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Fusarium Seedpiece Decay of Potatoes In Idaho and Its Relation to Blackleg

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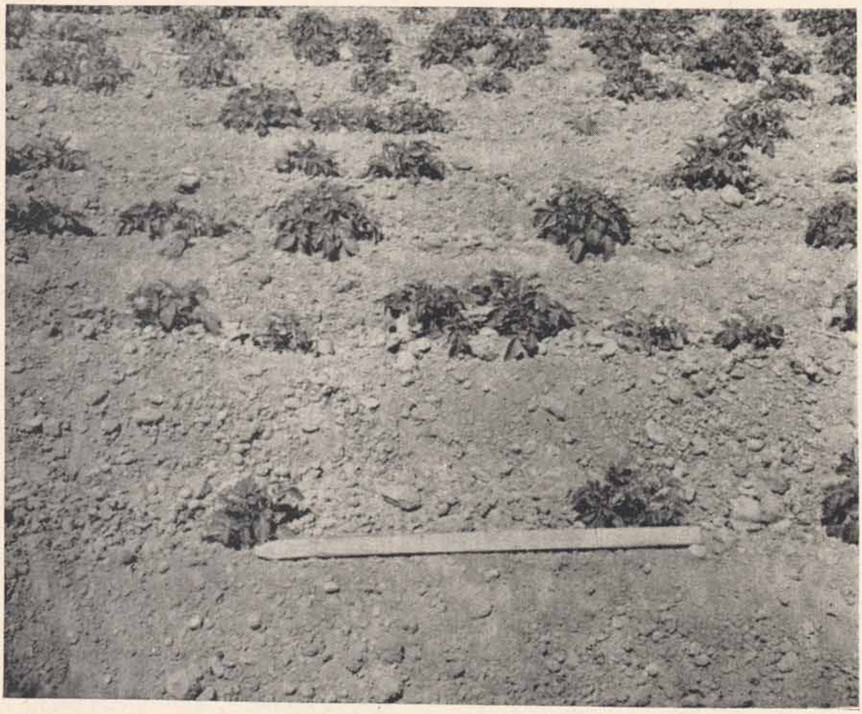

Rows of Russet Burbank potatoes having missing hills and weak plants caused by Fusarium seedpiece decay.

FUSARIUM SEEDPIECE DECAY OF POTATOES IN IDAHO AND ITS RELATION TO BLACKLEG

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Seedpiece decay of potatoes is not a new problem in Idaho potato production. A decay caused by *Fusarium trichothecioides* Wollenw. was described by Pratt in 1916 (17)[2]. Kraus and Woodbury (9) studied various methods of handling seedpieces to reduce decay after planting. They found that less decay occurred when freshly cut seedpieces were planted immediately in soils sufficiently moist to assure germination. More recently, it has become apparent that seedpieces so handled frequently decay with resulting poor stands and reduced yields. This pointed to a need for additional work to determine the cause of seedpiece decay and more satisfactory methods of controlling it.

During the growing seasons of 1945, 1946, and 1947, an attempt was made to determine the organism or organisms responsible for seedpiece decay. As a result of these investigations several pathogenic organisms were isolated from decaying seedpieces.

A soft rot producing bacterium was frequently associated with *F. solani* as a secondary pathogen. *Fusarium roseum* (Lk.) was isolated from about 5 percent of the diseased seedpieces and often from seedpieces also infected with *F. Solani*. The organism from another seedpiece decay was not successfully isolated. It is suspected that a pathogen was responsible for this decay as inoculation tests in the laboratory using diseased tissue as inoculum caused a decay of healthy tubers. Under field conditions this decay progressed rapidly and destroyed many seedpieces before sprouts had emerged from the soil. The affected seedpiece had a sour odor when cut open, and affected tissue was gray and watery in appearance yet semi-firm when squeezed. Diseased tissue turned pink in color when exposed to the air. This suggested that the disease might be pink rot caused by *Phytophthora erythroseptica* Pethyb.. This seedpiece decay was observed only once.

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[2] Figures in parentheses refer to literature cited.

[3] The writer is indebted to Dr. O. A. Reinking, New York Agricultural Experiment Station, Geneva, New York, and Dr. W. C. Snyder, University of California, Berkeley, California for identifying the Fusaria species. According to the Wollenweber and Reinking classification (25) the organisms are designated *Fusarium coeruleum* (Lib.) Sacc. and *Fusarium sambucinum* Fuckel *f.* 6 Wr. The classification followed in this paper is that proposed by Snyder and Hansen (21, 22) in which these organisms are classified *Fusarium solani* (Mart.) App. et Wr. (21) and *Fusarium roseum* (Lk.) (22) respectively.

Owing to the greater predominance of seedpiece decay caused by *F. solani* alone and in conjunction with the soft rot bacterium, this report is devoted primarily to the decay caused by these pathogens and their effect on the growth of the plants, yield of tubers, incidence of blackleg, and their control by seedpiece treatment.

Review of Literature Pertaining to Fusarium Seedpiece Decay

Pratt (17) first reported on a seedpiece decay in Idaho. He found that seedstock affected with *Fusarium trichothecioides* produced poor stands of potatoes. Plants from affected seedpieces emerged slowly and were weak during their early period of growth. Pratt (16) also reported on a seedpiece decay caused by *Fusarium radicicola* Wollenw. This pathogen passed from the affected seedpieces into the growing plant and the new crop of tubers. The round, white-skinned varieties—Charles Downing and Pearl—were susceptible while Russet Burbank was not seriously affected. Schmidt (20) found *F. coeruleum* capable of destroying seedpieces under field conditions and that the decay may cause the death of young sprouts before or after emergence. In other cases, stems develop normally while the seedpiece decayed later with no apparent effect on the plant or new tubers. In 1940, Eddins (7) described a seedpiece decay that occurred in Florida, and attributed it to *Fusarium oxysporum* Schlect. On the basis of cultural characteristics of the pathogen, symptoms, and plant development, this disease was quite similar to that caused by *F. solani* in Idaho. Cunningham and Reinking (6) report that *F. coeruleum* and *F. sambucinum f.* 6 were the major causes of seedpiece decay on Long Island, New York. In some years one of the organisms was isolated more frequently than the other; in other years the reverse was true. In many cases seedpiece decay caused by these organisms greatly reduced stands, necessitating replanting or abandoning the crop. They found that inoculum was carried by soil adhering to seed potatoes and containers.

It is generally recognized that *F. solani* is an important storage rot pathogen of potatoes (23, 24, 25) and gains entrance through wounds. *F. roseum* (*F. sambucinum f.* 6 *or F. sulphureum*) is likewise a wound pathogen of stored potatoes (24, 25). These species have been isolated from potatoes stored under Idaho conditions (2, 5).

Materials and Methods

The Russet Burbank variety of potatoes was used for most of the experiments reported. In general the seedstock was produced at the Aberdeen Experiment Station from certified seed and rarely had over 2 to 4 percent of the tubers affected with virus diseases, and from a trace to 15 to 20 percent affected with *Verticillium albo atrum* R. and B. In those experiments on the distribution of the causal organisms, tubers from certified and commercial table stocks were used.

For most experiments seedpieces averaged between 1½ and 2 ounces in size. They were cut and handled according to the practices prevailing in the commercial potato producing areas. They were planted with manually assisted-feed planters to a depth of 2½ to 3 inches below the surface of the seedbed and at 12-inch spacings in the row. The subsequent cultivation and irrigation practices used were those generally employed in commercial table stock production.

In a number of experiments, the seedpieces were inoculated with Fusarium spores by momentarily immersing the tubers or seedpieces in a spore suspension. The spore suspensions were prepared from 10 to 14 day old cultures grown on potato-dextrose agar. Spores from three to five isolates were added to a single suspension. The number of spores per volume of suspension was not determined, but it was assumed to be large.

Two experimental plot designs were used for the field studies. If the number of treatments in any experiment was small (4 to 8), they were frequently arranged in a Latin square design. For experiments having a large number of treatments, four replications of the randomized block were usually used. The plot size for experiments conducted in 1945 and 1946 was 3x45 feet, and for 1947, 3x40 feet.

All data from plot experiments were analyzed by the analysis of variance and appropriate tests of significance computed. Correlation coefficients (r) were calculated for paired data.

Symptoms

The most apparent symptoms of seedpiece decay are those locally described as dry or wet pitting (Figure 1). These symptoms are generally noticed in seedpieces stored a week or longer after cutting. The dry type pit is inconspicuous in its early stage of development and frequently the lesion can be demonstrated only by cutting through it and observing the underlying light brown rot. If the humidity of the storage cellar is around 60 percent, or lower, the pits remain inconspicuous for two or three weeks but finally become sunken and form pockets on the cut surface. Under humid conditions a white cottony growth of the casual organism develops over the cut surface.

The wet or black type of pitting develops when high humidity prevails at the time or soon after cutting and is evident much sooner than the dry type. In this case bacteria are growing in conjunction with the *Fusarium spp.* at the foci of infection, and seem to follow very closely the ingress of the *Fusarium spp.* Isolations made from such pits when first detected gave a mixture of organisms in culture, usually bacteria and one of the *Fusarium spp.* If the isolations were made two or three weeks after the pits first appeared and the humidity had lowered, the *Fusarium spp.* could be isolated predominantly from the advancing margin of decay.

A transverse section through the cut surfaces of diseased seedpieces 2 to 3 weeks after cutting reveals a light brown to brown, semi-firm, dry rot progressing into the seedpiece. The rot destroys 1½ to 2-ounce seedpieces in 4 to 6 weeks of common storage temperatures—50° to 60° F.

Diseased seedpieces taken from the soil 2 to 4 weeks after planting have essentially the same internal symptoms. Fungal growth on cut surfaces may or may not be present. Many of the Fusarium-affected seedpieces taken from the soil have a watery bacterial soft rot in addition to the Fusarium rot. It appears that the soft rot bacterium gains entrance through Fusarium decay wounds. The bacterial decay progresses rapidly and completes the destruction of the seedpiece. The soft rot bacterium also enters

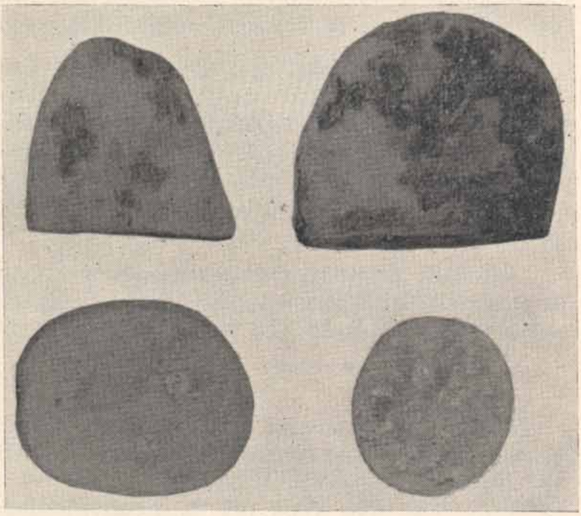

Figure 1. — Diseased seedpieces showing dry and wet pitting. Upper pieces have dry-type pitting, while the lower pieces have the wet-type.

seedpieces through lenticels (Figure 2). Seedpieces affected with soft rot alone or in conjunction with a *Fusarium spp.* are destroyed more rapidly than those affected only with a *Fusarium spp.*

Seedpiece decay causes a reduction in stand and an increase in weak or small plants (Figure 3). Diseased seedpieces generally produce fewer sprouts. When plants are about 4 to 6 inches high, those from decaying seedpieces are faintly chlorotic in contrast to the vigorous plants growing from healthy seedpieces. As the season progresses, the chlorotic symptom disappears and there is no evidence of the disease except for missing hills and the presence of small plants.

Isolation Studies

Diseased seedpieces both from storage and dug from the soil at various periods of time after planting were used for isolation purposes. Those collected from the field were placed in paper bags, and wrapped in moist burlap sacks until delivered to the laboratory for isolation. They were thoroughly washed, immersed in 1:1000 bichloride of mercury solution for 10 to 15 minutes,

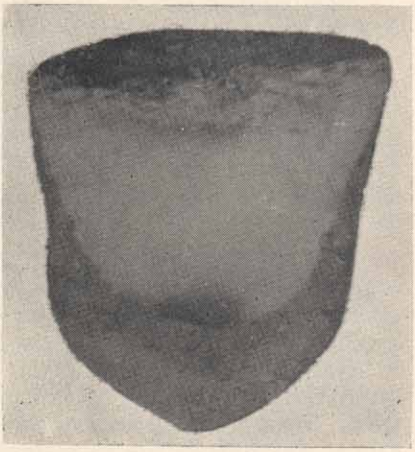

Figure 2.—Seedpieces dug from the soil 4 weeks after planting. Fusarium decay developed at the cut surface, and bacterial soft rot, initiated at a lenticel, is evident at the bottom of the fresh cut.

and two samples of rotting tissue from each seedpiece were aseptically removed from the advancing margin of decay and planted on potato-dextrose agar. The results of isolations made from seedpieces during the three-year period are summarized in Table 1.

Table 1. — Relative frequency of isolating certain *Fusarium Spp.* from decaying seedpieces taken from storage or dug from the soil after planting.

	Seedpieces from storage				Seedpieces from field			
Year	Number Seedpieces	Fusarium *solani*	Fusarium *roseum*	Other *Fus.* spp.	Number Seedpieces	Fusarium *solani*	Fusarium *roseum*	Other *Fus.* spp.
1945	7	7	0	0	69	67	0	1
1946	132	128	6*	0	246	151	19**	0
1947	....	....	....	....	26	3	0	0
Percentage		97.1	4.3			64.8	5.6	

* Four of these isolated from seedpieces also affected with *F. solani*.
**Six of these isolated from seedpieces also affected with *F. solani*.

Fusarium solani was the dominant organism isolated from seedpieces, whether collected from storage or the field. It grew from a large percentage of seedpieces taken from storage; whereas, it was isolated from a smaller proportion of seedpieces dug from the soil. This lower percentage of recovery from planted seedpieces was due, in part, to invasion of the diseased seedpieces by secondary organisms. This is particularly apparent for those seedpieces studied in 1947. These seedpieces were collected July 30 and 31 and numerous other fungi and bacteria were isolated from the 26 seedpieces. The three cultures of *F. solani* were the only fungi capable of causing decay when inoculated into healthy potatoes. *F. roseum* was isolated from a relatively small number of diseased seedpieces, and it was often isolated from seedpieces also affected with *F. solani*. Bacteria were frequently isolated from seedpieces taken from the soil. The number of bacteria isolated from any sample generally increased with the length of time the seedpieces had been planted.

The pathogenicity of the organisms isolated was tested by inoculating healthy surface disinfected tubers. Twenty-five isolates of *F. solani* were tested and all of them produced the light brown rot in 17 days at temperatures varying from 56° to 62° F. and all were re-isolated. The pathogenicity of *F. roseum* was likewise demonstrated. Of 12 bacterial isolates inoculated into healthy tubers, seven were pathogenic and produced a soft, light brown rot. The rot was similar in appearance to that produced by bacteria isolated from decaying tubers from plants having blackleg.

The source of *F. solani* inoculum that causes the widespread seedpiece infection in Idaho is of interest. This organism is reported to be carried in soil adhering to seedstock or to dirty containers (6) and it has been isolated from potato soils 2 years after a potato crop was grown (8). It has also been found causing an important storage rot in all potato sections of Idaho (1). Isolations were made from stored seed and table stock to see if *F. solani* was one of the prevalent rot-producing organisms. Rotting tubers were collected from three storage cellars in the vicinity of Aberdeen and a record kept of the type of injury through which the rot had developed. Decaying tubers were also taken from bags of certified seed produced and stored in the Lost river section and from bins of several seed storage cellars in the vicinity of Ashton. A summary of these isolations is presented in Table 2.

Table 2.—Organisms isolated from rotting tubers taken from storage between March 6 and May 27, 1946.

			No. tubers from which stated organisms isolated				
Source of rotting tubers	Number of tubers	Inoculation court	*Fusarium solani*	*Fusarium roseum*	Other *Fusaria*	Other fungi	Bacteria
Certified seed tubers stored in seed areas	45		26	3	0	0	12
Table stock tubers,	164	Digger cuts	124	5	5	7	8
stored in farm and	58	Frost damage	12	0	0	3	32
commercial cellars	39	Bruises	25	5	4	4	0
	26	Stem-end	7	0	0	2	6
	53	Broken off knobs*	42	5	0	0	4
	21	Unknown	1	0	0	1	12
Total	406		237	18	9	17	74**
Percentage of tubers affected			58.4	4.4	2.2	4.2	18.2

* Broken off knobs, wound resulting from breaking a secondary tuber (knob) from the primary tuber.
** Of 44 isolates inoculated into healthy tubers, 11 caused soft rot.

F. solani was most frequently isolated from decaying seed and table stock tubers. Wounds of mechanical origin were most important as infection courts. This was also true for *F. roseum* and the data are in agreement with those previously reported that these two organisms are wound pathogens.

Tufts of fungal growth on the surface of rotting tubers can easily be found in storage cellars during late winter and early spring. These tufts of mycelial growth are frequently Fusarium sporodochia bearing conidia. During the sorting operations, these conidia are undoubtedly broken free and scattered by air currents or contact to the surfaces of healthy seedstock and equipment. So long as the epidermal layers of the sound tuber are not broken, the organisms seem incapable of causing infection, but the numerous wounds created by seedpiece cutting are inadvertently inoculated. From these studies and observations it is evident that inoculum is produced in storage cellars.

Effect of Fusarium Seedpiece Decay on the Crop

Fusarium seedpiece decay may obviously reduce stand and plant vigor and less noticeably the number of stems per hill, the quality and yield of the crop. To study the effect of Fusarium seedpiece decay on early plant growth, young plants and their seedpieces were carefully dug from the soil 41 to 60 days after planting. Seedpieces were removed from the plants and the amount of Fusarium rot determined by weighing each seedpiece before and after cutting away the decay. Plants produced by each seedpiece were also weighed. The data were then arranged according to seedpiece size, i.e., 1 to 1½ ounces, 1½ to 2 ounces, and 2 to 3 ounces. In 1946 the seedpieces were weighed before planting and the amount of rot later determined as indicated above. These studies were conducted during each of the 3 years under discussion. The correlation coefficient was calculated for each seedpiece size and the data are presented in Table 3.

For the 3-year period a significant negative correlation was found to exist between the amount of Fusarium decay in seedpieces and the size of plants produced. The correlations noted in Table 3 are based upon the effect of Fusarium decay alone.

Table 3.—Correlation between extent of Fusarium decay and size of young plants produced by individual seedpieces.

Year	Days after planting	Seedpiece weight group					
		1 to 1½ oz.		1½ to 2 oz.		2 to 3 oz.	
		r	r*	r	r*	r	r*
1945	41	−.658	.404	−.628	.413	−.624	.444
1946	60	−.371	.325	−.468	.361	−.785	.374
1947	42	**		**		−.584	.423

* r at 5 percent level of significance
** sample too small

Similar studies were made relative to the height of plants in early July and their yielding capacity when harvested. In the year 1945, hills from a field badly infected with Fusarium seedpiece decay were used for this study. Twenty-five hills in the following height groups were staked at random July 9, i.e., 1 to 3 inches, 4 to 6 inches, and 8 to 10 inches. At harvest time, the following data were recorded: Stems per hill, weight of tubers per hill, and whether the plants grew from a cut or uncut tuber.

It was found that plants small or weak in early July have reduced yielding capacity. Hills with small plants also have fewer stems per hill. Cut seedpieces predominantly produced medium to small plants. All large plants developed from uncut tubers. The negative correlation between plant size and seedpiece decay suggest that the small plants in this test were largely caused by Fusarium seedpiece decay. Small plants are also produced by small seedpieces. To clarify this point, additional data were taken in 1946. In this case, seedpieces weighing 1½ to 2 ounces and carrying natural inoculum were planted May 7. Only 3-stem hills were used for the study and on July 9 the maximum height of all plants was measured. After harvest, plant height was correlated with the yield of potatoes. The correlation coefficient (r) was .705 with .418 required for significance at the 1 percent level. Comparable plants and seedpieces dug from the same planting on July 9 were affected with Fusarium decay, and a significant negative correlation was found to exist between plant size and seedpiece decay (Table 3).

These preliminary data were substantiated by experiments conducted in 1946 and 1947. In these experiments, freshly cut seedpieces from healthy seed stock were compared with seedpieces variously affected with *F. solani.* A description of the condition of the seedpieces is presented in Table 4. Those seedpieces cut from

Table 4.—The effect of planting seedpieces naturally or artificially infected with *F. Solani* on growth and yield of the crop.

Treatment No.	Condition of seedpieces	Seedpieces producing plants: No. per plot 1946*	No. per plot 1947	No. Weak Hills 1946*	No. Weak Hills 1947	Stems per seedpiece 1946*	Total yield sacks Acre*** 1946*	Total yield sacks Acre*** 1947
1	Seedpieces from healthy tubers	42.7	37.13**	10.0	6.37**	3.46	268.5	207.8**
2	Seedpieces from healthy portions of tubers naturally or artificially infected with *F. solani*	40.2		17.0		3.18	241.2	
3	Each seedpiece with small amount of rot. Cut from tubers naturally or artificially infected with *F. solani*	37.4		28.5		3.31	218.9	
4	Seedpieces cut from healthy tubers but pitted from natural inoculum in storage	40.0	30.5	18.2	20.5	3.04	252.8	165.4
	L. S. D. 5 percent	2.4	2.3	4.2	4.5	.30	23.8	38.3

* Data for 1946 are a summary of three planting dates.
** Seedpieces from healthy tubers dipped one minute in Semesan Bel solution; 1947 plots 40 feet long, others 45 feet.
*** One sack of potatoes equals 100 pounds.

naturally affected tubers (Treatment 3) were larger than usual, as it was necessary to select many large diseased tubers in order to get enough seed stock for the experiment. Some of these seedpieces were well over 2 ounces in weight.

Fusarium seedpiece decay reduced the stand, the number of stems per hill, the total yield, and increased the number of small plants. Those seedpieces from the healthy portion of tubers

Figure 3.—Effect of Fusarium seedpiece decay on plant vigor. Upper view, three hills of plants having large differences in vigor. Lower view, the same plants showing extent of Fusarium decay in respective seedpieces. Fusarium decay largely destroyed seedpieces on small plants.

naturally or artificially affected with *F. solani* (Treatment 2) are of particular interest. It is believed that all of the Fusarium rot was removed from these tubers before cutting seedpieces. The data suggest that the rot had adversely affected the remaining healthy tissue. From these data, it is evident that Fusarium seedpiece decay not only reduces stand but also plant vigor and subsequent yield. Vigorous plants are as essential as a good stand of plants for maximum yield.

Kraus has shown that stands of Russet Burbank potatoes having one- or two-stemmed hills produce many knobby tubers (10). In the course of these studies plots with poor stands and few stemmed hills caused by Fusarium seedpiece decay produced more knobby tubers than multiple-stemmed, uniform hills from healthy seedpieces. Seedpiece decay is probably responsible for some of the knobby potatoes produced each year in Idaho.

Fusarium Seedpiece Decay and Blackleg

The inter-relationship between seedpiece decay caused by *F. solani* and blackleg was suggested by Blodgett (2). Other reports suggest this relationship. It has been pointed out that Fusarium seedpiece decay is a firm, somewhat slow rot, unless secondary decay organisms enter the seedpiece causing it to become soft and mushy (6, 7).

Cool, wet soils are conducive to the development of blackleg (11, 19). Early work indicated that the blackleg bacterium was seed borne and did not survive from year to year in the soil (15). More recently, evidence was presented minimizing seed stock as the important means of transmitting the pathogen and emphasizing the importance of its survival in potato soils (12). Larvae of the seedcorn maggot (*Hylemyia cilicrura* Rond.) and a related species (*H. trichodactyla* Rond.) have been demonstrated as being capable of inoculating seedpieces with the blackleg pathogen in their feeding processes (3, 11). Lesions caused by bacterial and fungal infections or fertilizer on the cut surfaces of seedpieces attract the insects (4, 18).

Much blackleg frequently develops soon after the potato plants emerge in crops affected with Fusarium seedpiece decay. Blackleg may destroy all of the stems or only one in a single hill, and the stems may be destroyed before emergence. In other cases, blackleg is not evident until the plants are 8 to 10 inches high. Most blackleg generally has developed by July 31.

Fusarium decay and blackleg were found to be more serious when cut seedpieces were planted. At the Aberdeen station the Idaho Crop Improvement Association each year plants a sample of certified seed from every Idaho certified grower's crop. Observations of disease content is the Association's objective in making these plantings. Small, uncut tubers are planted in these plots. When an occasional tuber is too large to pass through the planter, a seedpiece is cut from it and planted without treatment. During the plot inspections of 1946, 104 blackleg affected hills were dug to see if the set was a cut tuber affected with Fusarium decay. Of the sets, 98 were seedpieces affected with Fusarium decay and bacterial soft rot; six sets had only bacterial soft rot. Five of this latter group were small uncut tubers.

A number of experiments were performed that show an increase of blackleg in plants growing from seedpieces affected with *F. solani*. In these experiments seedpieces variously affected with Fusarium decay were used. Blackleg readings were usually taken from the last of June to the last week of July. In 1946 and 1947, the plots were examined at 7- or 10-day intervals and hills with blackleg were staked. A description of the seedpieces used in the experiments and the incidence of blackleg are presented in Table 5.

Table 5.—Incidence of blackleg in plants grown from seedpieces variously affected with Fusarium seedpiece decay. Summary of experiments conducted from 1945 to 1947, inclusive. Plots 40 (1947) and 45 feet long.

Condition of seedpieces at time of planting	Average number of blackleg plants		
	1945	1946*	1947
Seedpieces from healthy tubers	1.2	0.9	0.1**
Seedpieces from healthy portions of tubers naturally or artificially infected with *F. solani*		2.7	
Each seedpiece with small amount of rot. Cut from tubers naturally or artificially infected with *F. solani*	7.9	2.8	
Seedpieces cut from healthy tubers but pitted from natural inoculum in storage		0.9	9.1
L. S. D. 5 percent	1.7	1.2	3.1

* Combined data from three planting dates.
** Seedpieces dipped in Semesan Bel.

Blackleg was more prevalent in plants grown from seedpieces affected with Fusarium decay. Seedpieces from the healthy portion of diseased tubers produced plants having more blackleg than similar seedpieces from healthy tubers. The great difference in the amount of blackleg found in plants developing from pitted sets in 1946 and 1947, suggests that the planting and early growing season influences the incidence of blackleg. The effect of environmental factors upon seedpiece decay and the incidence of blackleg is discussed in a later section.

Data on the relationship of blackleg to seedpiece decay caused by *F. solani* is preliminary and fragmentary, but the following pathological processes apparently develop (Figure 4). The blackleg bacterium, as well as other organisms, gain entrance to seedpieces through Fusarium decay wounds on the cut surfaces. The blackleg bacterium decays seedpieces more rapidly than *F. solani* and, after it has gained entrance, completes rotting of the seedpiece and passes into the stem to cause blackleg. Under Idaho conditions, this bacterium also gains entrance into seedpieces independently of Fusarium decay, and this type of infection apparent-

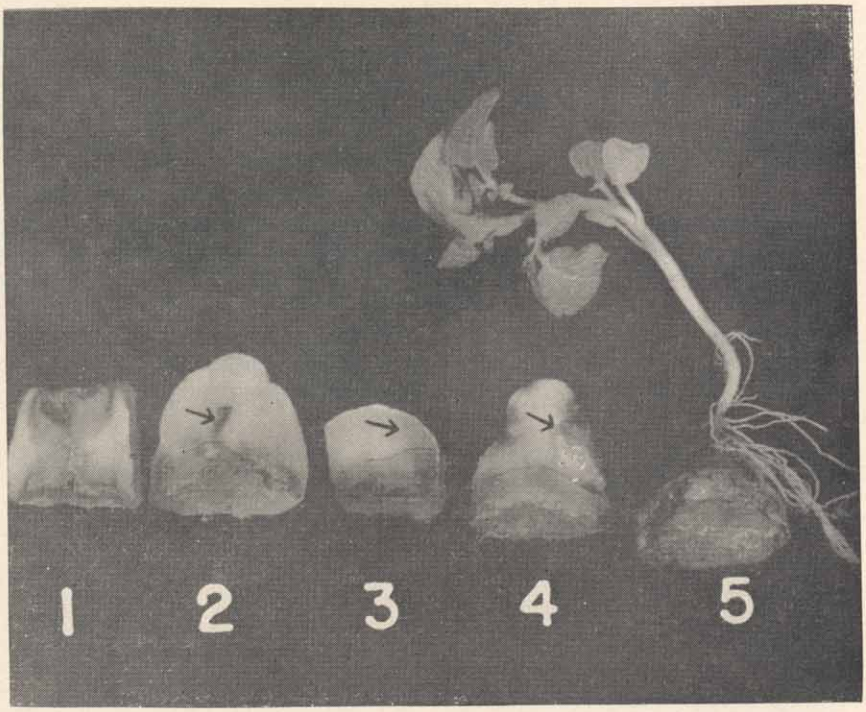

Figure 4.—Diseased seedpieces selected to illustrate secondary infection by soft rot or the blackleg bacteria through lesions caused by Fusarium solani. Number 1 is affected at the two cut surfaces with Fusarium decay; 2 to 5 show progressive stages of secondary infection by soft rot bacteria. Black thread was placed on seedpieces 2, 3 and 4 to delimit Fusarium decay. Arrows on these pieces point to regions affected with bacterial soft rot. Number 5 is completely decayed and the young plant has blackleg. The firm Fusarium decay is evident on the cut surface.

ly takes place through lenticels. Blackleg attributable to lenticel infection has occurred less frequently than infections through Fusarium wounds.

Relation of Seed-Corn Maggot to Blackleg

It has been shown by Leach (11) and Bonde (3) that the seed-corn maggot is a vector of the blackleg pathogen and that larvae are attracted by lesions on seedpieces (4, 18). In 1945 the planting and early growing seasons were relatively cold with frequent showers. Decaying seedpieces were frequently infested with larvae of the seed-corn maggot[4]. In numerous cases soft rot was also developing with the Fusarium rot; and it was suspected that the larvae feeding upon the Fusarium decay were acting as vectors of the bacterium. The planting and early growing season of 1946 was dry and relatively warm in contrast to 1945, and few larvae were found associated with the affected seedpieces. This situation

[4] The writer is indebted to Dr. H. C. Manis, Department of Entomology, University of Idaho, for identifying the larvae.

again occurred in 1947. Failure to find the larvae plentiful in 1946 led to a close examination of diseased seedpieces for the larvae or evidence of their feeding tunnels. In most cases there was no evidence that the seed-corn maggot had fed upon seedpieces that were affected with the *Fusarium spp.* and soft rot bacterium. Failure to find them as numerous in 1946 and 1947 as in 1945 was possibly due to differences in ecological factors. The insect is most serious in cold, wet seasons, and, of the three years, 1945 most closely approached this situation. During 1945 it was not unusual to find as many as 4 to 6 larvae in a single seedpiece. Owing to these observations, it was concluded that under Idaho conditions larvae of the seed-corn maggot are not essential for inoculating Fusarium affected seedpieces with the blackleg bacterium.

Varietal Susceptibility to Fusarium Seedpiece Decay and Blackleg

Schmidt (20) reported a varietal difference in susceptibility to *F. solani.* Weiss, et al (24), also reported varietal differences in susceptibility but attributed this to the relative efficiency of the six varieties studied to produce suberin. In the present investigations, the relative susceptibility of 14 varieties of potatoes was studied in two experiments. In the first experiment, four replications of 25 seedpieces from each variety were inoculated by immersing them in a spore suspension prepared from three cultures of *F. solani.* Each replication of 25 seedpieces was then placed in a new paper bag and the top closed with paper clips. The seedpieces were inoculated February 7, 1947, and immediately placed in a storage cellar for incubation and rot development. The temperature in the storage cellar varied from 34° to 47° F. and the relative humidity from 30 to 59 percent. Under these conditions, the suberization processes would be greatly retarded and the degree of infection may be a measure of varietal resistance. On April 10 and 11, each seedpiece was cut in half at right angles to the cut surface and the maximum penetration of rot measured in millimeters. The average penetration of each lot of 25 seedpieces was calculated and the data are summarized in the first column of Table 6.

In a second experiment performed under field conditions, the same varieties were employed. In this case, four replications of 40 seedpieces were inoculated and planted, April 28, 1947. As the growing season progressed data relative to stands, small plants, blackleg and total yield were recorded. These data are also summarized in Table 6.

The several varieties of potatoes responded differently to the ingress of *F. solani* and the differences between some varieties are significant. It is believed that the data indicate the relative susceptibility of these varieties to *F. solani.* Weiss, et al (24), found that at a temperature of 10° C. 10 or more days were required for tubers of six varieties to produce sufficient suberization

Table 6.—Susceptibility of potato varieties to Fusarium seedpiece decay and subsequent blackleg.

Variety	Extent of seed-piece penetration by *F.solani* -mm.*	Seedpieces inoculated and planted				
		Stand 6-26	Stand 9-16	Weak plants** 6-28	Total yield lb./plot	Hills with blackleg
Pawnee	7.17	35.5	35.5	3.0	43.9	1.3
Bliss Triumph	4.85	35.3	29.5	11.5	10.9	15.3
White Rose	3.27	36.5	35.3	3.5	40.1	4.0
Pontiac	7.20	34.5	31.3	11.7	58.3	10.8
Charles Downing	1.57	35.3	33.7	5.6	27.1	9.5
Menominee	3.75	35.3	34.5	4.3	72.3	6.0
Mesaba	6.07	35.3	34.0	5.3	36.9	4.0
U. S. D. A. Seedling 47105	5.42	26.5	17.7	11.5	30.1	14.5
Earlaine	9.20	35.5	32.0	16.5	19.8	6.3
Russet Burbank	7.97	37.5	37.0	10.0	46.4	6.0
Sebago	7.87	28.7	24.5	13.5	47.1	15.0
Kasota	4.42	36.7	35.7	7.8	42.8	11.0
Teton	8.50	31.0	26.0	16.3	32.4	13.5
Lewellyn	4.32	30.5	28.3	13.3	14.9	17.8
L. S. D. 5 percent	1.34	3.3	3.5	4.1	8.6	3.8

* These data are based on a separate experiment with inoculated seedpieces held in storage.

** Determined by comparing relative plant size in each plot.

to stop infection by *F. solani*. Lower temperatures were used in this experiment and inoculation was made immediately after cutting. Since *F. solani* is capable of growing at the temperatures found in cold storage, it is believed that suberization had little to do with the penetration recorded.

There are significant differences in all categories studied for the plants produced by inoculated seedpieces. An inspection of the data shows that these differences are not always associated with varietal susceptibility to Fusarium decay as measured by penetration of the seedpieces. The incidence of blackleg appears to be more closely related to the growth response categories than does Fusarium decay. To test whether the growth responses measured were more closely related to Fusarium susceptibility than the incidence of blackleg, Table 7 is presented which gives the

Table 7.—Correlation existing between blackleg and Fusarium seedpiece decay and the growth responses presented in Table 6.

	Growth Response				
	Stand		Small Plants	Black-leg	Total yield —lb.
	6-28	9-16			
Diseases	r	r	r	r	r
Fusarium seedpiece decay	— .086	—.148	.502	—.058	.036
Blackleg	— .476	—.568	.585	—	—.363
r: 5 percent	.273				

correlation existing between the two diseases and the several growth responses. Susceptibility to *F. solani* as measured by penetration is significantly correlated only with the number of small plants. Blackleg is significantly correlated with all categories. It should be pointed out that Fusarium penetration was not correlated with blackleg and this may cast some doubt on the interpretation of preceding data. The data in preceding sections are based upon studies with the Russet Burbank variety. In this experiment, the susceptibility of several varieties to blackleg is superimposed upon varietal responses to *F. solani*.

Some of the varieties were also planted in a variety experiment in a different field. In this case, the same size and number of plots were used except that the seedpieces were dipped in Semesan Bel. A consideration of the data derived from the several varieties in which seedpieces were treated to control Fusarium decay aids in interpreting data from inoculated seedpieces. Only stand and yield data were recorded for the variety plots, and these are compared with the same data of the six varieties grown from inoculated seedpieces (Table 8).

In this comparison, it must be emphasized that the effect of seed treatment is confounded with location, and it is impossible to separate the relative importance of the two factors. On the

Table 8.—A comparison of stands and total yields of plants produced by seedpieces inoculated with *F. Solani* and similar seedpieces treated with Semesan Bel. Data for six of the varieties presented in Table 6. Plots 40 feet long.

Variety	Stand			Total yield per plot—lb.		
	Inoculated	Treated	Difference	Inoculated	Treated	Difference
Pawnee	35.5	34.2	− 1.3	43.9	85.9	42.0
Menominee	34.5	35.0	0.5	72.3	86.1	13.8
Russet Burbank	37.0	38.2	1.2	46.4	81.2	34.8
Earlaine	32.0	30.2	− 1.8	19.8	64.2	44.4
Sebago	24.5	31.0	7.5	47.1	69.2	22.1
Lewellyn	28.3	38.5	10.2	14.9	90.6	75.7
L. S. D. 5 percent	3.60	3.73		11.75	8.72	

basis of data to follow, it is believed that the effect of Fusarium seedpiece decay was largely eliminated by seed treatment.

The yields for plants from treated seedpieces were larger than for plants from untreated seedpieces. The amount of increase varied considerably with the several varieties. A consideration of the varieties Menominee, Russet Burbank, and Earlaine is of interest. These varieties had about six hills per plot with blackleg (Table 6), suggesting that this disease affected them equally. The inoculated seedpieces produced as many hills of plants as those treated. The increase in yield following seedpiece treatment appears to be correlated with the susceptibility of these varieties to Fusarium seedpiece decay. Menominee is least susceptible, and its increase in yield is smallest. Earlaine is most susceptible, and its increase in yield from treating seedpieces is greatest. Russet Burbank is intermediate in both categories. The Lewellyn variety shifted from the lowest to the highest yielding sort. These data suggest that the location for planting the treated seedpieces does not account for all the increase in yield and that Fusarium seedpiece decay was controlled.

The increase in stand for the varieties Sebago and Lewellyn is large. Of the six varieties, these two have a large proportion of plants with blackleg (Table 6). Blackleg is correlated with a reduction in stand (Table 7). The increase in stand from treated seedpieces suggests that the severity of blackleg is reduced. This circumstantial evidence indicates that the relative importance of blackleg as shown in Table 7 is conditioned by initial *F. solani* infection that predisposed the seedpieces to infection by the blackleg pathogen.

The interactions, variety x treatment, for both stand and yield were significant. The interaction for yield was strikingly so, and much of the variability was due to the response of the Lewellyn variety. Keeping in mind the confounded nature of the data, the control measures so far developed for the Russet Burbank variety may not apply when used for other varieties.

The Effect of Moisture and Temperature on Seedpiece Decay

No carefully controlled tests were performed on the effect of soil moisture and temperature on the decay caused by *F. solani* alone or in conjunction with the soft rot bacterium. However, some data were recorded showing the effect of these factors. The station storage cellar is equipped with three experimental chambers in which the temperature can be controlled. These chambers and the open storage cellar were used for making preliminary studies on the effect of soil temperature and moisture on the development of Fusarium seedpiece decay. Large boxes measuring 12 by 12 inches by 5 feet long were filled with moist-to-dry field soil. The moisture content of this soil was barely adequate for the production of young plants. Two boxes of soil were placed in each of the chambers and the open cellar. In one box at each location fifty seedpieces carrying natural inoculum were planted. In the other box 75 seedpieces were planted. The second box was irrigated until the soil was definitely wet and verging on puddling. These plantings were made August 20, 1945. At 2- to 7-day intervals the soil temperature at the seedpiece level was measured with mercury thermometers. All seedpieces were dug for examination on September 10 and 11. The number of infected seedpieces was determined, and the depth of the penetration of the seedpieces by decay was measured (millimeters). A summary of these data is presented in Table 9.

Table 9.—The effect of soil moisture and temperature on Fusarium infection and penetration of seedpieces carrying natural inoculum. Seedpieces examined 21 days after planting.

Storage Chamber	Temp.—°F.	Percent of seedpiece infected		Extent of seedpiece penetration by Fusarium decay —mm.*
		Wet soil	Moist Dry soil	
1	36.8-37.4	57.3	22.0	1.8
2	42.8-50.0	30.7	90.2	3.0
3	53.6-59.0	52.0	84.0	5.9
Open cellar	54.8-63.1	46.7	90.0	6.5

* Depth of penetration so similar in both soil moistures at each temperature range that data were averaged together.

Except for the lowest temperature, a greater percentage of infection occurred in the drier soil. The moisture content of wet soils may reduce infection by beneficially influencing the healing processes or altering antagonistic biological activity at the cut seedpiece surfaces. The rate of decay penetration increased with temperature over the range studied. At the lowest temperature, the measurements are only approximate, as the decay in many cases had entered only a short distance. Isolations made from diseased seedpieces held at all temperatures and the two moisture levels showed that *F. solani* was the cause of the decay.

Additional data showing the effect of soil moisture were taken under field conditions. Here again soil moisture levels are only relative. In this case, data were recorded from a field plowed from alfalfa in 1947 and planted with seedpieces carrying natural inoculum. The alfalfa was irrigated before plowing, but at one end four areas were not irrigated. This was not detected until the land was plowed. As the plants emerged and started growing, those in the dry areas were suffering from drought in contrast to plants growing only a short distance away in soil that was irrigated prior to plowing. Five replications of 20 to 22 hills were dug from both the dry and the moist soils on July 7, 47 days after planting. The following data were recorded relative to the condition of seedpieces: Fusarium decay only, Fusarium decay plus soft rot, soft rot only, and healthy. (Table 10).

Table 10.—The effect of relative soil moisture under field conditions on Fusarium, Fusarium-soft rot, and soft rot seedpiece decay of Russet Burbank potatoes.

Relative soil moisture	Average number of seedpieces with decay due to:				
	Fusarium total	Fusarium alone	Fusarium plus soft rot	Soft rot alone	Sound
Dry	18.6	9.8	8.8	0.4	1.8
Moist	16.6	3.0	14.0	1.2	2.4
L. S. D. 5 percent	2.0	2.3	0.3	N.S.	N.S.

These data show the importance of soil moisture in the development of the Fusarium-soft rot type of decay. It is this type of decay that later develops into blackleg. Dry soil had more sets affected with only Fusarium rot and fewer seedpieces with the Fusarium-soft rot decay. There was no difference in the number of seedpieces affected with soft rot at the two moisture levels. However, the trend is in favor of the moist soil. If more replications, or larger samples, had been studied this difference might have been significant. There were fewer seedpieces in the moist soil affected with *F. solani* and the difference is barely significant, but does support the data recorded above. The greater amount of Fusarium infection found in dry soils may partially explain the ill effects of planting in such soils as reported by Kraus and Woodbury (9).

A number of experiments studying the effect of planting date on seedpiece decay points to the importance of ecological factors on the severity of the diseases. Only one experiment will be presented to illustrate this relationship. The categories, average stand and hills with blackleg will be given for an experiment performed in 1946 and previously mentioned (Tables 4 and 5). In this presentation, a summary of the individual planting dates is given in addition to the interaction, condition of seedpieces x planting dates (Table 11).

The average stand and number of hills with blackleg were quite different for the three planting dates when using the same type of seedpieces. The condition of the seedpiece significantly affected these two categories, as did the date of planting. The interaction, condition of seedpieces x planting dates, was also significant. The data clearly indicate that ecological factors at the time of planting or soon after influence the severity of seedpiece decay. For 1946, soil temperature was possibly the important factor (Figure 5). At

Table 11.—Earliness of planting as related to stand and hills having blackleg. Seedpieces variously affected with *Fusarium Solani* planted in plots 45 feet long.

Condition of seedpieces	Average number of hills with blackleg in plantings made:			Average stand from plantings made		
	May 7	May 17	June 5	May 7	May 17	June 5
Seedpieces from healthy tubers	1.00	1.00	0.75	43.5	45.0	39.7
Seedpieces from healthy portions of tubers naturally or artificially infected with *F. solani*.	1.75	5.75	0.50	42.0	37.3	41.5
Each seedpiece with small amount of rot. Cut from tubers naturally or artificially infected with *F. solani*.	4.00	4.50	0.00	38.5	31.0	42.7
Seedpieces cut from healthy tubers but pitted from natural inoculum in storage	0.25	2.50	0.00	40.0	39.5	40.5
L. S. D. 5 percent	2.16	N.S.	N.S.	3.01	4.6	N.S.

Date of Planting	Ave. No. Hills with blackleg	Ave. Stand
May 7	1.75	41.0
May 17	3.43	38.2
June 5	0.31	41.1
L. S. D. 5 percent	1.27	2.0
Interaction:		
Condition of seedpiece x planting date	5 per cent	1 percent

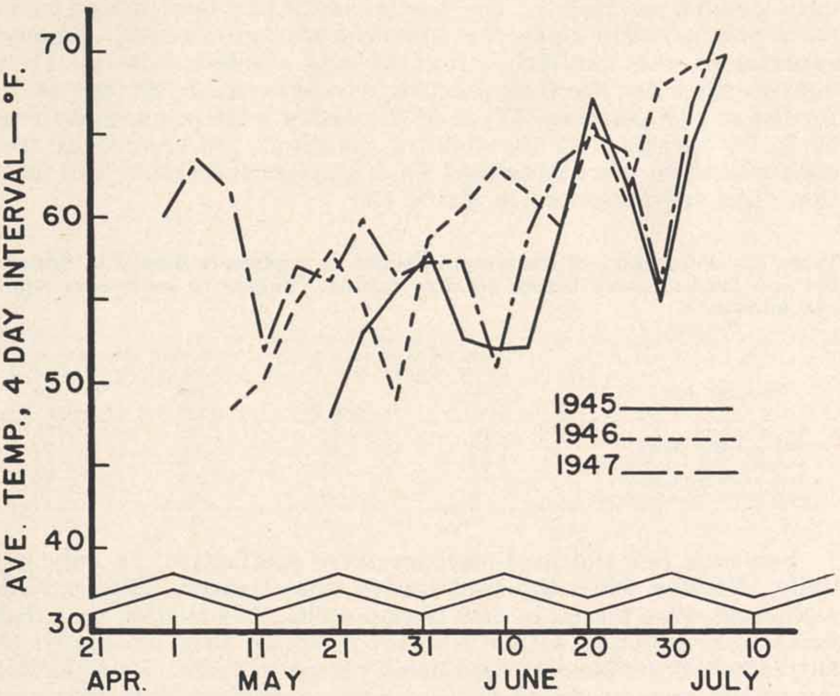

Figure 5.—Mean daily temperature for the planting and early growth seasons of 1945, 1946, and 1947 at the Aberdeen Experiment Station. Temperature data based on 4-day intervals.

the Aberdeen station a cold period shortly after mid-May was the only apparent adverse climatic factor of the 1946 planting season. Under favorable growing conditions as existed after June 5, 1946, Fusarium decay had no deleterious effect on the crop.

Studies on Control of Fusarium Seedpiece Decay and Blackleg by Seedpiece Treatment

Losses from seedpiece decay and storage rots caused by *F. solani* have been reduced by chemical treatments (8, 18). Various fungicidal dipping baths have been satisfactory in New York for treating seedstock, providing containers for handling seedpieces are free from the pathogen. Under Long Island, New York, conditions, it is recommended that treatment be made before cutting (6). In the present studies, acid-mercury (1 quart hydrochloric acid plus 4 ounces bichloride of mercury per 25 gallons of water) and Semesan Bel (1 pound per 7½ gallons of water) were studied most extensively for controlling Fusarium seedpiece decay. In 1946, seed tubers and seedpieces were treated with these two chemicals by immersing them for one minute. The treatments were performed 3- to 4-weeks, 2-weeks, and immediately before planting. Seedpieces were held in new burlap sacks in the Station storage cellar until planted on May 7. The burlap sacks had been stored in the open potato cellar since the previous storage season. A second experiment was similarly prepared and planted June 5. Cellar temperatures for the first planting varied between 38° and 54°F.; for the second planting, 51° to 59°F. with a relative humidity from 60 to 93 percent. At the time of planting, 100 seedpieces from each treatment were examined for Fusarium infection. The infection data are presented in Table 12.

Table 12.—Percentage of Fusarium infection in seedpieces dipped in Semesan Bel and Acid-mercury before or after cutting. Tubers or seedpieces dipped one minute.

Chemical dip	Percent infection in seedpieces planted May 7		Percent infection in seedpieces planted June 5	
	cut April 6	cut April 27	cut April 6	cut April 27
No treatment	99	74	100	100
Semesan Bel, tubers	100	43	37	98
Semesan Bel, seedpieces	22	4	8	18
Acid-mercury, tubers	9	1	20	68
Acid-mercury, seedpieces	2	0	14	6

Semesan Bel and acid-mercury were ineffective, or only partially effective when the seed tubers were treated. Although the seedpieces were placed in new burlap sacks, it is evident that these sacks were infested with Fusarium inoculum that inoculated the untreated cut surfaces of seedpieces placed in them. Data pertaining to the crop produced by seedpieces receiving these treatmnts are summarized in Table 13.

Owing to a favorable growing season in 1946, differences be-

Table 13.—Average stand, small plants, and total yield of plants from seedpieces dipped before and after cutting in Semesan Bel and Acid-mercury. Plantings made May 7 and June 5, 1946. Data based upon 45 foot plots.

Chemical dip	Planting May 7			Planting June 5		
	Ave. Stand	Ave. No. small plants*	Total yield lb.	Ave. Stand	Ave. No. small plants**	Total yield lb.
Control	43.6	3.1	90.5	42.3	11.8	77.5
Semesan Bel, tubers	43.0	3.6	91.8	43.8	10.8	79.8
Semesan Bel, seedpieces	44.4	1.2	100.9	42.3	4.3	79.4
Acid-mercury, tubers	44.6	1.4	97.8	41.3	8.3	78.6
Acid-mercury, seedpieces	43.7	2.3	96.5	39.8	10.2	75.7
L. S. D. 5 percent	N.S.	N.S.	8.0	1.6	3.0	N.S.

* Plants in hill under 8 inches.
** Plants in hill under 12 inches.

tween the treatments were not pronounced. In the first planting there was only a significant increase in total yield by the plants from seedpieces dipped in Semesan Bel. In the second planting the differences were in stand and number of small plants. In this case, seedpieces dipped in Semesan Bel produced fewer small plants and those treated with acid-mercury were injured as evidenced by the reduced stand. The total yields for the June 5 planting are low as the plants did not reach maturity before they were killed by frost September 18. On both planting dates, those seedpieces cut and treated immediately before planting were superior to those cut and treated 2 or 3 weeks prior to planting.

In another experiment, seedpieces were first inoculated with Fusarium spores and then treated with various chemicals immediately before planting. The chemicals used were Semesan Bel, corrosive sublimate (1:1000, 5-minute dip), acid mercury, hydrated lime (dust), and sulfur (dust). This experiment was performed twice and planted May 7, and June 5, 1946. The efficacy of these treatments in controlling Fusarium seedpiece decay as measured by stand and yields is summarized in Table 14. Here again, Semesan Bel gave better results in both plantings. Acid mercury was injurious to the crop. The yield results obtained from acid-mercury as a seedpiece treatment are in agreement with results reported by Lutman (14). Hydrated lime and sulfur dusts were ineffective.

In 1946, control of Fusarium seedpiece decay also reduced the incidence of blackleg. In one experiment inoculated seedpieces were

Table 14.—The effect of various seedpiece treatments on stand and total yield of crop. Seedpieces inoculated by immersing in spore suspension of *F. Solani* prior to treatment.

Seedpiece treatment	Planted May 7		Planted June 5	
	Ave. Stand	Total yield–lb.	Ave. Stand	Total yield–lb.
Control	42.8	85.0	43.0	77.1
Semesan Bel	44.8	89.7	42.5	84.0
Bichloride mercury	42.5	87.9	42.3	80.9
Acid-mercury	40.5	88.1	30.5	59.4
Hydrated lime-dust	41.8	84.4	41.3	75.5
Sulfur-dust	41.3	81.7	42.8	78.6
L. S. D. 5 percent	2.4	N.S.	1.9	5.6

used. One-half of them were dipped in Semsan Bel and stored for 11 days before planting on June 5. The remaining untreated seedpieces were also stored. Twenty plots were planted with each lot of seedpieces. In the treated plots there was an average of 0.39 hills showing blackleg per 45-foot plot in the resulting crop, and an average of 2.0 hills per plot for non-treated seedpieces. This reduction in blackleg is significant at the 1 percent level.

The beneficial effects of seedpiece treatment for reducing losses from Fusarium decay and the incidence of blackleg were again demonstrated in 1947. Seedpieces were cut and inoculated with *F. solani*, 19, 7, and 0 days before planting. Similar seedpieces were inoculated and treated with Semesan Bel just before planting. At the time of planting, April 28, those inoculated 19 days earlier were pitted. Data pertaining to stand, number of small plants, total yield and hills with blackleg are presented in Table 15. Only the pitted seedpieces were inferior in all categories. The treated seedpieces tended to be superior in all respects.

Table 15.—The effect of seedpiece treatment with Semesan Bel on stand, number of small plants, total yield and hills with blackleg. Data average of 8, 40-foot plots, planted April 28, 1947.

Treatment of seedpieces	Stand	Small plants*	Total yield	Hills with blackleg
Freshly cut, inoculated, dipped	37.1	6.4	57.2	.12
Freshly cut, inoculated	36.3	8.0	49.4	6.50
Cut, inoculated April 21	38.1	8.4	50.2	2.16
Cut, inoculated April 9, cut surfaces pitted	30.5	20.5	45.6	9.12
L. S. D. 5 percent	2.3	4.5	10.5	3.09

* Plants in hill less than 8 inches June 28, 1947.

The above mercury seedpiece treatments kill a layer of tissue on the cut surfaces that turns black in 2 or 3 days. Acid-mercury adversely affects the crop in some cases although it gives good control of Fusarium decay. It is not known whether Semesan Bel as used in these tests adversely affects the growing plant. If treated seedpieces are placed in large piles with no provision for aeration, the cut surface injuries caused by this treatment may serve as an avenue of entrance to the seedpiece for soft rot bacteria. The undesirable toxic effect of Semesan Bel to the cut surfaces led to other investigations in search of a fungicide capable of controlling Fusarium seedpiece decay without phytocidal effect on the seedpiece.

A study of old and new fungicides for controlling Fusarium seedpiece decay was started in 1947. A total of 13 organic and inorganic fungicides were tested. A preliminary screening test of the fungicides was conducted in the storage cellar and consisted of dipping inoculated seedpieces in the various chemicals and then observing the infection at a later date. Four replications of 60 seedpieces were inoculated, treated, placed in clean Kraft paper sacks, and the top clipped shut to avoid contamination from dust or contact with containers and other objects present in the storage cellar. The treated seedpieces were held in storage from April 2 until May 1, 1947. The cellar temperatures varied from 43° to 56°F., and the relative humidity from 25 to 45 percent. At the end of the storage period, each seedpiece was examined by slicing repeatedly through the cut surfaces to determine whether infection had taken place, and the number of infected seedpieces was recorded for each replication. The chemicals employed, composition and concentration used, and the infection data are summarized in Table 16. A 1-minute dip was used for the mercury treatments and a 3-minute dip for the newer or organic fungicides.

Puratized Agricultural Spray controlled infection as well as did the standard mercury treatments, and the cut surfaces were not injured. Phygon was also promising for controlling infection but gave a slight browning of the cut surfaces. Arasan SF was promising in that the cut surfaces appeared to be normal. Most of the sets were infected but the foci were few with shallow penetration. Yellow oxide of mercury did not control infection as well as the other mercury treatments. It was observed that yellow oxide of mercury precipitated rapidly from suspension and it is believed that failure to get better control with this material was associated with this factor. These promising organic fungicides and the four mercury treatments were included in a field experiment.

For the field experiment, seedpieces carried natural inoculum. They were cut, treated, and planted May 10, 1947. The eight treatments, including a control, were replicated eight times and arranged in a Latin square design. The concentration of Arasan SF was increased to 36 gms. per gallon. The temperatures during the 4 weeks after planting were quite favorable for rapid plant emergence. Data relative to stand, small plants, blackleg, and yield were taken, but none of the data showed differences in favor of the treatments.

On September 18, 10 hills from each plot were dug and the seedpieces or their remains were carefully removed from the soil and examined for evidence of Fusarium infection on the cut surfaces. Owing to the semi-firm nature of Fusarium decay, it is possible to ascertain at this late date whether Fusarium decay developed by the presence of a fibrous pulpy tissue just within and attached to the cut surface. In many cases the seedpiece had been destroyed by bacterial soft rot as the only remaining tissue was the epidermal layers, xylem tissue, and the suberized cut surface. Moisture from the decayed tissue had dried out, leaving just a shell of the seedpiece. Those seedpieces affected with the Fusarium decay-soft rot combination were quite similar except that the cut surfaces had a fibrous tissue attached to the inner side. Seedpieces showing this latter characteristic were classified as infected with Fusarium decay. Data from the examination of seedpieces are presented in Table 17.

All treatments significantly reduced the number of seedpieces infected with Fusarium decay. Phygon again compared favorably

Table 16.—Relative efficiency of several fungicides for controlling infection of seedpieces by *Fusarium Solani*.

Fungicidal dip[1]	Active chemical component	Amount per gal. of dip solution	Ave. No. infected seedpieces	Appearance of cut surfaces
Phygon [1]	2,3 dichloro naphthoquinone 1,4	30.5 gms.	9	Good, slight discoloration
Spergon[1]	Tetrachloropara benzoquinone	54.5 gms.	53.5	
Puratized Agricultural Spray[2]	Phenyl mercury triethanol ammonium lactate	9.5 cc.	2.5	Good
Puratized 177[2]	Phenyl amino cadmium dilactate	18.0 gms.	34.0	Good
Dithane, Z-78[3]	Zinc ethylene bisdithiocarbamate	18.0 gms.	58.5	Good
Dithane, D-14[3]	Disodium ethylene bisdithiocarbamate	19.0 gms.	39.5	Good, cut surface clear, no evidence of injury.
Arasan SF[4]	Tetramethyl thiuramdisulfide	18.0 gms.	54.5	Good, cut surface clear.
G-4-40[5]	Dihydroxydichlorodiphenyl methane	20.0 cc.	18.0	Very toxic, underlying tissue pink, soft rot following.
Yellow Oxide of Mercury	Mercuric oxide	15.0 gms.	37.5	Toxic; dry, dark tough rind over surface
Mercurnol	Hydrochloric acid solution containing 10 percent $HgCl_2$	42.5 cc.	0.3	do
Semesan Bel	Hydroxymercurinitrophenol and Hydroxymercurichlorophenol	60.5 gms.	1.5	do
Acid-corrosive sublimate	75 cc. HCl plus 13.6 gms. $HgCl_2$	37.5 cc.	0.5	do
Control			59.75	
L. S. D. 5 percent			8.4	

[1] These chemicals supplied gratis by the following companies:

1. Naugatuck Chemical, Division United States Rubber Company, Naugatuck, Connecticut.
2. Gallowhur Chemical Corporation, 801 Second Avenue, New York 17, New York.
3. Rohm & Hass Company, Washington Square, Philadelphia 5, Pennsylvania.
4. E. I. duPont De Nemours and Company, Semesan Division, 101 West Tenth Street, Wilmington 98, Delaware.
5. Givaudon, Delawauna, Inc., 330 West 42nd Street, New York 18, New York.

Table 17.—Relative amount of Fusarium decay on cut surfaces of seedpieces treated with various fungicides. Ten seedpieces dug from each plot September 18, 1947, and data based upon microscopic examination of cut surfaces.

Chemical seed treatment	Average number of seedpieces infected with *Fusarium spp.*
Control	7.62
Phygon	1.00
Puratized Agricultural Spray	2.63
Yellow oxide of mercury	1.13
Arasan SF	2.37
Mercurnol	1.13
Semesan Bel	3.13
Acid-mercury	1.75
L. S. D. 5 percent	1.09

with the mercuries; Semesan Bel gave poorest protection to the seedpieces. Puratized Agricultural Spray and Arasan SF performed as well as Semesan Bel. In this experiment, yellow oxide of mercury was equal to the best material. This suspension was thoroughly agitated before immersing the seedpieces, which possibly accounts for the difference in performance for the two experiments.

On the basis of data now available, Semesan Bel is recommended over acid-mercury for treating seedpieces. Acid-mercury provides as good control or better than Semesan Bel, yet for treating seedpieces, its effect on the resulting crop is unpredictable. Losses from injury due to the treatment may be more severe than losses from Fusarium decay. Insufficient data on yellow oxide of mercury and the promising organic fungicides make it impossible to recommend the use of these chemicals at this time.

Discussion

The severity of loss from seedpiece decay caused by *F. solani* is dependent upon ecological factors, particularly cool soil temperatures. Infected seedpieces planted when the season is favorable for rapid emergence and early growth produce a normal stand of vigorously growing plants. Such a performance of diseased seedpieces usually develops when they are planted in late May or early June. Similarly diseased seedpieces, when planted at an early date, most generally produce the poor stands and weak plants described above. These circumstances possibly account for the late planting practiced in most sections of southern and eastern Idaho. This late planting has several disadvantages. Plantings made the last of May or the first of June may never reach full maturity before fall frosts. The Russet Burbank requires a growing season of 115 to 120 days, and killing frosts frequently occur by mid-September. Thus, planting should be completed by mid-May to assure maximum tonnage and quality.

Low temperatures affect the growth of the plant and that of *F. solani*. At early May temperatures of 40° to 50°F., the growth of the plant is retarded much more than that of *F. solani*. It is believed that this difference in rate of growth under similar temperature conditions largely accounts for the losses due to seedpiece decay. If growing conditions are such that it takes 3 to 4 weeks for plants to emerge from the soil, many seedpieces are largely destroyed by the ingress of *F. solani.* If the soils are wet, bacterial soft rot may develop in seedpieces having Fusarium decay. Under such conditions, seedpiece decay progresses more rapidly and stands are reduced accordingly.

Untreated or infected seedpieces may produce good stands and satisfactory yields under favorable early season growing conditions. However, a sudden change to adverse weather may cause serious reductions in stand. This was amply demonstrated in 1947. The months of May and June were favorable for rapid emergence and early growth. In most potato sections a satisfactory stand of potatoes was obtained. On June 29 an untimely frost killed vines completely in much of eastern Idaho. By this time the seedpieces had largely decayed from Fusarium and soft rot infection. Consequently, stands in many fields were markedly reduced, and many surviving plants recovered slowly from the frost damage. Yields were reduced as much as 50 percent. In contrast, fields of the same area planted with treated seedpieces retained 80 to 90 percent of a stand and produced yields comparable to a late planted crop.

Blackleg may prove to be an important problem in crops developing from seedpieces affected with *F. solani,* even though a good stand of plants is produced. This is of particular importance to the certified seed grower who, under present regulations, must rogue blackleg affected plants from his crop.

The association of blackleg with Fusarium seedpiece decay may account for the inexplicable occurrence of blackleg in various instances. This relationship is possibly not confined to Idaho and may explain the incidence of blackleg in other areas, particularly during early plant growth.

Wounds caused by *F. solani* probably attract the larvae of the seed-corn maggot when the insect is present; or, they may serve as avenues of entrance to seedpieces for the blackleg bacterium independent of the insect larvae. The greater amount of soft rot in Fusarium-affected seedpieces planted in moist soils suggests that water serves as a medium through which bacteria invade Fusarium wounds on cut surfaces. On the basis of these studies, it is impossible to say whether the blackleg pathogen is soil- or seed-borne.

All plants from seedpieces affected with both Fusarium rot and bacterial soft rot do not develop blackleg. In observed cases, a relatively few plants develop the disease. A satisfactory explanation of this phenomenon is not available on the basis of present information. Decay caused by *F. solani* exerts a stunting effect on young plants, and plants so weakened may be predisposed to blackleg infection from the jointly diseased seedpieces. The deleterious effects of *F. solani* on the plant varies with the seasonal climatic conditions, as does the development of blackleg.

Data recorded above indicate that the control of blackleg by seed treatment under Idaho conditions is largely indirect. It is believed that control is accomplished by eliminating Fusarium infections (wounds) that serve as inoculation courts for the blackleg bacterium.

Additional experiments on the efficiency of chemical seed treatments need to be made. At present Semesan Bel is recommended over acid-mercury for the following reasons even though the latter gives as good or better control of Fusarium decay. First, acid-mercury may injure the crop even though used in the same manner for each treatment. No explanation of this response or methods of eliminating it are now available. Second, owing to the chemical composition of the two materials, depletion of the toxicant in the acid-mercury bath is more likely to take place than with Semesan Bel. Third, acid-mercury is corrosive to metal and would necessitate repairs and reconstruction of automatic metal treating machines now being adopted by growers. Semesan Bel has been used in such a machine for 8 or 9 years without corroding the galvanized iron used in its construction.

Under Idaho conditions it is recommended that seedpieces be treated. As pointed out above, this recommendation is based upon the omnipresence of inoculum and to eliminate all sources of this inoculum would be an insurmountable task for most growers. Owing to the low humidities found under most Idaho conditions it is believed that the dipping of seedpieces can be practiced without ill effects, providing the growers use caution in case it is necessary to store seedpieces after treatment. They should not be stored in large solid piles. The high humidity that develops in such piles of seedpieces would not allow the cut and treated surfaces to dry. Under these conditions infection by soft rot bacteria may become established on the dead cut surfaces and destroy the seedpiece in a relatively few days. It is believed that by carefully piling treated seedpieces to allow for aeration losses from such decay can be avoided. On the basis of experiments so far conducted, it is not advisable to cut and treat seedpieces in advance of planting. Best results have been obtained by cutting and treating seedpieces immediately before planting (within 1 to 3 days).

Summary

Seedpiece decay is a problem in all potato growing areas of Idaho. In years favorable for rapid emergence and early growth, decay is prevalent, although its effect on the crop may not be serious. Three distinct pathogens have been found responsible for seedpiece decay: *F. solani, F. roseum,* and presumably *Erwinia atroseptica* (Von Hall) Jennison. *F. solani* is most important as the initiator of seedpiece decay and causes a relatively slow rot.

This decay is frequently associated with bacterial soft rot. This combination of rots may rapidly destroy the seedpiece. During the period of these investigations, seedpiece decay caused by *F. roseum* was found in about 5 percent of the cases studied and frequently affects the same seedpiece as *F. solani*.

Decay caused by *F. solani* influences the potato plant in various ways, although it has never been isolated from plants. Plants from diseased seedpieces are frequently chlorotic for a time while young, weak and slow in development. In addition diseased seedpieces may either fail to produce plants or produce only a reduced number. Poor stands and weak plants yield poorly, and the quality of the crop is impaired due to an increased number of knobby potatoes.

Evidence is presented indicating that cold wet weather after planting is conducive to serious losses from Fusarium decay and the associated soft rot. Blackleg is more severe in plants developing from Fusarium affected seedpieces. It is suggested that the blackleg bacterium enters seedpieces through Fusarium lesions on cut surfaces with the assistance of seed-corn maggot larvae or moisture.

Mercury seedpiece treatments have given good control of Fusarium decay and blackleg. Owing to the universal presence of *F. solani* inoculum, it is recommended that seedpieces be treated, thus protecting cut surfaces against inoculation that may occur from contaminated equipment. Under the conditions of low humidity generally found in southern and eastern Idaho, no ill effects have developed if treated seedpieces are held 2 or 3 days. Best results have been obtained by planting seedpieces as soon as practicable after treatment. It is believed that control of blackleg is accomplished indirectly by eliminating Fusarium infection of cut surfaces. Semesan Bel is recommended over acid-mercury as a seedpiece dip. Preliminary tests indicate that yellow oxide of mercury, Phygon, Puratized Agricultural Spray, and Arasan SF may have promise, but additional work must be done before their value is fully known or they can be recommended.

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