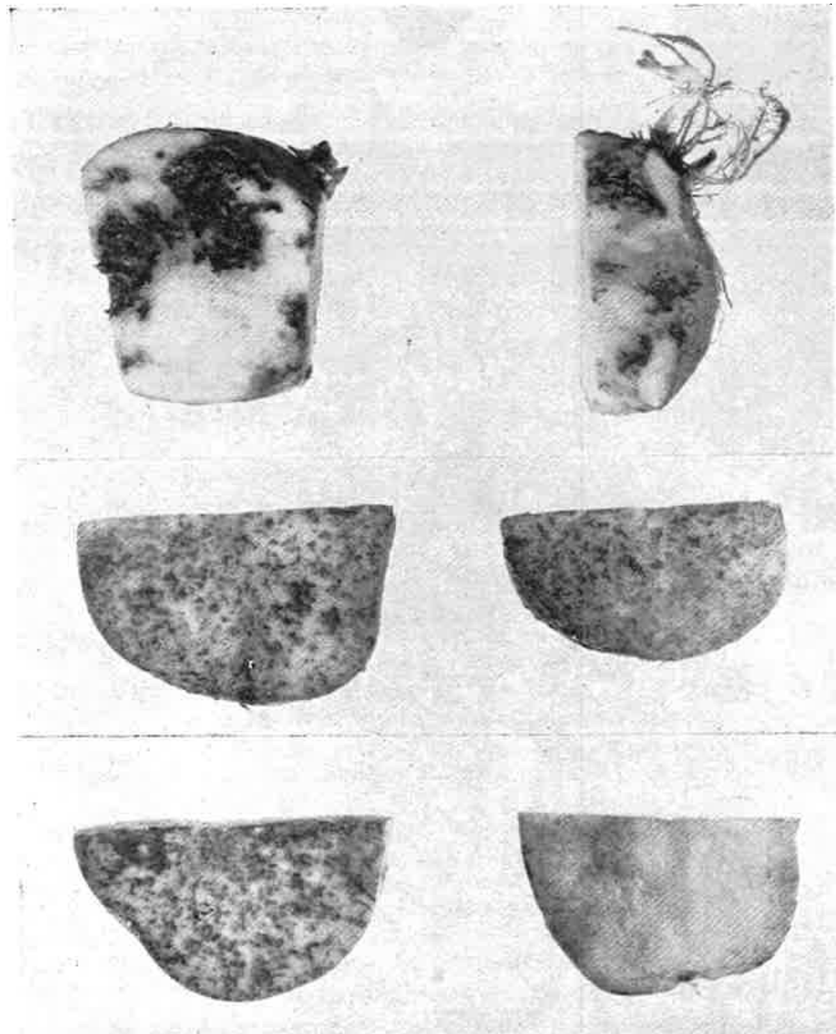

FIGURE 8. Upper: Injury by the Seed Corn Maggot on Unsuberized Seed Pieces Planted in Soil from South Carolina Containing Pathogenic Bacteria.

Lower and Middle: Primary Bacterial Lesions on Freshly-cut Seed Pieces Planted in Non-sterilized Soil.

The young seed corn—or potato maggots enter through such lesions and may destroy the seed pieces. Healthy seed piece on lower right was suberized and was not attacked by soil bacteria and the maggots.

potatoes. They generally enter the seed pieces through lesions that have been formed in the bin prior to being planted and not from soil contamination as in South Carolina. In Aroostook County, freshly cut potato seed may be safely planted without danger of injury by maggots provided they are free of bacterial and fungus lesions.

LITERATURE CITED

(1) Bonde, Reiner. Comparative studies of the bacteria associated with potato blackleg and seed-piece decay. Phytopath. 29:831-851. 1939.

(2) Bonde, Reiner. Some conditions determining potato-seed-piece decay and blackleg induced by maggots. (Abstract) Phytopath. 20:128. 1930.

(3) Bonde, Reiner. Summary report of progress, 1932. Maine Agr. Exp. Sta. Bul. 363, p. 279. 1932.

(4) Bonde, Reiner. Summary report of progress, 1934. Maine Agr. Exp. Sta. Bul. 377, p. 358-360. 1934.

(5) Bonde, Reiner. Summary report of progress, 1935. Maine Agr. Exp. Sta. Bul. 380, p. 169-170. 1935.

(6) Bonde, Reiner. The role of insects in the dissemination of potato blackleg and seed-piece decay. Jour. Agr. Res. 59:889-918. 1940.

(7) Bonde, Reiner. The transmission of potato blackleg by the seed-corn maggot in Maine. Phytopath. 18:459. 1928.

(8) Chupp, Charles. Studies on clubroot of cruciferous plants. Cornell Agr. Exp. Sta. Bul. 387. 1917.

(9) Clayton, E. E. Potato seed treatment experiments on Long Island with special reference to the organic mercury instant dips. N. Y. State Agr. Sta. Bul. 564. 1929.

(10) Gratz, L. O. Disease and climate as pertaining to the Florida and Maine potato sections. Phytopath. 20:267-288. 1930.

(11) Kunkel, L. O. A contribution to the life history of *Spongospora subterranea*. Jour. Agr. Res. 4:265-278. 1915.

(12) Leach, J. G. Potato blackleg: The survival of the pathogen in the soil and some factors influencing infection. Phytopath. 20:215-228. 1930.

(13) Leach, J. G. Survival of the potato-black-leg pathogen in the soil and some factors influencing infection. (Abstract.) Phytopath. 20:127. 1930.

(14) Leach, J. G. The nature of seed-piece transmission of potato blackleg. Phytopath. 17:155-160. 1927.

(15) Leach, J. G. The relation of the seed-corn maggot (*Phorbia fusciceps* Zett.) to the spread and development of potato blackleg in Minnesota. Phytopath. 16:149-176. 1926.

(16) Melhus, I. E., J. Rosenbaum, and E. S. Schultz. *Spongospora subterranea* and *Phoma tuberosa* on the Irish potato. Jour. Agr. Res. 7:213-253. 1916.

(17) Morse, W. J. Blackleg. A bacterial disease of the stem and tuber of the Irish potato. Maine Agr. Exp. Sta. Bul. 174. 1909.

(18) Morse, W. J. Control of the blackleg or blackstem disease of the potato. Maine Agr. Exp. Sta. Bul. 194. 1911.

(19) Morse, W. J. Potato diseases in 1907. Maine Agr. Exp. Sta. Bul. 149. 1907.

(20) Morse, W. J. Studies upon the blackleg disease of the potato with special reference to the relationship of the causal organisms. Jour. Agr. Res. 8:79-126. 1917.

(21) Nielsen, L. W. Fusarium seedpiece decay of potatoes in Idaho and its relation to blackleg. Idaho Agr. Exp. Sta. Res. Bul. 15. 1949.

(22) Patel, M. K. Viability of certain plant pathogenes in soils. Phytopath. 19:295-300. 1929.

(23) Ramsey, Glen Blaine. Studies on the viability of the potato blackleg organism. Pathopath. 9:285-288. 1919.

(24) Reid, W. J., Jr., W. M. Peacock, and R. C. Wright. Seed-corn maggot injury avoided by suberizing potato seed pieces before planting. U.S.D.A. Agr. Yearbook pp. 331-333. 1932.

(25) Rosenbaum, J., and G. B. Ramsey. Influence of temperature and precipitation on the blackleg of potato. Jour. Agr. Res. 13:507-515. 1918.

(26) Schultz, E. S., Reiner Bonde, and W. P. Raleigh. Isolated tuber-unit seed plots for the control of potato virus diseases and blackleg in northern Maine. Maine Agr. Exp. Sta. Bul. 370. 1934.

(27) Schultz, E. S., L. O. Gratz, and Reiner Bonde. Effect of seed-potato treatment on yield and rhizoctonia in northeastern Maine from 1925 to 1928. Phytopath. 20:47-64.

(28) Schultz, E. S., L. O. Gratz, and Reiner Bonde. Seed potato treatments for rhizoctonia conducted in northeastern Maine from 1925 to 1928. Potato Assoc. of Amer. Proc. 15:102-111. 1928.

(29) Smith, Erwin F. Bacteria in relation to plant diseases. Bacteria with myxomycetes. Carnegie Institution of Washington. 1911.

(30) Tucker, John. The effect of seed treatment on blackleg. Potato Assoc. Amer. Proc. 15th Ann. Meeting New York, 1928. pp. 71-73. 1929.

(31) Tucker, John. The effect of seed treatment on blackleg. Seed treatment reduces, but does not control blackleg. Dominion Canada Dept. Agr. Report. Report of the Dominion Botanist for 1928, pp. 204-206. 1929.

(32) Tucker, John, and E. W. Harber. Seed treatment for potato blackleg. Scientific Agriculture 14:(2) 70-72. 1923.