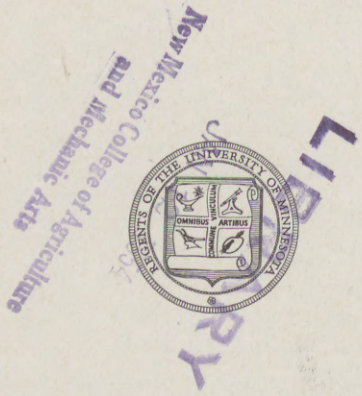
Technical Bulletin 206 June 1953

The Black Point Disease of Wheat in the United States

E. W. Hanson and J. J. Christensen
Department of Plant Pathology and Botany



University of Minnesota
Agricultural Experiment Station

CONTENTS

Submitted for publication May 2, 1952 2-53—3M

The Black Point Disease of Wheat In the United States[1]

E. W. Hanson and J. J. Christensen[2]

THE SEED DISCOLORATION of wheat commonly known as black point in the United States, as kernel smudge in Canada, and by various other names in other countries, is a very common disease in Minnesota and adjoining states. Black point occurs in most of the wheat producing countries of the world, causes some damage almost every year, and occasionally causes a very significant reduction in quality, especially of durum wheat.

Seed discoloration is particularly objectionable in durums due to the difficulty in removing the dark specks that appear in the flour or semolina milled from discolored grains. Also, discolored seed usually means diseased seed and may indicate the presence of parasitic fungi that can cause seedling blight if such seed is sown. Studies indicate that infected seeds are the primary source of inoculum for seedling blight in Minnesota.

Considerable work has already been done on the black point problem and much useful information obtained. Machacek and Greaney *(19)* have given an excellent summary of previous work throughout the world and have made extensive studies of the disease in Canada. Elsewhere investigations have been less extensive; for the most part, they have been based on relatively few samples grown under local conditions or have not been continued over extensive periods of time.

In the United States little work has been done on the microflora of wheat seed in relation to seedling blight and root rot. Recently, Canadian workers *(18)* have made a comprehensive study of the prevalence of microorganisms on and in the kernels of wheat, oats, and barley. In England, Hyde *(16)* studied the prevalence of internal mycelium in wheat kernels obtained from many of the wheat growing countries. In these and other studies there were tremendous variations in the kind and number of microorganisms present in different seed lots; in some cases patho-

[1] Cooperative investigations between the Minnesota Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture.

[2] The writers wish to acknowledge their indebtedness to E. R. Ausemus of the Minnesota Agricultural Experiment Station; J. G. Dickson and R. G. Shands of the Wisconsin Agricultural Experiment Station; the late L. C. Burnett of the Iowa Agricultural Experiment Station; T. Bonnett and W. M. Bever of the Illinois Agricultural Experiment Station; G. H. Cutler of the Indiana Agricultural Experiment Station; G. S. Smith and L. R. Waldron of the North Dakota Agricultural Experiment Station; A. N. Hume of the South Dakota Agricultural Experiment Station; K. S. Quisenberry of the Nebraska Agricultural Experiment Station; L. P. Reitz and E. D. Hansing of the Kansas Agricultural Experiment Station; I. M. Atkins of the Texas Agricultural Experiment Station; R. H. Bamberg of the Montana Agricultural Experiment Station; D. C. Tingey of the Utah Agricultural Experiment Station; O. A. Vogel of the Washington Agricultural Experiment Station; and to all others who supplied seed lots of the wheats used in these studies. Thanks are due also to C. Arndt and E. Herrling for suggestions and assistance in preparing illustrations.

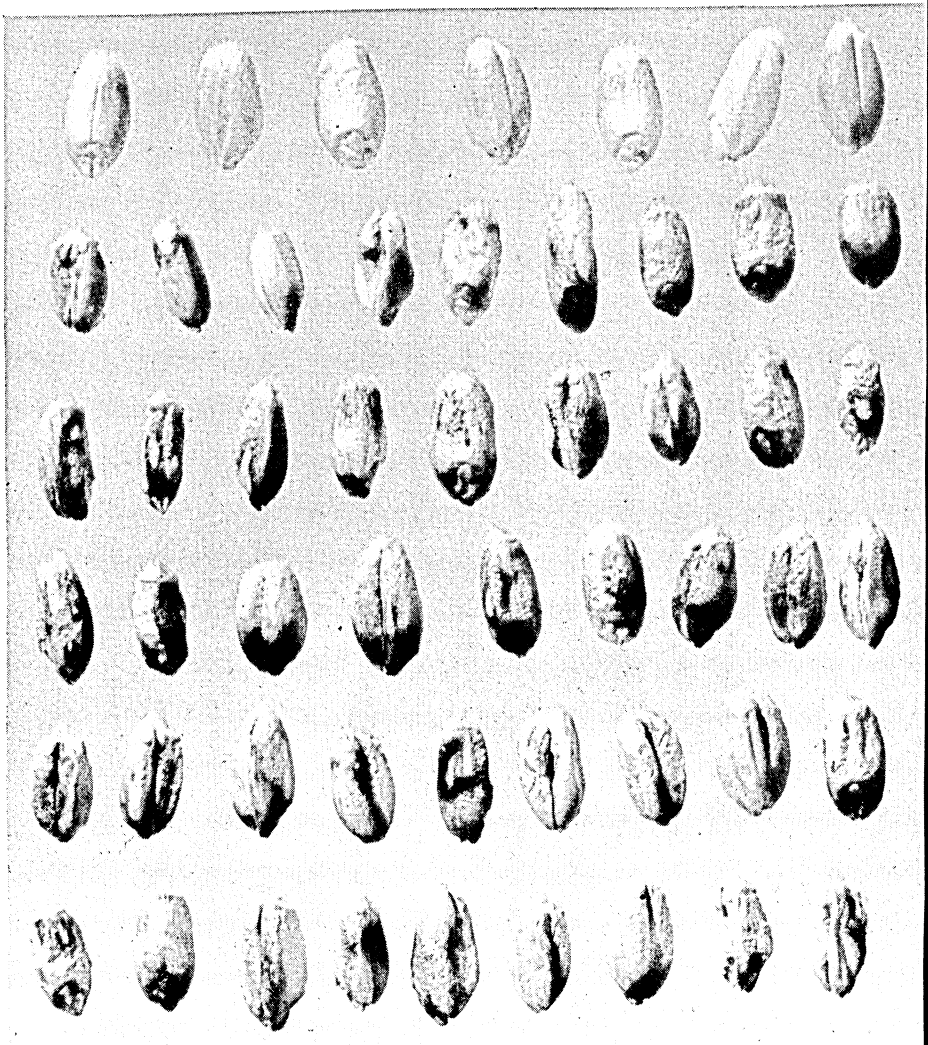


Fig. 1. Symptoms of seed discoloration on wheat. Kernels in top row are free of discoloratio all others show various degrees and kinds of discoloration at different locations on the see

gens were abundant, in others saprophytes predominated. Christensen *(4)* and others have shown that microflora play an important role in deterioration of stored wheat. As this problem is beyond the scope of this paper, no further references will be made to it.

The present investigation was mad to obtain further information concern ing the prevalence, severity, distribu tion, symptoms, causes, and effects the black point disease in the Unit States and especially to determine th amount of variation in these facto

from year to year and between different regions and localities in the same year. Studies also were made on the prevalence of root-rotting fungi in the seed in relation to the prevalence of black point and to seedling blight.

NATURE OF THE DISEASE

Black point or kernel smudge is a disease of the kernels of wheat, barley, rye, and certain wild and cultivated grasses. Symptoms are more or less localized areas of brownish or blackish discoloration on any part of the seed (see figure 1). Commonly this discoloration occurs around the embryo end of the seed (see figure 2), but it may occur near the brush, in the crease, or on any other part of the kernel. The discoloration may be light or dark and fairly uniform in color or it may appear as light colored lesions with dark margins.

The majority of investigators believe that this type of seed discoloration is caused primarily by *Alternaria spp.* and/or *Helminthosporium spp. (2, 3, 9, 11, 15, 19, 29)*. Many other organisms including bacteria have been isolated from discolored seed but the relative prevalence of these in comparison with Alternaria and Helminthosporium has usually been small. Simmonds and Mead *(25)* reported that certain weeds, such as Russian thistle, could stain wheat seed, and Pasinetti *(21)* after investigating a kernel discoloration of wheat in Argentina and not being able to isolate any of the usual organisms, concluded that the discoloration was due to adverse environmental conditions.

SCOPE OF PRESENT INVESTIGATION

An extensive survey was made of wheats from all parts of Minnesota during the nine-year period from 1935 to 1943, inclusive. In 1940 a survey also was made of a collection of durums from North Dakota, and in 1942 and 1943 the survey included samples from 13 wheat producing states extending from Washington to Indiana and Minnesota to Texas. Samples from Mexico, Canada, and several South American countries were also examined and found to have the disease, but will not be discussed in this paper.

Fig. 2. A common type of seed discoloration on durum wheat.

MATERIALS AND METHODS

Percentages of discolored kernels in the threshed grain were determined by actual counts. At least two 100-kernel lots were selected at random from each sample and the number of kernels showing blackish or brownish discoloration determined. The average of these determinations was then used to represent the amount of black point in a given sample. All determinations were made with the unaided eye, under uniform, artificial light, by the same person.

The microflora of the various seed lots was determined by plating tests. Two hundred or more kernels from each lot were surface disinfected by submerging them for 10 seconds in 70 per cent ethyl alcohol, soaking them for about 2½ minutes in a 1:1000 solution of mercury bichloride, and then rinsing them in two changes of 1 per cent sodium hypochlorite solution. Immediately after surface disinfection the seeds were placed on potato-dextrose agar in Petri plates and incubated for 10 days at about 22°C. The kind and relative prevalence of the microorganisms present were then observed and recorded. Since this method of surface disinfection is likely to kill organisms present immediately beneath the pericarp, where they often occur in considerable abundance, the technique probably detects mainly the fungi present within the inner seed coats.

PREVALENCE

Seed discoloration probably occurs wherever cereals are grown and has been reported from Algeria *(17)*, Argentina *(15, 21)*, Canada *(12, 19)*, France *(24)*, Germany *(1)*, India *(9, 10)*, Italy *(8, 22)*, Java (see *19)*, Morocco *(20, 23)*, Siberia *(31)*, South Africa (see *18)*, and the United States *(2, 3, 11, 14, 15, 30)*. The percentage of discolored kernels varies from 0 to nearly 100, depending on the locality, year, variety and seed lot studied. Machacek and

Table 1. Percentages of Black Point Kernels in Threshed Grain Samples of Wheat Grown at 15 Locations in 13 States During 1942 and 1943

Class of wheat and source	Number examined		Average percentages of kernels discolored*			
	Seed lots	Varieties	1942	1943	Average (1942-43)†	Range between seed lots
Durum						
Kansas (Manhattan)	2	1	41	10	26	10–41
Minnesota (Crookston)	7	5	38	61	50	18–74
Nebraska (Lincoln)	2	1	1	1	1	1–1
North Dakota (Fargo)	11	6	32	39	36	10–68
North Dakota (Langdon)	12	6	12	20	16	9–27
South Dakota (Brookings)	2	1	12	13	12	12–13
Texas (Denton)	1	1	.....	31	.....	.....
Hard Red Spring						
Illinois (Urbana)	15	8	10	21	16	1–37
Iowa (Ames)	3	3	7	34	20	3–34
Kansas (Manhattan)	16	11	11	3	7	1–37
Minnesota (Crookston)	21	16	4	7	6	1–17
Montana (Bozeman)	6	6	0	.....	.....	0–0
Montana (Havre)	5	5	.....	0	.....	0–0
Nebraska (Lincoln)	12	6	T‡	1	1	0–2
North Dakota (Fargo)	12	8	4	5	5	1–15
North Dakota (Langdon)	11	8	3	9	6	0–18
South Dakota (Brookings)	10	6	12	6	9	3–16
Texas (Denton)	4	4	.....	4	.....	2–6
Utah (Logan)	1	1	0	.....	.....	.....
Washington (Pullman)	3	2	0	0	0	0–0
Wisconsin (Madison)	6	4	22	13	18	5–33
Soft Red Winter						
Indiana (Lafayette)	4	2	10	4	7	3–12
Texas (Denton)	4	2	3	8	6	1–14
White						
Washington (Pullman)	2	2	.....	T‡	.....	0–1

* Results based on 200 kernels of each seed lot.
† All varieties.
‡ T = 0.5 per cent or less. All other percentages have been given to the nearest whole numb

Table 2. Percentages of Black Point Kernels in Threshed Grain Samples of Spring Wheat Grown in Six Localities in Minnesota During the Nine-Year Period from 1935 to 1943, Inclusive

Class of wheat and locality	Number examined		Percentages of discolored kernels*		
	Seed lots	Varieties	Average (1935-43)†	Range	
				In yearly averages	Greatest between samples
Durum					
Crookston	28	5	22	2–61	0–74
Duluth‡	2	1	11	10–11	10–11
Grand Rapids‡	3	1	11	3–21	3–21
Morris	16	2	24	0–53	0–71
St. Paul	15	5	16	1–43	1–55
Waseca	9	1	16	2–70	2–70
Total or average	73	5	17	0–70	0–74
Hard Red Spring					
Crookston	108	38	5	1–11	0–25
Duluth	55	21	3	1–4	0–11
Grand Rapids	54	21	5	2–18	0–37
Morris	103	37	6	1–12	0–25
St. Paul	133	41	6	1–11	0–31
Waseca	118	39	7	1–13	0–37
Total or average	571	41	5	1–18	0–37

* Results based on 200 kernels of each seed lot.
† All varieties.
‡ Durum varieties were grown at Duluth only in 1935 and 1936 and at Grand Rapids only in 1935, 1936, and 1937.

Greaney *(19)* found 93.6 per cent of discolored kernels in Pentad wheat grown at Winnipeg, Manitoba, in 1935, and the writers have seen as much as 95 per cent in certain seed lots of Kubanka durum grown in North Dakota. An indication of the amount of seed discoloration on wheat in the United States in 1942 and 1943 is given in table 1 and the amounts that occurred in six localities in Minnesota during the 9-year period from 1935 to 1943 are shown in table 2.

While it was not always possible to obtain the same varieties from every location, enough of the same varieties were grown at several stations to show clearly that there were large differences in the amount of seed discoloration in different regions and localities (see figures 3 and 4). Hard red spring wheats produced in Washington, Montana, and Utah had virtually no seed discoloration in 1942 or 1943, or in other years when samples were examined,[3] while the same wheats grown in Wisconsin, Iowa, Illinois, Minnesota, and the eastern parts of North and South Dakota had relatively high percentages of discolored seeds.

Differences between years were also great. Wheats grown in Minnesota, North Dakota, Iowa, Illinois, and Texas had more discoloration in 1943 than in 1942, while those grown in Kansas, Wisconsin, and Indiana had more discoloration in 1942 (see table 1). On wheats grown in South Dakota, there was little difference between the two years in the amount of damage on durum varieties, but hard red spring varieties had considerably higher percentages of discolored kernels in 1942. Nebraska wheats had relatively little discoloration either year.

[3] Samples of hard red spring wheats were obtained from these states almost every year between 1937 and 1943 and only rarely was there more than a trace of seed discoloration.

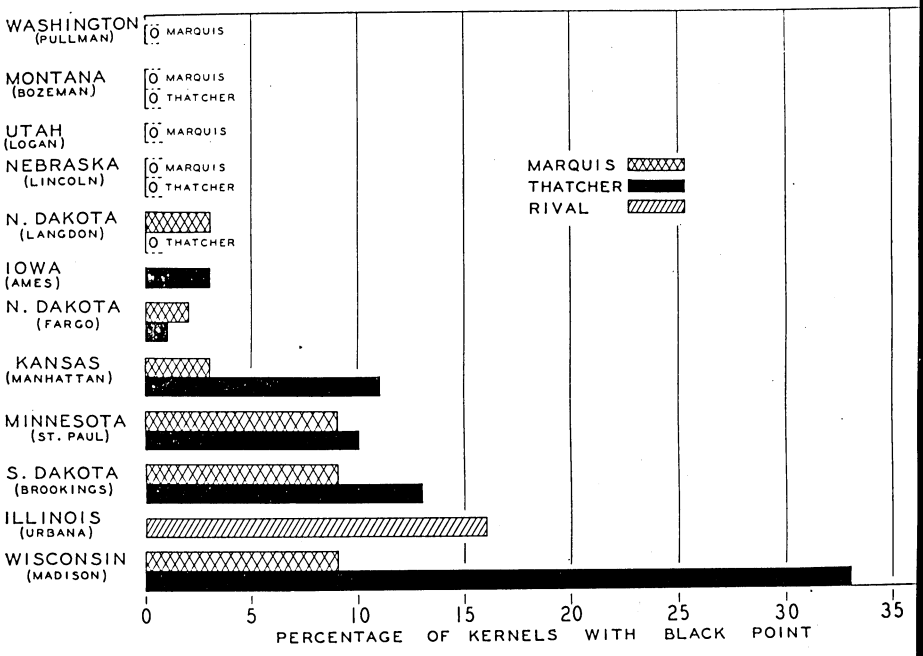


Fig. 3. Percentage of kernels with discoloration in three varieties of hard red spring whe grown at 12 locations in 1942. Results based on 200 kernels for each seed lot.

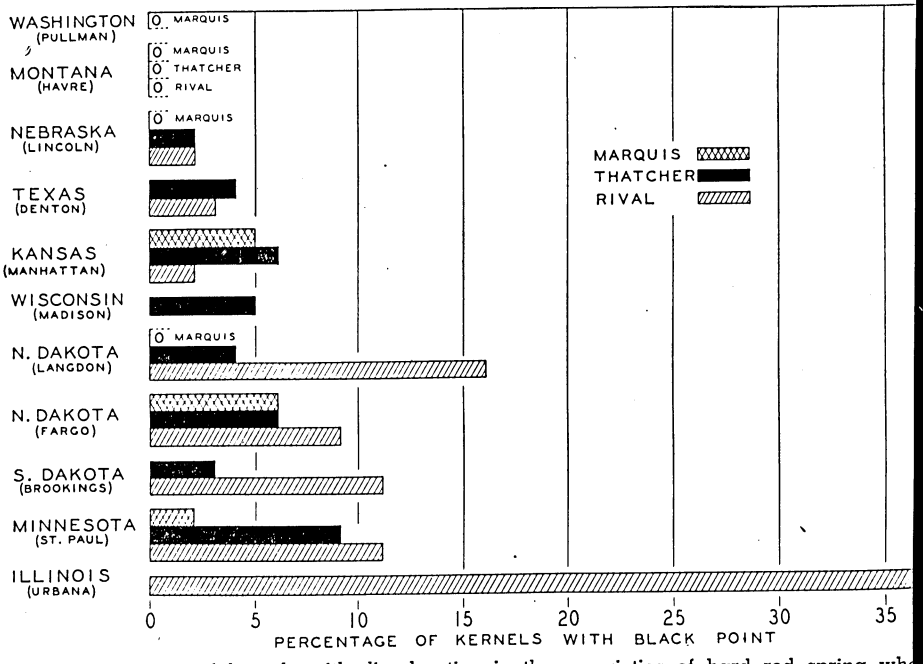
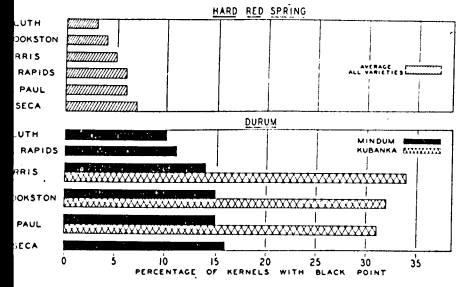


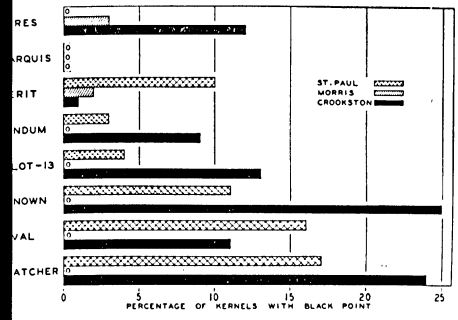
Fig. 4. Percentage of kernels with discoloration in three varieties of hard red spring wh grown at 11 locations in 1943.. Results based on 200 kernels for each seed lot.



ig. 5. Percentage of discolored kernels in amples of hard red spring and durum wheats rown at six locations in Minnesota during ne nine-year period from 1935 to 1943, inclusive.

Differences among localities within state are indicated for Minnesota in gure 5. These data are based on samles grown at six locations during the eriod from 1935 to 1943, and show that ne percentages of discolored kernels anged from 3 to 7 for hard red spring vheats, 10 to 16 for Mindum durum, nd 31 to 34 for Kubanka durum.)uluth had the lowest average perentages of discolored kernels and Wa-eca the highest. Other localities were ntermediate.

As might be expected, the differences etween localities were greater in some ears than in others. As shown in figre 6, these differences were particularly striking in 1940 when no discoloration was found in samples of Thatcher and Renown grown at Morris but 24 and 25 per cent, respectively, in these same varieties grown at Crookston (these two locations are approximately 155 miles apart).



g. 6. Percentage of kernels with discolora-on in eight varieties of spring wheat grown three locations in Minnesota in 1940. Re-lts based on 200 kernels for each seed lot.

The average percentages of discolored kernels in hard red spring and durum wheats grown in Minnesota are given in figure 7 for each year during the period from 1935 to 1943. The average percentage of kernels discolored for the hard red spring varieties ranged from 2 in 1936 to 8 in 1940 and 1943, for Mindum durum from 4 in 1940 to 46 in 1942, and for Kubanka durum from 3 in 1936 to 72 in 1943.

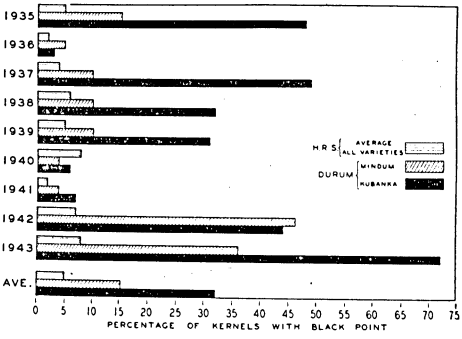


Fig. 7. Percentages of kernels with discoloration in hard red spring and durum wheats grown at six locations in Minnesota during the nine-year period from 1935 to 1943, inclusive.

These data show that, in general, hard red spring wheats had lower percentages of discolored seed than the durum varieties; and of the durums Mindum had less than Kubanka. Occasionally, however, there were striking exceptions to this as shown in figure 8. For example, at Crookston, Minnesota, in 1940, Thatcher, a hard red spring wheat, had considerably higher percentages of discolored seed than either Mindum or Kubanka, and at the same station in 1936 Mindum had more

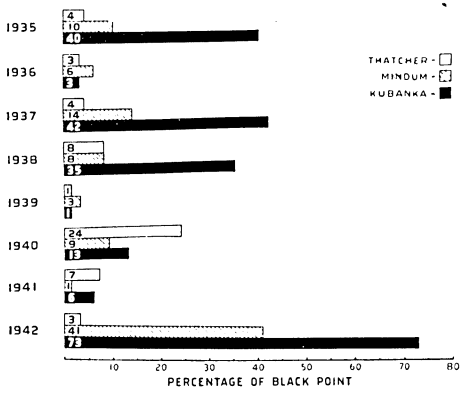


Fig. 8. Percentage of kernels with discoloration in three varieties of spring wheat grown at Crookston, Minnesota, during the eight-year period from 1935 to 1942, inclusive.

discolored seed than Kubanka. The relative differences between hard red spring and durum wheats and between varieties of each class are given in figure 9. Over a nine-year period the durum variety, Kubanka, had four times as much discoloration as the most susceptible hard red spring wheat studied. Similarly, Mindum, a more resistant durum, had nearly twice as much as any of the hard red spring wheats. Among the latter, Marquis showed least black point while Rival had the most. Other hard red spring wheats were intermediate.

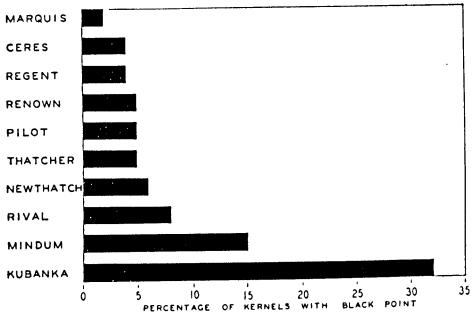


Fig. 9. Percentage of kernels with discoloration in 10 varieties of spring wheat grown at six locations in Minnesota during the nine-year period from 1935 to 1943, inclusive.

MICROFLORA

Discolored kernels were usually infected with fungi so that lots having high percentages of discolored kernels usually had high percentages of infected seeds. On the other hand, lots which had none or only a little kernel discoloration were not necessarily free from fungi; some apparently clean lots were heavily infected. Plating tests on nutrient agar, therefore, were necessary to determine the percentage of kernels infected and the nature of the microflora involved.

The percentage of kernels infected and the relative prevalence of the various organisms present varied tremendously from one state to another. The extent of this variation is indicated in figures 10 and 11.

In 1942 the average percentage of kernels infected with fungi for all varieties of hard red spring wheat exceeded 90 per cent at Madison, Wisconsin; Manhattan, Kansas; Fargo and Langdon, North Dakota; Brookings, South Dakota; St. Paul, Minnesota; Urbana, Illinois; and Ames, Iowa; while it was only 27 per cent at Lincoln, Nebraska and less than 7 per cent at Pullman, Washington, at Logan, Utah, and at Bozeman, Montana.

Similar data were obtained in 1943 indicating that such locations as Bozeman and Havre in Montana, Pullman, Washington, and Logan, Utah, had much lower percentages of infected kernels than locations in the areas where there was more humidity during the susceptible period. The data show that the relative prevalence of the various fungi also varied greatly with location.

In 1942 Alternaria was the most prevalent fungus in most states but Helminthosporium was most prevalent in wheats grown at Madison, Wisconsin. In most states Fusarium was the leas

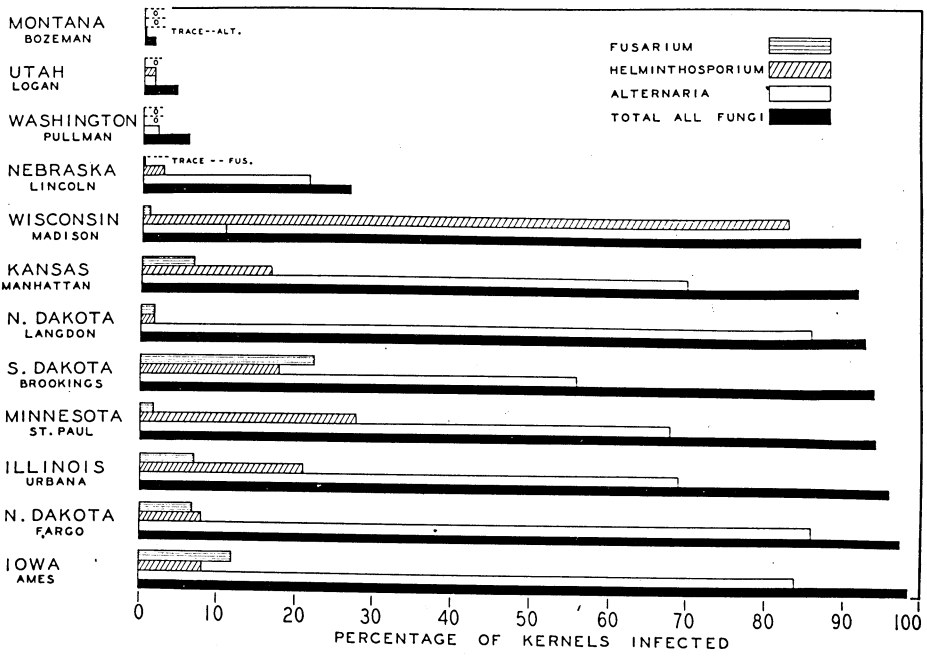


Fig. 10. Average percentage of kernels of hard red spring wheats infected with fungi, based on samples grown at 12 locations in 1942. Percentages based on 200 kernels for each seed lot.

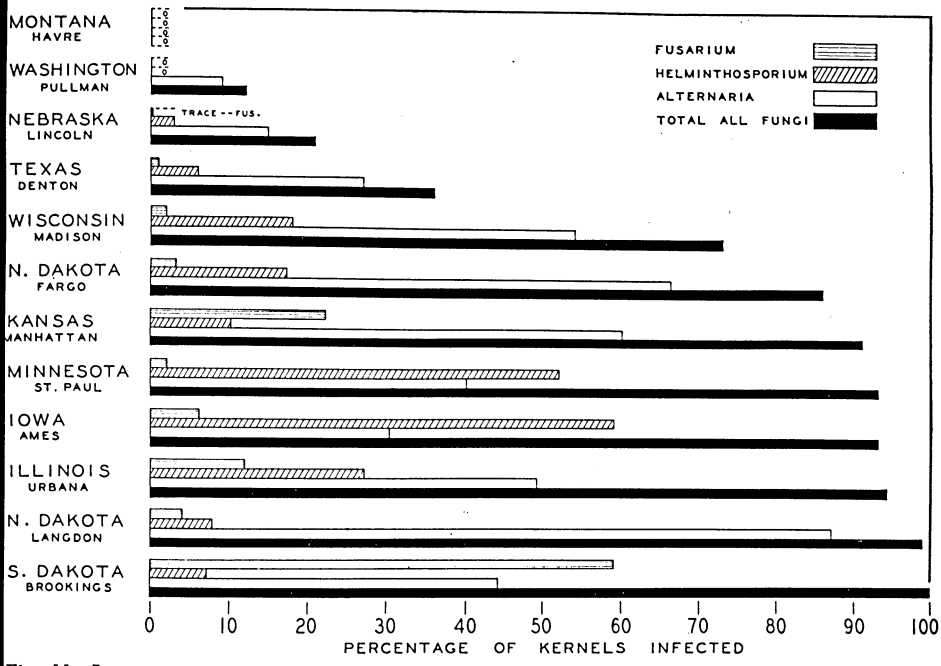


Fig. 11. Average percentage of kernels of hard red spring wheats infected with fungi, based on samples grown at 12 locations in 1943. Percentages based on 200 kernels for each seed lot.

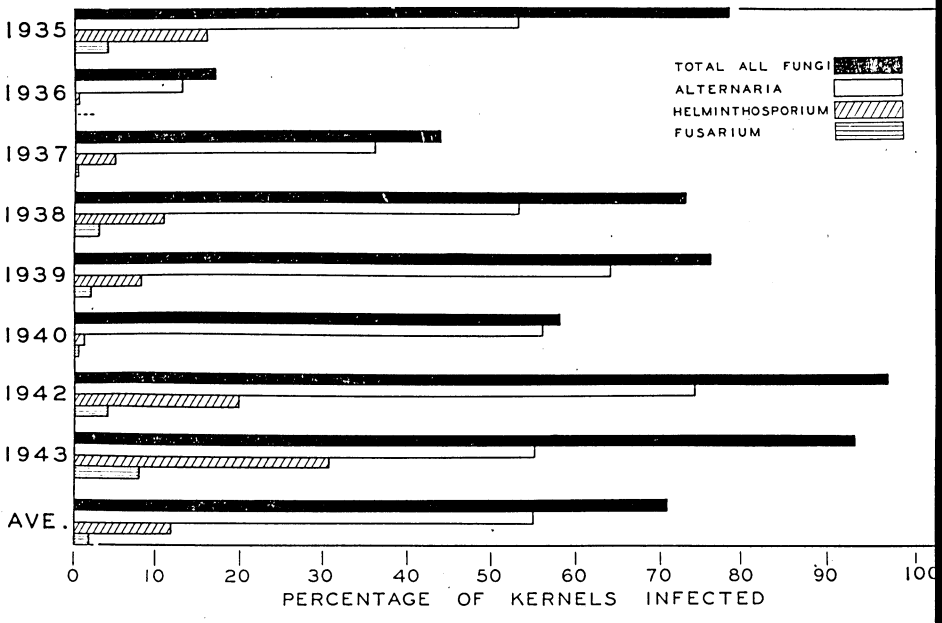


Fig. 12. Average percentage of kernels of hard red spring wheat infected with fungi in eight different years, based on samples from six locations in Minnesota.

prevalent of the fungi studied but in 1943 at Brookings, South Dakota, it was the most prevalent. Higher percentages of the seeds from Brookings, South Dakota, were infected with Fusarium than in any of the other locations in both 1942 and 1943.

The microflora of wheat seed also varied from year to year at a given location. Helminthosporium was the most prevalent fungus on Wisconsin wheats in 1942, but Alternaria was most prevalent in this state in 1943. At St. Paul, Minnesota, and Ames, Iowa, Alternaria predominated in 1942 but Helminthosporium was most prevalent in 1943.

Further data concerning variation in microflora from year to year are given for Minnesota for the eight-year period from 1935 to 1943 in figures 12, 13, and 14. Alternaria was the most prevalent fungus on hard red spring wheats in all years, but the relative percentages of seeds infected by the different fungi varied considerably from year to year. Least infection occurred in 1936 and most infection in 1942, the range being from 17 to 97 per cent. Highest percentages of pathogenic fungi, Helminthosporium and Fusarium, were obtained in 1935, 1938, 1942, and 1943; the lowest percentage of these fungi was found in 1936.

The relative prevalence of the various fungi isolated from Mindum durum was very similar to that of the hard red spring wheats with one exception and that was in 1943 when Helminthosporium was slightly more prevalent than Alternaria (see figure 13). Kubanka durum differed from all the other wheats studied in that it had a higher relative prevalence of Helminthosporium than Alternaria in three of the eight years (1937, 1942, and 1943) of the test (see figure 14).

The average percentages of kernels infected with fungi at six different lo-

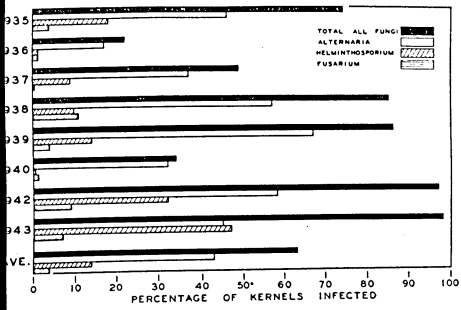


Fig. 13. Average percentage of kernels of Mindum durum wheat infected with fungi in eight different years, based on samples from six locations in Minnesota.

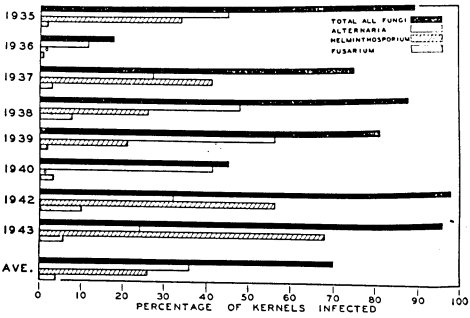


Fig. 14. Average percentage of kernels of Kubanka durum wheat infected with fungi in eight different years, based on samples from four locations in Minnesota.

cations in Minnesota during the eight-year period from 1935 to 1943, for hard red spring, Mindum durum, and Kubanka durum are given in figures 15, 16, and 17, respectively. These data show that for hard red spring wheats the percentage of kernels infected varied from 63 at St. Paul to 86 at Duluth and that the most prevalent fungus at all locations was Alternaria. This fungus also was the most common one isolated from Mindum durum during this period. Kubanka was grown at only three locations for the entire period and while Alternaria was most prevalent at Crookston and Morris, Helminthosporium was most prevalent at St. Paul.

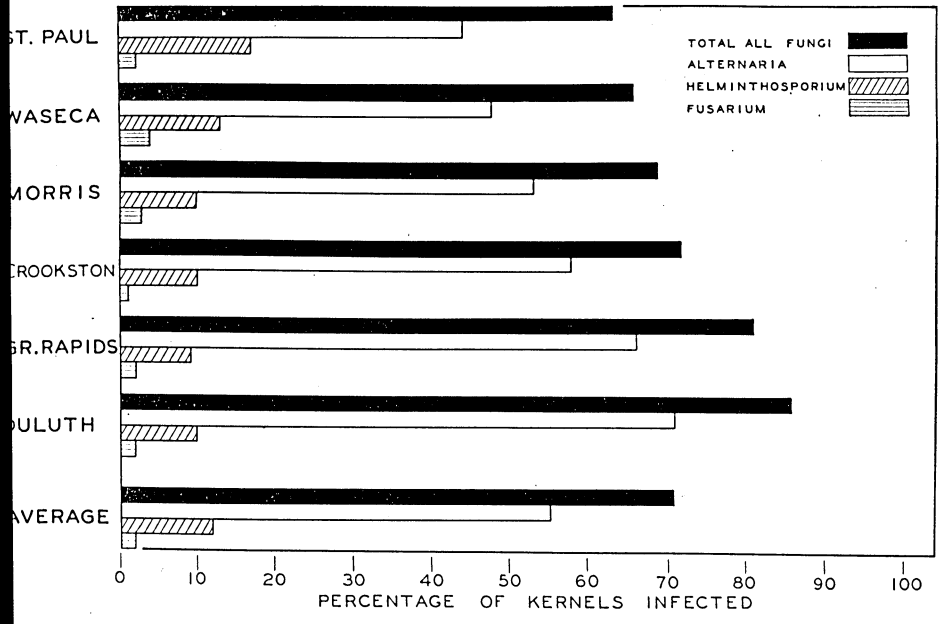


Fig. 15. Average percentage of kernels of hard red spring wheat infected with fungi for six locations in Minnesota during the eight-year period from 1935 to 1943.

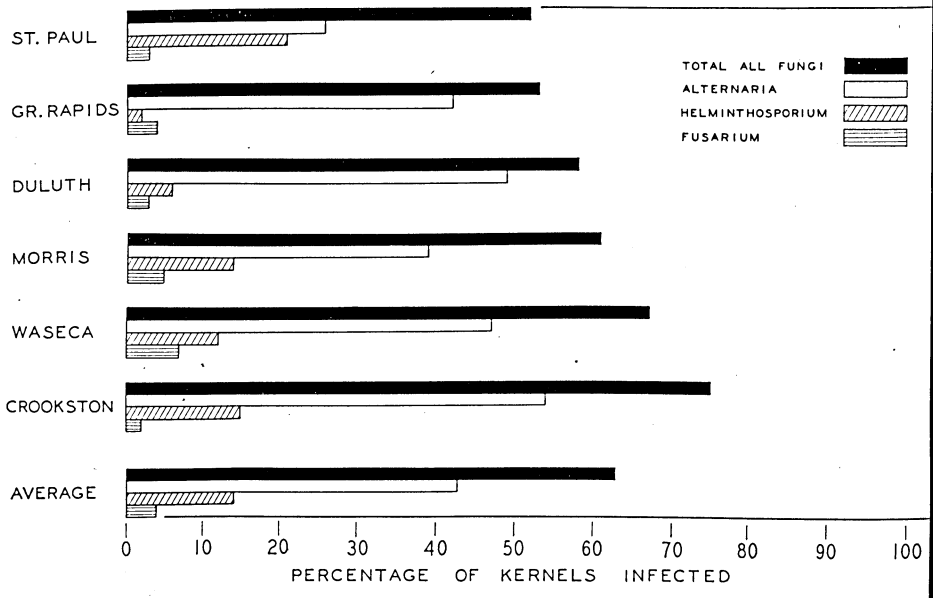


Fig. 16. Average percentage of kernels of Mindum durum wheat infected with fungi for si locations in Minnesota during the eight-year period from 1935 to 1943.

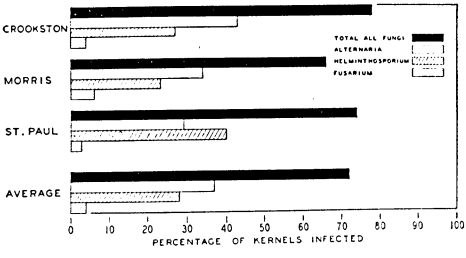


Fig. 17. Average percentage of kernels of Kubanka durum wheat infected with fungi for three locations in Minnesota during the eight-year period from 1935 to 1943.

EFFECTS OF BLACK POINT

On Size and Weight of Kernels

Bolley *(2)* reported that black-pointed grains were usually lighter in weight than the normal best grains. Peyronel *(22)*, Rosella *(23)*, Waldron *(27)*, and Machacek and Greaney *(19)*, on the other hand, found that in a large number of cases the kernel weight of discolored grain was greater than tha of normal grain.

To obtain further information o this relationship as it applies to Nort Central United States, studies wer made at St. Paul, Minnesota in 1939 an 1942. In 1939, 30 seed lots of whea from North Dakota and 50 seed lot from Minnesota were examined. Fift kernels with discoloration and an equa number with no discoloration were se lected at random from each lot. Th discolored and normal kernels wer then weighed and it was found tha the discolored kernels were almost al ways heavier; in some of the sample of durum they were 20 per cent heav ier than normal kernels.

The study was repeated in 1942 us ing 43 seed lots grown at four loca tions in Minnesota. In 42 of the 43 lot the discolored kernels were heavie than those free from discoloration; o the average they were 7 per cent heav ier. Differences in weight between nor

mal and discolored kernels for the 43 lots ranged from 0 to 17 per cent, depending on the variety and location.

Why are discolored kernels heavier than normal kernels from the same lot? Do the larger kernels become infected because they are large or are they large as a result of the infection? Waldron *(27)* made a careful study of the amounts of black point in different parts of the spike and found that the heavier mid-spike kernels had more discoloration than the kernels in the end of the spike. He also found that the third-floret kernels showed less discoloration than the heavier paired kernels in the same spikelets. In other words, he found that there was a higher percentage of discolored kernels in those locations of the spike where the kernels are normally the largest. However, he states that within any kernel group of the spike, such as the third-floret group, the discolored kernels were significantly heavier than the normal ones and suggested that this difference in weight might be due in part to a stimulatory effect of the fungus on the endosperm.

Machacek and Greaney *(19)* suggest that the reason discolored kernels are frequently larger than the normal ones is that the larger kernels force open their covering glumes, thus affording access to air-borne spores, whereas the glumes of small kernels remain closed and exclude such spores. At present, the evidence on this point is inconclusive.

On Germination and Seedling Stand

The relation of seed discoloration to germination and stand depend on what organism or organisms caused the discoloration. If Alternaria caused it, there is little if any effect. If Helminthosporium caused it, there may be detrimental effects.

Since there is great variation in the relative prevalence of these two fungi in different localities and in different years, it is understandable that workers should have reached different conclusions as to the effects of seed infection on germination and stand. Miége *(20)* found no differences in germination between healthy and discolored seed lots. Waldron *(28)* obtained only slight reductions in germination when discolored seed was shown. Peyronel *(22)* stated that the effect on germination varied; in certain seed lots the germination was slightly lower in the affected grain.

Most of these workers did not indicate the kind of fungi associated with the discoloration of the seed lots studied *(19)*. Since Alternaria is the most common fungus associated with wheat seed in most years, it is probable that most of the lots that gave no reduction in stand were infected with Alternaria or some other nonpathogenic fungus rather than with Helminthosporium.

Stakman *(26)*, Christensen *(5)*, Henry *(15)*, Weniger *(30)*, Machacek and Greaney *(19)*, and Hanson and Christensen *(14)*, and others have reported that wheat kernels infected with *H. sativum* commonly germinated poorly, and that in most cases, diseased seedlings resulted from such seed. Dastur *(10)* showed that the value of a crop was appreciably reduced when grain infected with *H. sativum* was used for seed. He found that the discolored seed germinated poorly, and that the resulting seedlings usually developed blight.

Bolley *(2)* reported that wheat seedlings from diseased kernels were usually weaker than those from healthy kernels. Machacek *(see 19)* found that discolored kernels selected from a number of wheat varieties germinated poorly.

Machacek and Greaney *(19)* compared two lots of Pentad durum, one produced in 1934 and containing mostly Alternaria and the other produced in 1935 containing mostly *Helminthospori-*

um sativum, in greenhouse and field tests. They found marked differences in both experiments. In their field study the seed infected with Alternaria produced an 87.5 per cent stand as compared with only 24.9 for the seed infected with *H. sativum.* Similarly, the seedling-disease rating on the plants from the seed infected with Alternaria was 28.5 as compared with 80.6 for the plants from the seed containing *H. sativum.*

The writers have made extensive replicated tests with several hundred seed lots of known microflora from numerous locations in steamed and nonsteamed soil in the greenhouse and in naturally infested soil in the field at St. Paul, Minnesota, during the nine-year period from 1935 to 1943.

In no cases have there been appreciable reductions in stand or increases in the amount of seedling blight as a result of Alternaria infection. Usually there were no differences whatsoever when such seed was compared with healthy seed.

Seed infected with *H. sativum,* on the other hand, commonly germinated poorly and some of these lots produced stands which were only 18 per cent as high as healthy or treated lots of the same varieties. It was the usual thing for seed infected with *H. sativum* to produce inferior stands with more seedling blight than clean seed, treated seed, or seed infected with Alternaria.

While the vast majority of Helminthosporia dealt with in this study were definitely pathogenic, a few were less pathogenic than the others. This is understandable as Christensen *(5)* has demonstrated that *H. sativum* comprises numerous physiologic races, some of which are much less pathogenic than others. Moreover, a small percentage of the Helminthosporium isolates were species other than *H. sativum* and usually were less pathogenic than the latter.

RESPONSE TO SEED TREATMENT

Many workers *(3, 6, 7, 19)* have obtained benefits from treating seed of cereals with organic mercury fungicides if the seed was infected with pathogenic fungi such as *Helminthosporium sativum* but not when the seed was infected with Alternaria.

Machacek and Greaney *(19)* observed no increase in seedling emergence or any appreciable reduction in the amount of root rot when they disinfected wheat seed grown in 1932, 1933, and 1934 with mercuric bichloride steep, Semesan steep, copper carbonate dust, Ceresan, or New Improved Ceresan. The reason for this, they stated, "seemed to be that Alternaria was the dominant fungus in the seed produced in those years, so that little or no disease developed in the seedlings, even in the controls." When, however, they used seed from the 1935 crop which was infected with *H. sativum,* New Improved Ceresan and Leytosan improved the stand, reduced root rot, and increased yield in replicated field tests.

The writers made numerous tests during the period of these investigations in steamed and nonsteamed soil in the greenhouse and in naturally infested soil in the field. They used Ceresan, New Improved Ceresan, and Semesan, Jr. The method of treatment was to apply an excess of the dusts to the seed, thoroughly mix, and screen off the excess dust.

The benefits obtained measured in terms of increases in seedling stand and reductions in the amounts of seedling blight, were determined almost invariably by the microflora on the seed. When the seed was clean or infected with Alternaria only, and sown in steamed soil, little—usually no—benefit was obtained from seed treatment. When such seed was sown in naturally infested soil either in the greenhouse or in the field, there usually was some benefit from seed treat-

Table 3. The Percentage Germination, Percentages of Seeds Infected With Helminthosporium or Fusarium, and Response to Seed Treatment with Semesan, Jr. of 35 Seed Lots Produced at Six Locations in Minnesota in 1942. The Response to Seed Treatment Was Determined in a Field at St. Paul in 1943

Source	Variety	Germination* on blotters in per cent	Per cent* of seeds infected with Helminthosporium or Fusarium	Response to seed treatment†					
				Seedling stand in per cent			Disease rating in per cent‡		
				Seed not treated	Seed treated	Per cent increase or decrease due to treatment	Seed not treated	Seed treated	Per cent increase or decrease due to treatment
Crookston	Ceres	96	21	79	89	+13	20	8	−60
	Kubanka	62	74	35	72	+106	63	3	−95
	Marquis	90	29	69	92	+33	26	8	−69
	Mindum	74	40	50	76	+52	37	4	−89
	Regent	84	32	69	94	+36	29	3	−90
	Rival	84	33	75	87	+16	17	3	−82
	Thatcher	91	19	75	86	+15	20	6	−70
	Average	83	35	65	85	+39	30	5	−79
Duluth	Marquis	94	12	78	90	+15	19	5	−74
	Regent	93	7	76	88	+16	19	6	−68
	Rival	96	11	79	80	+1	19	16	−16
	Thatcher	94	12	83	84	+1	13	11	−15
	Average	94	11	79	86	+8	18	10	−43
Grand Rapids	Marquis	83	24	63	66	+5	30	21	−30
	Regent	91	18	63	83	+32	33	9	−73
	Rival	88	15	74	77	+4	19	13	−32
	Thatcher	90	15	68	81	+19	27	11	−59
	Average	88	18	67	77	+15	27	14	−49
Morris	Ceres	91	8	65	85	+31	30	8	−73
	Kubanka	58	41	36	58	+61	40	7	−83
	Marquis	91	14	74	86	+16	23	7	−70
	Mindum	81	33	52	74	+42	38	10	−74
	Regent	88	15	73	91	+25	24	2	−92
	Rival	83	24	72	87	+21	20	3	−85
	Thatcher	91	10	76	91	+20	17	2	−88
	Average	83	21	64	82	+31	27	6	−81
St. Paul	Ceres	91	40	67	86	+28	34	7	−79
	Kubanka	66	81	23	67	+191	10	10	−85
	Marquis	91	26	70	94	+34	27	1	−96
	Mindum	68	50	30	70	+133	59	6	−90
	Regent	85	38	48	81	+69	49	12	−76
	Rival	89	35	70	71	+1	22	20	−9
	Thatcher	94	40	75	71	−5	21	9	−57
	Average	83	44	55	77	+64	40	9	−70
Waseca	Ceres	88	43	66	86	+30	29	4	−86
	Marquis	90	38	68	88	+29	25	5	−80
	Mindum	63	43	41	71	+73	48	15	−69
	Regent	83	66	52	87	+67	46	5	−89
	Rival	90	34	69	79	+15	26	13	−50
	Thatcher	87	25	67	87	+30	26	3	−89
	Average	84	42	61	83	+40	33	8	−77

Results based on:

* Each lot includes 200 kernels.

† Four replicates of 400 seeds each per lot sown in 12-foot rows.

‡ Disease rating based on the extent and intensity of discoloration and decay of underground parts—the higher the disease rating, the greater the severity of infection.

ment due to protection against soil-inhabiting pathogens.

Plating tests of diseased seedlings from check plots in such a study usually yielded *H. sativum,* indicating that the disease on the seedlings was not due to the Alternaria on the seed. Most benefit from seed treatment was always obtained when the seed lots had a relatively high percentage of the kernels infected with Helminthosporium or Fusarium.

The relation of microflora of seed in response to seed treatment is illustrated in tables 3, 4, 5, and 6. In 1943, two tests were made with seed from the 1942 crop. One of these included seed lots of seven varieties from six locations in Minnesota (see table 3) and the other included 10 varieties from 14 locations (see table 4) in the United States. All of these lots were sown in the spring of 1943 in 12-foot rows, 400 seeds per row, in a split-plot test replicated four times in a field at St. Paul, Minnesota.

All except one of the seed lots produced in Minnesota gave increased stands when treated and all of these lots had less disease than those receiving no treatment. The percentage increase or decrease in stand due to treatment ranged from −5 to +191. The percentage decrease in disease ranged from 9 to 95. In most years it would be highly desirable to treat all seed lots grown in Minnesota.

In states other than Minnesota, the

Table 4. The Percentage Germination, Percentage of Seeds Infected with Helminthosporium or Fusarium, and Response to Seed Treatment with Semesan, Jr. of 36 Seed Lots Obtained from 14 Locations. These Samples of Wheat Were Produced at the Indicated Locations in 1942 and Their Response to Seed Treatment Determined in a Field at St. Paul, Minnesota in 1943

Source	Variety	Germination* on blotters in per cent	Per cent* of seeds infected with Helminthosporium or Fusarium	Response to seed treatment†: Seedling stand in per cent: Seed not treated	Seedling stand in per cent: Seed treated	Seedling stand in per cent: Per cent increase or decrease due to treatment	Disease rating in per cent‡: Seed not treated	Disease rating in per cent‡: Seed treated	Disease rating in per cent‡: Per cent increase or decrease due to treatment
Illinois	Pilot-13	89	35	61	84	+38	34	9	−74
	Renown	86	20	71	79	+11	21	11	−48
	Rival	86	33	76	85	+12	16	9	−44
	Average	87	29	69	83	+20	24	10	−55
Indiana	Fairfield	97	7	86	89	+4	12	9	−25
	Purkof	98	2	84	94	+12	15	5	−67
	Average	98	5	85	92	+8	14	7	−46
Iowa	Pilot-13	93	20	76	83	+9	23	14	−39
	Thatcher	90	22	69	73	+6	27	20	−26
	Average	92	21	73	78	+8	25	17	−33
Kansas	Marquis	91	30	71	76	+7	25	18	−28
	Mindum	84	31	48	81	+69	45	7	−84
	Thatcher	93	22	85	84	−1	13	11	−15
	Average	89	28	68	80	+25	28	12	−42

Results based on:
* Each lot includes 200 kernels.
† Four replications of 400 seeds each sown in 12-foot rows.
‡ Disease rating based on the extent and intensity of discoloration and decay of underground parts—the higher the disease rating, the greater the severity of infection.

Table 4—Continued.

Source	Variety	Germination* on blotters in per cent	Per cent* of seeds infected with Helminthosporium or Fusarium	Response to seed treatment†: Seedling stand in per cent: Seed not treated	Seedling stand in per cent: Seed treated	Seedling stand in per cent: Per cent increase or decrease due to treatment	Disease rating in per cent‡: Seed not treated	Disease rating in per cent‡: Seed treated	Disease rating in per cent‡: Per cent increase or decrease due to treatment
Minnesota (St. Paul)	Marquis	91	26	64	92	+44	33	15	−55
	Mindum	68	50	45	82	+82	41	3	−93
	Thatcher	94	40	74	81	+10	23	14	−39
	Average	84	39	61	85	+45	32	11	−62
Montana	Marquis	90	0	82	90	+10	10	5	−50
	Pilot-13	91	0	82	76	−7	12	18	+50
	Thatcher	79	0	82	81	−1	7	3	−57
	Average	87	0	82	82	+1	10	9	−19
Nebraska	Marquis	82	9	52	68	+31	38	18	−53
	Mindum	84	8	72	81	+13	18	11	−39
	Thatcher	83	3	73	71	−3	14	15	+7
	Average	83	7	66	73	+14	23	15	−28
N. Dakota (Fargo)	Marquis	95	14	77	89	+16	20	8	−60
	Mindum	89	22	59	78	+32	37	13	−65
	Thatcher	97	7	81	85	+5	17	14	−18
	Average	94	14	72	84	+18	25	12	−48
N. Dakota (Langdon)	Marquis	96	3	82	83	+1	17	15	−12
	Mindum	91	9	70	79	+11	26	14	−46
	Thatcher	97	4	81	69	−15	17	28	+65§
	Average	95	5	78	77	−1	20	19	+2
S. Dakota	Marquis	80	36	52	79	+52	38	8	−79
	Mindum	68	45	33	70	+112	53	5	−91
	Thatcher	78	36	45	70	+56	44	12	−73
	Average	75	39	43	73	+73	45	8	−81
Texas	Denton	89	13	72	79	+10	21	11	−48
	Fultz	90	1	73	83	+14	20	9	−55
	Average	90	7	73	81	+12	21	10	−52
Utah	Marquis	76	2	63	75	+19	20	6	−70
	Average	76	2	63	75	+19	20	6	−70
Washington	Marquis	97	0	82	87	+6	18	11	−39
	Renown	93	0	78	85	+9	18	10	−44
	Average	95	0	80	86	+8	18	11	−42
Wisconsin	Marquis	73	92	50	74	+48	40	3	−93
	Pilot-13	92	87	67	82	+22	33	12	−64
	Thatcher	85	71	47	72	+57	45	23	−49
	Average	83	83	55	76	+42	39	13	−69

Results based on:

* Each lot includes 200 kernels.

† Four replications of 400 seeds each sown in 12-foot rows.

‡ Disease rating based on the extent and intensity of discoloration and decay of underground parts—the higher the disease rating, the greater the severity of infection.

§ Seed lot injured by seed treatment.

Table 5. Percentage Germination, Percentage of Seeds Infected with Helminthosporium or Fusarium, and Response to Seed Treatment with Semesan, Jr. of 31 Lots of Spring Wheat Produced at Six Locations in Minnesota in 1943. The Response to Seed Treatment was Determined in the Greenhouse at St. Paul in 1944

Source	Variety	Germination* on blotters in per cent	Per cent* of seeds infected with Helminthosporium or Fusarium	Response to seed treatment†					
				Seedling stand in per cent			Disease rating in per cent‡		
				Seed not treated	Seed treated	Per cent increase or decrease due to treatment	Seed not treated	Seed treated	Per cent increase or decrease due to treatment
Crookston	Ceres	97	28	64	96	+50	48	14	−71
	Kubanka	42	74	20	90	+350	77	13	−83
	Marquis	99	17	81	97	+20	38	14	−63
	Mindum	51	39	21	87	+314	78	18	−77
	Regent	71	30	61	93	+52	49	20	−59
	Rival	73	24	24	94	+292	76	18	−76
	Thatcher	94	24	80	97	+21	31	11	−64
	Average	75	34	50	93	+157	57	15	−70
Duluth	Regent	88	41	54	96	+78	61	19	−69
	Rival	92	40	64	97	+52	49	9	−82
	Thatcher	97	30	78	96	+23	34	12	−65
	Average	92	37	65	96	+51	48	13	−72
Grand Rapids	Regent	89	35	64	88	+38	52	22	−58
	Rival	92	26	62	91	+47	41	13	−68
	Thatcher	97	21	82	94	+15	26	11	−58
	Average	93	27	69	91	+33	40	15	−61
Morris	Ceres	95	25	63	90	+43	48	16	−67
	Kubanka	64	85	16	88	+450	80	22	−72
	Marquis	98	19	76	91	+20	33	20	−39
	Mindum	87	59	46	82	+78	53	21	−60
	Regent	87	36	58	93	+60	51	19	−63
	Rival	92	36	69	94	+36	38	12	−68
	Thatcher	96	36	71	95	+34	39	16	−59
	Average	88	42	57	90	+103	49	18	−61
St. Paul	Ceres	87	65	43	93	+116	68	13	−81
	Marquis	88	32	50	92	+84	61	15	−75
	Mindum	65	68	18	71	+294	78	17	−78
	Regent	76	65	40	92	+130	67	17	−75
	Rival	86	44	44	87	+98	59	14	−76
	Thatcher	89	64	56	88	+57	50	10	−80
	Average	82	56	42	87	+130	64	14	−78
Waseca	Ceres	91	46	57	86	+51	51	16	−69
	Marquis	88	41	61	85	+39	50	19	−62
	Regent	86	57	43	90	+109	63	17	−73
	Rival	86	68	61	87	+43	46	13	−72
	Thatcher	93	51	71	94	+32	37	11	−70
	Average	89	53	59	88	+55	49	15	−69

Results based on:
* Each lot includes 200 kernels.
† Four replications of 100 seeds each per lot.
‡ Disease rating based on the extent and intensity of discoloration and decay of underground parts—the higher the disease rating, the greater the severity of infection.

responses to treatment were in general proportional to the amount of root-rotting fungi in the seed. Lots having high percentages of seed infected with Helminthosporium and Fusarium usually responded most to treatment. The percentage increase or decrease in stand ranged from −15 to +112 and in disease rating from +65 (this lot injured by treatment) to −93. Most of the lots benefited from treatment. The disease ratings were based on the extent and intensity of discoloration and decay of underground parts— the higher the disease rating, the greater the severity of infection.

Similar studies also were made in 1944. These included seven varieties produced at six locations in Minnesota in 1943 and 46 lots produced in 13 locations in the United States in 1943. The Minnesota lots were sown March 20, 1944, in flats in a greenhouse at St. Paul in naturally infested field soil using a split-plot design and four replications of 100 seeds per treatment per seed lot. The results of the study are summarized in table 5 and show that seed treatment caused increases in stand up to 450 per cent in the durum wheats and up to 292 per cent in some of the bread wheats.

Forty-six lots produced in 12 states in 1943 were seeded in a field at St. Paul in the spring of 1944 in 12-foot rows replicated four times as described for the 1943 field test. The results are given in table 6. The average percentage of infected seed in these lots varied from 0 in the lot from Montana to 99 per cent in the North and South Dakota lots. Similarly, the average percentage of Helminthosporium and Fusarium varied from 0 in the lot from Montana to 66 per cent in the South Dakota lot.

It would be expected that with seed lots varying so greatly in their microflora, some would respond to seed treatment and others would not. This is precisely what happened. The lots from Indiana, Washington, and all except one from Montana showed little benefit from seed treatment while most of the lots from other states showed marked benefits. There was a high negative correlation between the percentage of kernels infected with Helminthosporium or Fusarium and per cent seedling stand.

RELATIONSHIPS BETWEEN FACTORS STUDIED

To further resolve the data and to facilitate their interpretation, the degree of association between some of the factors studied was determined by calculating correlation coefficients. The factors correlated, the source of the wheats upon which these data were based, the number of comparisons, and the correlation coefficients obtained are given in table 7.

Relation of Per Cent Discolored Kernels to Per Cent Shriveling

The seed lots used in this study were classified as to the amount of shriveling of the kernels by comparing them with standards of the same varieties, based both on the percentage of kernels shriveled and the degree of shriveling. The amount of shriveling in the lots used ranged from 5 to 50 per cent.

As indicated in table 7, there were large differences between the correlation coefficients calculated when different sources of wheats were studied. For example, when 25 wheats grown at 13 locations in the United States in 1942 were used, a highly significant negative correlation coefficient (−.638) was obtained. This result would suggest that the greater the amount of shriveling the lower the percentage of discolored seed.

When the amounts of stem rust or of leaf rust were correlated with the percentage of discolored kernels produced by the rusted plants, negative

Table 6. The Percentage Germination, Percentage of Seeds Infected with Helminthosporium or Fusarium, and Response to Seed Treatment with Semesan, Jr. of 46 Lots of Wheat Produced at 13 Locations in 1943. The Response to Seed Treatment was Determined in a Field at St. Paul, Minnesota in 1944

Source	Variety	Germination* on blotters in per cent	Per cent* of seeds infected with Helminthosporium or Fusarium	Response to seed treatment†: Seedling stand in per cent: Seed not treated	Seedling stand in per cent: Seed treated	Seedling stand in per cent: Per cent increase or decrease due to treatment	Disease rating in per cent‡: Seed not treated	Disease rating in per cent‡: Seed treated	Disease rating in per cent‡: Per cent increase or decrease due to treatment
Illinois	Pilot	96	55	63	76	+21	36	22	−39
(Urbana)	Renown	92	42	71	77	+8	25	19	−24
	Rival	88	36	70	84	+20	24	9	−62
	Average	92	44	68	79	+16	28	17	−42
Indiana	Fairfield	97	11	89	88	−1	10	9	−10
(Lafayette)	Purkof	98	4	89	89	0	11	10	−9
	Average	98	8	89	88	−1	10	10	−10
Iowa	C.I.12265	80	65	47	66	+40	43	20	−53
(Ames)	Average	80	65	47	66	+40	43	20	−53
Kansas	Comanche	95	8	77	82	+6	19	14	−26
(Manhattan)	Pawnee	98	6	88	86	−2	11	12	+9
	Red Chief	98	8	86	91	+6	14	8	−43
	Tenmarq	93	12	68	78	+15	27	16	−41
	Average	96	8	80	84	+6	18	12	−25
Minnesota	Mindum	65	68	42	55	+31	39	19	−51
(St. Paul)	Rival	86	44	60	77	+28	34	14	−59
	Thatcher	89	64	49	77	+36	47	14	−70
	Average	80	59	50	70	+32	40	16	−60
Montana	Marquis	94	0	76	74	−3	21	22	+5
(Havre)	Pilot	91	0	68	68	0	27	26	−4
	Rival	92	0	69	77	+12	25	17	−32
	Thatcher	98	0	82	75	−9	17	24	+41
	Average	94	0	74	74	0	22	22	+2
Nebraska	Marquis	86	1	55	62	+13	38	29	−24
(Lincoln)	Mindum	75	10	41	48	+17	47	39	−13
	Rival	94	4	68	80	+18	32	17	−47
	Thatcher	96	2	74	84	+14	26	14	−46
	Average	88	4	60	68	+16	36	25	−32
North Dakota	Carleton	84	34	51	77	+51	41	12	−71
(Fargo)	Kubanka	82	40	48	75	+56	44	12	−73
	Marquis	94	17	80	83	+4	18	14	−22
	Mindum	80	40	59	74	+25	30	10	−67
	Pentad	93	31	63	85	+35	36	11	−69
	Rival	97	24	67	89	+33	32	9	−72
	Thatcher	94	18	66	81	+23	31	15	−52
	Average	89	29	62	81	+32	33	12	−61

Results based on:
* Each lot includes 200 kernels.
† Four replications of 400 seeds each per lot sown in 12-foot rows.
‡ Disease rating based on the extent and intensity of discoloration and decay of underground parts—the higher the disease rating the greater the severity of infection.

Table 6—Continued.

Source	Variety	Germination* on blotters in per cent	Per cent* of seeds infected with Helminthosporium or Fusarium	Response to seed treatment†: Seedling stand in per cent: Seed not treated	Seedling stand in per cent: Seed treated	Seedling stand in per cent: Per cent increase or decrease due to treatment	Disease rating in per cent‡: Seed not treated	Disease rating in per cent‡: Seed treated	Disease rating in per cent‡: Per cent increase or decrease due to treatment
North Dakota (Langdon)	Carleton	93	22	69	77	+16	29	19	−34
	Kubanka	89	35	65	78	+20	30	14	−53
	Marquis	98	8	82	89	+9	19	11	−42
	Mindum	91	21	74	80	+8	22	15	−32
	Rival	94	12	88	86	−2	10	12	+20
	Thatcher	98	12	84	86	+2	16	13	−19
	Average	94	18	77	83	+9	21	14	−27
South Dakota (Brookings)	Mindum	54	64	45	52	+16	25	10	−60
	Rival	77	59	63	78	+24	24	8	−67
	Thatcher	80	75	63	69	+10	25	15	−40
	Average	70	66	57	66	+17	25	11	−56
Texas (Denton)	Denton	86	7	75	77	+3	14	11	−21
	Fultz	89	5	77	70	−9	16	22	+38
	Mindum	87	18	61	67	+10	34	26	−24
	Rival	92	11	70	74	+6	27	21	−22
	Average	88	10	71	72	+2	23	20	−7
Washington (Pullman)	Federation	98	0	83	83	0	16	16	0
	Marquis	97	0	87	88	+1	12	10	−17
	Average	98	0	85	86	+1	14	13	−8
Wisconsin (Madison)	Henry	96	7	80	81	+1	18	18	0
	Pilot	94	25	71	85	+20	28	12	−57
	Thatcher	96	29	73	85	+16	26	13	−50
	Average	95	20	75	84	+12	24	14	−36

Results based on:
* Each lot includes 200 kernels.
† Four replications of 400 seeds each per lot sown in 12-foot rows.
‡ Disease rating based on the extent and intensity of discoloration and decay of underground parts—the higher the disease rating, the greater the severity of infection.

coefficients were also obtained suggesting the same kind of relationship. However, when the degree of association between the amount of shriveling and the percentage of discolored kernels was determined for a collection of 25 wheats grown in Minnesota in 1939, significant positive correlation coefficient (+.353) was obtained suggesting that shriveled lots have more seed discoloration than nonshriveled lots. Similar results were obtained in the study of 22 wheats grown in Minnesota in 1942.

These widely differing results would scarcely permit any generalization as to the relationship between the percentages of shriveled and discolored seed. Apparently, sometimes shriveled seed lots show more discoloration than nonshriveled lots and other times the opposite is true. Perhaps it makes a difference when the shriveling occurs. There are, of course, many factors that can cause shriveling in wheat but it has not been established that the fungi associated with the black point type of discoloration is one of these. Also the

Table 7. Factors Correlated, Source of Wheats Studied, Number of Comparisons, and Correlation Coefficients Obtained

Factors correlated	Source of wheats studied	Number of comparisons (N)	Correlation coefficient (r)†
Per cent discolored kernels to per cent shriveling	25 wheats from 13 locations in the United States in 1942	71	—.638**
Per cent discolored kernels to amount of stem rust‡	18 wheats grown in 6 localities in Minnesota, 1935 to 1942	257	—.101 N.S.
Per cent discolored kernels to amount of leaf rust‡	18 wheats grown in 6 localities in Minnesota, 1935 to 1942	264	—.188**
Per cent discolored kernels to per cent shriveling	25 wheats grown in 6 localities in Minnesota in 1939	97	+.353**
Per cent discolored kernels to per cent shriveling	22 wheats grown in 6 localities in Minnesota in 1942	93	+.273**
Per cent discolored kernels to per cent kernels infected with Alternaria	10 wheats grown in 6 localities in Minnesota, 1935 to 1942	227	+.024 N.S.§
Per cent discolored kernels to percent kernels infected with Helminthosporium	10 wheats grown in 6 localities in Minnesota, 1935 to 1942	227	+.621**
Per cent discolored kernels to per cent kernels infected with Fusarium	10 wheats grown in 6 localities in Minnesota, 1935 to 1942	227	+.167*
Per cent discolored kernels to per cent seedling stand‖	10 wheats grown at 13 locations in the United States in 1942	33	—.511**
Per cent discolored kernels to per cent seedling stand‖	7 wheats grown in 6 localities in Minnesota in 1942	35	—.771**
Per cent discolored kernels to seedling blight infection rating‖	10 wheats grown at 13 locations in the United States in 1942	33	+.614**
Per cent discolored kernels to seedling blight infection rating‖	7 wheats grown in 6 localities in Minnesota in 1942	35	+.758**
Per cent kernels infected with Alternaria to per cent seedling stand‖	10 wheats grown at 13 locations in the United States in 1942	33	—.009 N.S.
Per cent kernels infected with Alternaria to per cent seedling stand‖	7 wheats grown in 6 localities in Minnesota in 1942	35	+.804** ¶
Per cent kernels infected with Helminthosporium to per cent seedling stand‖	10 wheats grown at 13 locations in the United States in 1942	33	—.494**
Per cent kernels infected with Helminthosporium to per cent seedling stand‖	7 wheats grown in 6 localities in Minnesota in 1942	35	—.691**
Per cent kernels infected with Fusarium to per cent seedling stand‖	10 wheats grown at 13 locations in the United States in 1942	33	—.454**
Per cent kernels infected with Fusarium to per cent seedling stand‖	7 wheats grown in 6 localities in Minnesota in 1942	35	—.452**
Per cent kernels infected with Helminthosporium or Fusarium or both to per cent seedling stand‖	10 wheats grown at 13 locations in the United States in 1942	33	—.621**
Per cent kernels infected with either Helminthosporium or Fusarium or both to per cent seedling stand‖	7 wheats grown in 6 localities in Minnesota in 1942	35	—.787**

† N. S. = not significant; * = significant at 5 per cent level; ** = significant at 1 per cent level.

‡ Average severity of rust on the plants producing the seed lot.

§ This does not mean that Alternaria does not cause seed discoloration; it means that in this case seed showing no discoloration had practically as high a percentage of kernels infected with Alternaria as did discolored seed.

‖ When these lots were sown in soil.

¶ This does not mean that seed infected with Alternaria is superior to clean seed. It means that Alternaria is less injurious to stand (it probably has almost no effect on stand or disease rating) than Helminthosporium or Fusarium. Virtually all wheat seed produced in Minnesota in 1942 was infected; there was no clean seed. It was a matter of the seed being infected with Alternaria, Helminthosporium, or Fusarium and the high correlation coefficient of +.804 means that it was better to have the seed infected with Alternaria than with the other two fungi.

results of the present correlation studies neither prove nor disprove the possibility that shriveled seeds are less likely to become infected than normal kernels.

Relation of Per Cent Discolored Kernels to Per Cent Infected Kernels

While it is possible to have nearly 100 per cent of the kernels infected with fungi and still show little or no no seed discoloration, correlation coefficients were calculated between the percentages of seeds discolored and the percentages of seeds infected with Alternaria, Helminthosporium, or Fusarium. Positive coefficients were obtained in each case indicating that there was an association between the presence of these fungi and the presence of discoloration. The correlation coefficient was highly significant when Helminthosporium was present. The association was positive but not significant when Alternaria was present.

The writers have repeatedly produced seed discoloration by artificial inoculation with Alternaria, and with Helminthosporium, but under natural conditions high percentages of seeds can become infected with Alternaria with only a low percentage of these kernels showing any discoloration.

A significant positive correlation was found between the percentage of kernels infected with Fusarium and the percentage of kernels discolored. However, the writers have not been able to artificially produce the black point type of discoloration on wheat with pure cultures of Fusarium.

Relation of Per Cent Discolored Kernels to Per Cent Seedling Stand

The relation of discolored seed to per cent seedling stand when such seed is used for sowing purposes depends upon what fungi caused the discoloration. Discolored seed may produce just as good stands as seed that is not discolored. This happens when the discoloration is due to fungi which are not pathogenic to seedlings. On the other hand, as indicated in table 7, there may be highly significant reductions in stand when discolored lots are infected with fungi that are pathogenic to seedlings.

Relation of Seed Microflora to Seedling Stand

The most important factor determining whether or not infected seed produced stands inferior to those of healthy or treated seed was the kind of fungi associated with the infected seed. When only Alternaria was present, little effect on stand was noted; on the other hand, when Helminthosporium or Fusarium was responsible for much of the infection, significant decreases in stand were common.

Relation of Seed Microflora to Amount of Seedling Blight

Again, the kind of fungi associated with the seed greatly influenced the amount of seedling blight. When the seed was infected with Alternaria only, no increase in the amount of disease as compared with clean seed was usually obtained. However, when the seed was infected with either Helminthosporium or Fusarium, the amount of seedling blight usually was very much increased.

DISCUSSION

The importance of seed discoloration is determined by the prevalence, severity, and cause of the discoloration. The severity is probably more important than prevalence to the milling industry because when the discoloration is localized in the germ end or does not extend beyond the bran layer,

it can be removed readily before the grain is ground. However, when the discoloration extends beyond the germ and into the endosperm, or when it extends into the crease of the kernel, it is very objectionable because then it is difficult and costly to remove.

Rarely is seed discoloration sufficiently prevalent and severe in bread wheats to constitute much of a problem, but it is very commonly a problem in the milling of durums where the discoloration appears as dark specks in the finished products thus lowering their value.

The kind of fungi involved determines the effect of discoloration on the value of the grain for sowing purposes. Two fungi, Alternaria and Helminthosporium, constitute by far the largest percentage of all fungi associated with this kind of seed discoloration. The former has little, if any, deleterious effect on the value of the infected grain for seed. Helminthosporium, on the other hand, commonly lowers germination, causes seedling blight and dwarfing, reduces stands, and may decrease yields.

The microflora of the seed cannot be accurately determined by microscopic examination; plating tests are necessary and these do not give a complete picture of internal infection because the methods commonly used kill all of the mycelium present immediately beneath the pericarp and may kill some of the mycelium in deeper tissues. The percentage of Fusarium associated with black point is very low, and since it has not been possible to produce the disease by artificial inoculations with this fungus, there is no evidence that it can cause black point. It has been definitely established by extensive artificial inoculations that both Helminthosporium and Alternaria can cause the disease, singly or in combination.[4]

[4] Unpublished data by the authors.

The percentage of discolored kernels varied from 0 to nearly 100 per cent, depending on the variety, locality, and year. The percentage of infected kernels varied as much but on the average was higher because many seeds were infected that showed no discoloration. Seed lots of the same varieties produced in the same year but in different localities often differed greatly in the percentage of kernels infected or discolored. Such differences sometimes were greater than differences between seed lots of the same varieties produced in the same locality in different years.

The tremendous variation in the amounts of discolored and infected seed is closely related to meteorological conditions. High humidity following heading of the crop appears to be the most important factor influencing infection. As a rule wheat seed produced under irrigation or in relatively arid regions is likely to be relatively free from black point, whereas seed produced in relatively moist regions is more likely to be heavily infected with microorganisms.

Within Minnesota there is great variability in precipitation from one season to another and from one locality to another so that one may expect striking variation in percentages of diseased kernels. This actually is the case. Field experiments in Minnesota, with and without muslin tents, have demonstrated that weather conditions may greatly influence not only the amount of infection but also the progress of the disease after infection has taken place.

In general, high temperatures in association with high humidity are conducive to the invasion of the developing seed by fungi. These conditions occur in most years in the hard red spring wheat area, particularly in Minnesota. The varieties most susceptible to black point may escape infection in a dry season, as in 1936, whereas even the

more resistant varieties may develop considerable black point in relatively wet seasons as in 1943. Therefore, in the future one may expect marked yearly fluctuations in kernel infection and occasional epidemics of black point, especially in the hard red spring wheat region.

Although the larger kernels within a given seed lot are most frequently discolored, small and shriveled kernels are not infrequently discolored. The writers have demonstrated repeatedly that *Helminthosporium spp.* and other fungi can cause severe discoloration and shriveling of wheat and barley kernels. The severity depends on time of infection—the earlier the infection, the greater the damage. Moreover, extensive laboratory and greenhouse tests indicate that apparently healthy seed without any sign of discoloration may harbor pathogenic fungi. It is recommended, therefore, that all seed lots of wheat produced in Minnesota be treated with an approved seed disinfectant before they are sown.

The black point disease is very difficult to control. Since the fungi that cause it are readily air-borne, cultural practices are of little, if any, value. The most promising method of control is the development of more resistant varieties.

The common wheats as a class are more resistant to discoloration than the durums, although some varieties are fairly susceptible. Durums are not all equally susceptible. All durums are late maturing varieties, but resistance is not necessarily associated with date of maturity. Reward is one of the early maturing wheats, yet it is one of the most susceptible of the vulgare group.

Extensive tests made over a period of years have shown that there are marked genetic differences in varietal susceptibility to black point. Marquis and Ceres are two of the more resistant varieties while Kubanka and Mindum are two of the more susceptible ones. If a large number of lines and varieties of durum wheats could be tested, perhaps resistant varieties within the durum class also might be found. Naturally, this would be of considerable practical importance in a durum breeding program.

SUMMARY

1. From 1935 to 1943 the prevalence of black point was ascertained for more than 1,000 lots of wheat seed produced in 13 states.
2. Most of the seed lots contained black point kernels. Seed lots with 25 per cent or more discolored seeds were not uncommon. The percentages ranged from 0 to 95.
3. The amount of black point present in different seed lots varied greatly from region to region and from season to season, depending largely upon the meteorological conditions under which the seed was produced. Warm and moist weather while the grain was maturing was conducive to the development of black point and kernel infection.
4. The relative susceptibility of varieties of wheat to black point was ascertained on seed lots from 20 stations in the 13 states. In general, the durums were much more susceptible than the vulgare wheats. Marquis, Ceres, and Regent were most resistant, whereas Mindum and Kubanka were most susceptible.
5. The percentage of kernels infected with fungi was almost always much higher than the percentage of discolored seed. Plating tests on nutrient media indicated that many species of fungi were associated with most seed lots whether or not they were discolored. *Alternaria spp.* and *Helminthosporium spp.* were the

predominant organisms associated with discolored seed. *Fusarium spp.* were also common in many lots but these have not been shown to cause black point of wheat.

6. *Helminthosporium spp.* and *Fusarium spp.* were the most common pathogens isolated from wheat kernels. Alternaria, although the most prevalent fungus, was either nonpathogenic or only weakly pathogenic and never caused seedling blight of wheat in the greenhouse or field.
7. Seed treatment improved germination and increased stand and vigor of the plants when the seed was infected with Helminthosporium and/or Fusarium, but it had little or no effect on disease-free seed or on seed infected with Alternaria. Since Helminthosporium and Fusarium frequently infect wheat seed and since their absence cannot be ascertained by visual inspection, it is recommended that all seed lots grown in Minnesota be treated before sowing.

LITERATURE CITED

1. Bockmann, H. Die Schwärzepilze des Getreides unter besonderer Berücksichtigung ihrer Pathogenität und des Vorkommens von Rassen innerhalb der Gattungen *Cladosporium* Link and *Alternaria* Ness. Angew. Bot. *15:* 308-321; 329-385. 1933.
2. Bolley, H. L. Wheat: soil troubles and seed deterioration. N. Dak. Agr. Expt. Sta. Bul. 107. 1913.
3. Brentzel, W. E. The black point disease of wheat. N. Dak. Agr. Expt. Sta. Bul. 330. 1944.
4. Christensen, Clyde M. Fungi on and in wheat seed. Cereal Chem. *28:* 408-415. 1951.
5. Christensen, J. J. Studies on the parasitism of *Helminthosporium sativum.* Minn. Agr. Expt. Sta. Tech. Bul. 11. 1922.
6. ———. Associations of microorganisms in relation to seedling injury arising from infected seed. Phytopathology *26:* 1091-1105. 1936.
7. ———, and Stakman, E. C. Relation of Fusarium and Helminthosporium in barley seed to seedling blight and yield. Phytopathology *25:* 309-327. 1935.
8. Curzi, M. La "puntatura" delle cariossidi di frumento e una nuova specie di Alternaria. Riv. di Patol. Veg. *16:* 125-136. 1926.
9. Dastur, J. F. Annual report on the Mycological Section for the year ending March, 1927. Reprinted from Rpt. Dept. of Agr. Central Provinces and Berar, for the year 1926-27, 1928. (Abstr. in Rev. Appl. Mycol. 7: 492-493. 1928).
10. ———. Foot rot and "black point" diseases of wheat in the Central Provinces. Agr. and Livestock in India. *2:* 275-282. 1932.
11. Evans, Nevada S. "Black point" of wheat. (Note) Phytopathology *11:* 515. 1921.
12. Greaney, F. J., and Machacek, J. E. Prevalence of seed-borne fungi on cereals in certain seed inspection districts of Canada. Sci. Agr. *22:* 419-437. 1942.
13. ———, and Wallace, H. A. H. Varietal susceptibility to kernel smudge in wheat. Sci. Agr. *24:* 126-134. 1943.
14. Hanson, E. W., and Christensen, J. J. Studies on the "black point" disease of wheat in the United States. (Abstr.) Phytopathology *33:* 1112-1113. 1943.
15. Henry, A. W. Root-rots of wheat. Minn. Agr. Expt. Sta. Tech. Bul. 22. 1924.
16. Hyde, M. B. The subepidermal fungi of cereal grains. I. A survey of the world distribution of fungal mycelium in wheat. Ann. Appl. Biol. *37:* 179-186. 1950.
17. Laumont, P., and Murat, M. Observations sur la moucheture et la mauvaise germination de quelques bles en 1933. Bul. Soc. d'Hist. Nat. de l'Afrique du Nord *25:* 253-265. 1934.

18. MACHACEK, J. E., CHEREWICK, W. J., MEAD, H. W., and BROADFOOT, W. C. A study of some seed-borne diseases of cereals in Canada. II. Kinds of fungi and prevalence of disease in cereal seed. Sci. Agr. *31:* 193-206. 1951.

19. ———, and GREANEY, F. J. The "black point" or "kernel smudge" disease of cereals. Canad. Jour. Res. *16:* 84-113. 1938.

20. MIÈGE, E. Le mouchetage des grains de ble. Rev. de Path. Veg. et d'Ent. Agr. de France. *17:* 262-337. 1930.

21. PASINETTI, L. Ricerche anatomo-fisiologiche sulla "punta nera" del frumento argentino "San Martin." Rev. Pat. Veg. *21:* 145-156. 1931.

22. PEYRONEL, B. La "puntatura" dello scudetto nelle cariossidi del frumento. Bol. R. Staz. Pat. Veg. *6:* 10-25. 1926.

23. ROSELLA, E. Quelques observations sur la moucheture des céréales. Rev. de Path. Veg. et d'Ent. Agr. de France. *17:* 338-344. 1930.

24. ———. Sur une moucheture de l'orge. Rev. de Path. Veg. et d'Ent. Agr. de France. *17:* 345-348. 1930.

25. SIMMONDS, P. M., and MEAD, H. W. The examination of wheat seed to determine the disease factor. Sci. Agr. *16:* 175-179. 1935.

26. STAKMAN, LOUISE J. A Helminthosporium disease of wheat and rye. Minn. Agr. Expt. Sta. Bul. 191. 1920.

27. WALDRON, L. R. Increase of kernel weight in common wheat due to black-point disease. Jour. Agr. Res. *48:* 1017-1024. 1934.

28. ———. Influence of black point disease, seed treatment, and origin of seed on stand and yield of hard red spring wheat. Jour. Agr. Res. *53:* 781-788. 1936.

29. WENIGER, WANDA. Diseases of grain and forage crops in North Dakota. N. Dak. Agr. Expt. Sta. Bul. 166. 1923.

30. ———. Blackpoint caused by *Helminthosporium sativum* Pam., King, and Bak. U.S. Dept. Agr. Plant Disease Reporter, Supplement 40: 136. 1925.

31. ZILING, M. K. ["Black germ" of wheat.] [Diseases of cereal crops], issued by Siberian Scient. Res. Institute for Cereal Industry, Omsk. pp. 15-39. 1932. (Abstr. in Rev. Appl. Mycol. *12:* 160-161. 1933.)