INCREASE OF KERNEL WEIGHT IN COMMON WHEAT DUE TO BLACK-POINT DISEASE [1]

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INTRODUCTION

This paper deals mainly with the relative weights of kernels of wheat (*Triticum vulgare* Vill.) showing the presence of "black point" and those free from this infection. The main study was made upon kernels from individual wheat plants from the F_5 population resulting from the cross Reward × ((Kota × Marquis) × Hope). The wheat, grown at Fargo in 1933, was planted on May 5, which was about 2 weeks later than the earliest date available for planting in the nursery where it was grown.

A sample of the infected kernels was submitted to H. B. Humphrey, of the Bureau of Plant Industry, United States Department of Agriculture. Dr. Humphrey reported that about one half of the kernels were infected with a strain of *Al'ernaria*, while the remainder were clearly and positively infected with *Helminthosporium sativum* Pam., King, and Bak. Black point was much in evidence in a number of common wheats in 1933 in the nursery, the percentage of infection varying decidedly with the breeding of the wheat and also, evidently, with the time of planting.

In previous reports upon black point, durum wheats have been held to be most commonly infected (Evans [2] and Weniger)[3] although the infection has not been at all rare upon common wheats. Weniger reports that *Helminthosporium* may produce different types of infection. She mentions head blighting characterized by typical glume lesions and empty spikelets, the latter often occurring several in a group, or as individual empty spikelets (or florets) in any portion of the head. In addition, the black-point type of infection is mentioned as occurring on the seeds. Christensen [4] shows that *H. sativum* attacks different parts of the wheat plant, producing various types of lesions.

According to Christensen the various *Helminthosporium* lesions in wheat or other plants result from repeated inoculations, and Stakman holds that the disease is not systemic.[5] The lesions of black point must be induced then by local spore infection in the ovules. Evidently the time of infection, with regard to the stage of the ovule, and the circumstances attending the development of the fungus until the ripening of the seed, have not been closely studied. Henry [6]

[1] Received for publication Feb. 9, 1934; issued July 1934. Paper no. 8 of the Journal series of the North Dakota Agricultural Experiment Station.

[2] EVANS, N. S. "BLACK POINT" OF WHEAT. (Abstract) Phytopathology 12: 34. 1922.

[3] WENIGER, W. DISEASES OF GRAIN AND FORAGE CROPS IN NORTH DAKOTA. N.Dak. Agr. Expt. Sta. Bull. 255, 97 pp., illus. 1932. (Revision of Bull. 166.)

[4] CHRISTENSEN, J. J. STUDIES ON THE PARASITISM OF HELMINTHOSPORIUM SATIVUM. Minn. Agr. Expt. Sta. Tech. Bull. 11, 42 pp., illus. 1922.

[5] STAKMAN, L. J. A HELMINTHOSPORIUM DISEASE OF WHEAT AND RYE. Minn. Agr. Expt. Sta. Bull. 191, 18 pp., illus. 1920.

[6] HENRY, A. W. ROOT-ROTS OF WHEAT. Minn. Agr. Expt. Sta. Tech. Bull. 22, 71 pp., illus. 1924.

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has shown that high temperatures are favorable for the development of *Helminthosporium*, and moisture conditions are of course important.

EXPERIMENTAL WORK

While taking notes on samples of grain threshed from individual plants, the writer was struck by the apparent differences in the size of kernels from any one plant, depending on whether the kernels showed the presence of black point or whether they were free from the infection. Certain of the plants had the weights in grams per 1,000 kernels shown in table 1.

TABLE 1.—*Weight of healthy wheat kernels and of kernels diseased with black point*

Plant no.	Weight per thousand kernels—	
	Healthy	Black-point
	Grams	*Grams*
48.12.247	27.1	33.1
48.12.257	30.7	35.9
48.12.259	26.2	33.9
48.12.288	30.2	36.1
48.12.298	32.2	38.4

The infected kernels in these instances weighed about 20 percent more than the kernels showing no infection.

Of the plants in the group studied in detail, about one half were eliminated in the field because of sterile florets. The remaining plants showed a small amount of floret sterility, but with the exception of 1 or 2 spikes, perhaps no more than might be expected in view of the extreme heat which had prevailed.

Sixteen plants were used in the study of relative weights of kernels. The kernels were carefully removed from the spike and laid in order in depressions cut in paraffin blocks and then weighed to fifths of milligrams. The 16 plants had 63 spikes and 2,030 kernels.

A cursory examination suggested that the differences in kernel weight might be ascribed to a differential incidence of black point on the different kernels of the spikelet relative to position. While the third kernel of the spikelet, when present, showed lesions less commonly than the basal kernels, it became evident that this did not entirely explain the differences.

TABLE 2.—*Number and weight of black-point and healthy kernels found paired in the spikelet, unpaired basal kernels, and kernels of the third floret*

Item	Black-point kernels		Healthy kernels		Excess weight of diseased over healthy kernels
	Number	Average weight	Number	Average weight	
		Milligrams		*Milligrams*	*Milligrams*
Paired	344	39.0±0.17	1,036	36.3±0.13	2.7±0.21
Unpaired	34	35.0± .71	191	32.5± .37	2.5± .80
Third floret	19	31.0± .63	406	27.1± .20	3.9± .66
Total or average	397	38.3± .18	1,633	33.5± .12	[a] 4.7± .22

[a] This value of 4.7 is simply the difference of the weighted means in columns 3 and 5.

The kernels, both those infected with black point and the healthy ones, were placed in three categories. Kernels found paired in the two basal florets comprised the major group; kernels of the third floret, the second group; and unpaired kernels of the basal florets, the third group. The number of kernels, and the average weight per kernel in each of the three classes, and the total weight, are given in table 2.

The elimination of the kernels found in the unpaired and in the third florets reduces the average difference in weight per kernel from 4.7 to 2.7 mg, but even this difference is highly significant as the odds are 3.3×10^{17} to 1 against the probability that a deviation as large as, or larger than, the one indicated could have arisen from random sampling. In the comparison shown in table 2, of the kernels of the third floret, the kernels of the basal spikelet which were significantly below the average in weight and were not infected, are included. Omitting the kernels of the basal spikelet, the difference in weight is still 3.7 ± 0.66 mg. The difference in weight in the unpaired basal kernels is 2.5 ± 0.8 mg and is significant. Considering the 16 plants individually, the black-point kernels of 15 of the plants were the heavier, and the difference was significant in 9 of the 15 cases. In the exceptional case the healthy kernels had the greater weight, but the difference was not significant.

STUDY OF KERNEL WEIGHT ALONG THE SPIKE

In studying the paired kernels attention was given to the disposition of the black-point and healthy kernels along the spike. The results for the 16 plants are summarized in table 3.

TABLE 3.—*Distribution along the spike of black-point and healthy kernels, in pairs, the differences in kernel weight and percentage distribution of kernel weight*

Spikelet no.	Black-point				Healthy				Differences in weight between diseased and healthy kernels		Healthy kernels
	Kernels		Kernel weight per spikelet	Distribution of kernel weight	Kernels		Kernel weight per spikelet	Distribution of kernel weight			
	Number	*Percent*	*Milligrams*	*Percent*	*Number*	*Percent*	*Milligrams*	*Percent*	*Milligrams*	*Percent*	*Percent*
1	27	7.9	35.7±0.55	7.2	145	14.0	32.9±0.30	12.7	2.9± .61	−5.5	84.4
2	52	15.1	40.1± .33	15.5	156	15.1	37.3± .26	15.5	2.8± .42	0	75.0
3	61	17.7	40.6± .33	18.5	157	15.1	39.2± .26	16.4	1.4± .42	2.1	72.1
4	75	21.8	41.0± .26	23.0	151	14.6	38.8± .27	15.6	2.2± .38	7.4	66.9
5	68	19.8	39.3± .33	19.9	148	14.3	38.0± .33	15.0	1.4± .47	4.9	68.5
6	39	11.3	35.4± .61	10.3	155	15.0	34.9± .34	14.4	.5± .70	−4.1	79.9
7	16	4.7	35.2±1.26	4.2	88	8.5	32.3± .44	7.6	2.9±1.34	−3.4	84.6
8	6	1.7	31.7±1.48	1.4	32	3.1	29.1± .77	2.5	2.6±1.67	−1.1	84.2
9	0	.0	.0 -----	.0	4	.4	34.2 -----	.4	---- -----	−.4	100.0
Total or average	344	100.0	39.0± .17	100.0	1,036	100.1	36.2± .13	100.1	2.8± .21	−.1	---------

From spikelet 1 (basal) to 6 the percentage distribution of the healthy kernels approaches uniformity, varying but 1.1 percent, while the distribution of black-point kernels over the same spikelets shows a range of 13.9 percent. The higher percentages for black-point kernels are found in the center of the spike, and it is there that the heavier healthy as well as black-point kernels are found. The average weights per kernel for each spikelet are multiplied by the corresponding percentage distributions, and these results, for the two groups, reduced to percentages, are found in columns 5 and 9. When the paired kernels in the two basal florets are studied, it is found that the heavier kernels are those which carry the greater amount of black point. The net results of this difference in weight are indicated in column 10.

The middle kernels of the spike are fertilized first, but the total time for blooming was quite certainly not over 3 days, as the weather was hot and dry. This earlier fertilization may have been responsible in part for a better nutrition of the central kernels and their consequent greater weight. The fungus may have found easier access to the ovules receiving the better nutrition. The time element may have been a factor influencing the place of infection on the spike, but it is doubtful whether the entire difference in weight can be attributed to this difference in time of infection.

It is seen in table 3 that differences in weight between the black-point and healthy kernels are found regularly in each spikelet. When the probable errors were calculated the differences were found to be statistically significant in the five lower spikelets. The few black-point kernels in 2 of the 3 upper spikelets resulted in probable errors too large for the differences to be significant although the absolute differences are relatively large. The sixth spikelet showed a small difference in weight in favor of the black-point kernels. The differences in the standard deviations are very generally contrary to those of the means, in that the distributions of the healthy kernels show greater variability than do those of the black-point kernels. The coefficients of variability of the two series, black point and healthy, for the eight spikelets are shown in table 4.

TABLE 4.—*Coefficients of variability of weights of the basal pair of kernels in the two groups, black point and healthy*

Spikelet no.	Coefficient of variability			Spikelet no.	Coefficient of variability		
	Black-point kernels	Healthy kernels	Difference		Black-point kernels	Healthy kernels	Difference
1	11. 70±1. 11	16. 44±. 67	4. 74±1. 30	5	10. 27± . 60	15. 93±. 64	5. 66± . 88
2	8. 66± . 58	12. 69±. 49	4. 03± . 76	6	15. 80±1. 25	17. 92±. 71	2. 12±1. 44
3	9. 32± . 57	12. 24±. 46	2. 92± . 73	7	20. 63±2. 56	18. 67±. 99	−1. 96±2. 75
4	8. 08± . 45	12. 46±. 49	4. 38± . 67	8	15. 42±3. 36	21. 90±. 97	6. 48±3. 51

In spikelets 1 to 5 the distribution of the healthy kernels has a variability significantly greater than that of the black-point kernels. If the two series of distributions are merged so that the distribution of the total healthy can be compared with the distribution of the total black point it becomes evident where the greater variability of the healthy-kernel series originates. The two distributions expressed in percentages are shown in table 5.

The sums of the positive and negative differences are necessarily equal. The healthy kernels show an excess of variates in the lower weight classes. This is suggested by the two means (table 2). The excess of distribution of the healthy kernels extends over 11 of the lower weight and 1 of the higher weight classes, while the corresponding deficiency is confined to 6 classes in the higher ranges. Skewness is negative in both cases but more pronounced in the case of the healthy kernels. The greater variability shown in table 5 in the healthy kernels characterizes most of the spikelets and especially those which have the greater numbers of kernels.

TABLE 5.—*Percentages of healthy and black-point kernels in the various weight classes*

Item	Percentage of kernels in weight class indicated									
	16 to 17 mg	18 to 19 mg	20 to 21 mg	22 to 23 mg	24 to 25 mg	26 to 27 mg	28 to 29 mg	30 to 31 mg	32 to 33 mg	34 to 35 mg
Healthy kernels	0.4	0.6	1.2	1.5	2.4	4.0	4.1	6.7	8.0	11.1
Black-point kernels	.3	.3	.0	.0	.6	.6	1.7	4.6	4.1	7.6
Difference	.1	.3	1.2	1.5	1.8	3.4	2.4	2.1	3.9	3.5

Item	Percentage of kernels in weight class indicated								
	36 to 37 mg	38 to 39 mg	40 to 41 mg	42 to 43 mg	44 to 45 mg	46 to 47 mg	48 to 49 mg	50 to 51 mg	Total
Healthy kernels	12.3	13.7	15.5	9.0	6.2	2.4	0.8	0.2	100.1
Black-point kernels	11.6	18.0	20.1	15.1	10.2	4.1	.6	.6	100.1
Difference	.7	−4.3	−4.6	−6.1	−4.0	−1.7	.2	−.4	.0

A study was made of the kernel weight of the first and second kernels per spikelet of spikes with nearly or quite healthy kernels. It was not evident that the lower kernel differed in weight from the kernel standing second in position. It follows, then, that the differentiation in weight of kernel with respect to incidence of black point upon the two lower kernels per spikelet is not due to the position of the kernel in the spikelet, associated with normal weight differences.

In any plant, on an average, the black-point kernels are heavier than those evidently free from disease. In part this weight difference may be ascribed to kernel position. Certain kernels of the spike are so located that their weight is decidedly less than that of kernels differently located. There is a differential in incidence of disease with regard to these two kernel groups. Thus weight differences of healthy and diseased kernels may be ascribed to weight differential due to locality in the spike, combined with a differential of disease incidence. But beyond this, between healthy and diseased kernels, weight differences are found which are not due to location in the spike, as is shown in table 2. Finally, a comparison, or series of comparisons, is to be found in the paired kernels of the basal florets of each spikelet. In each of the eight spikelets, the black-point kernels are the heavier (table 3). In these instances, also, the heavier weight of the black-point kernels is not due to any deviation from the normal in kernel size in conjunction with differences in incidence of disease.

The question arises whether the normally larger kernels of the spike were attacked by *Helminthosporium* (and *Alternaria*) or whether, when the young kernels of a group of potentially the same mature size were attacked, such kernels were somehow stimulated to develop a larger amount of endosperm[7] than if no infection had taken place. It appears that both factors are responsible for the greater weight of the black-point kernels in the spike and in the plant.

CORRELATION RESULTS

It was possible to calculate correlation coefficients between percentages of black point and yield in the 1933 crop. In one instance a considerable number of yields were calculated from 5-foot rows. These rows were planted with F_5 selections from the cross Ceres × Hope-Florence; a single mother plant seeded one row. The stands of grain varied more or less; before harvest, notes were taken on the stand, and the yields were corrected to a uniform stand. The errors involved in this correction were thought to be less than those which would arise from uncorrected yields. Countings were made on the threshed samples of the frequency of the occurrence of black point and the percentages estimated. The weight per 1,000 kernels was also determined. The means and the standard deviations of these three characters calculated from 267 variates are shown in table 6.

TABLE 6.—*Correlations [a] between yield of wheat, weight of black-point kernels, and percentage of black-point kernels in the 1933 crop*

Item	Yield per acre	Weight of 1,000 kernels	Black-point kernels
	Bushels	*Grams*	*Percent*
Mean	34. 45±0. 31	37. 14±0. 09	21. 98±0. 48
Standard deviation	7. 57± . 22	2. 06± . 06	11. 63± . 34

[a] The 3 correlation coefficients calculated were: Black point and yield, 0.22±0.04; yield and 1,000-kernel weight, 0.32±0.04; black point and 1,000-kernel weight, 0.17±0.04.

None of these coefficients is very high, but the first one, which perhaps is of greatest interest, is about five times the probable error. Evidently there is a positive relationship between the presence of the infection and the yield, as secured. When the weight per 1,000 kernels is held constant the partial correlation between yield and black point is 0.18 ± 0.04. This still shows some significance.

In the cross first mentioned in this paper it was possible to calculate correlations similar to those given, except that weight of grain per plant was used instead of yield. The coefficients are as follows:

Black point and grain yield per plant	−0. 09 ± 0. 04
Yield per plant and 1,000-kernel weight	. 27 ± . 04
Black point and 1,000-kernel weight	. 32 ± . 03

When the weight per 1,000 kernels is held constant the correlation between black point and grain yield per plant becomes essentially zero. The total correlation between these characters is negative but not significant. Correlation of fairly high significance is shown between black point and 1,000-kernel weight. This is in keeping with the results shown in the earlier part of this paper.

[7] As the endosperm in a normal kernel of wheat comprises about 85 percent of the total weight it is fair to presume that the excess weight of the diseased kernels would be distributed mainly to the endosperm. The black-point kernels appeared to be normal in shape. Any contribution to the greater weight of the black-point kernels made by the substance of the invading organism must have been negligible.

DISCUSSION

More exact studies as to the causal relationships with regard to the various external factors are greatly desired. It is known that the epidemic of black point in 1933 was associated with high temperatures and low seasonal moisture conditions. The wheats studied, started heading about June 22, and blossoming was probably well under way by June 25. A comparison of temperatures and rainfall for the last 5 days of June and the first 15 days of July are shown in table 7.

TABLE 7.—*Temperatures and precipitation for the last 5 days of June and the first 15 days of July 1933* [a]

Item	June 26–30	July 1–5	July 6–10	July 11–15	Total
Temperature:	° *F.*	° *F.*	° *F.*	° *F.*	
Average daily mean	75	75	73	74	
Normal	67	68	67	67	
Excess in 1933	8	7	6	7	
Precipitation:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Total in 1933	1.65	.0	.81	.17	2.63
Normal	.86	.77	.47	.59	2.69

[a] Data are from the official records of the United States Weather Bureau. The normal values of precipitation were taken from the Monthly Weather Review, Vol. 58, Suppl. No. 34, p. 59, May 1930.

The daily temperatures were greatly in excess of the normal for the whole 20 days and particularly during the last 5 days of June. The season was unusually dry, but from June 26 to 30, 1.65 inches was recorded, which was decidedly in excess of the expected amount for the 5-day period. Thus for a short period, in the early life of the wheat seed, conditions of high temperature and high rainfall obtained. It is quite unknown, of course, whether the weather conditions varied in such a manner during the period of infection as to account for the differences in incidence of black point which were shown to exist between basal kernels and kernels of the third floret and also between the mid-spike kernels and those near the base and near the tip of the spike. It is not conceivable that any differentiation in weight due to position could be brought about within a single spikelet or in the third-floret kernels within the spike, as was the case in several instances.

On the other hand there seems to be no report in the literature that a seed infected by a fungus is stimulated, and consequently increases in growth. If stimulation resulted in this case, an increased amount of endosperm must have been laid down, but there seems to be little or no information as to any causal relationship which might have brought this about.

SUMMARY

A heavy infection of black point, caused largely by *Helminthosporium sativum* Pam., King, and Bak., was found on various common wheats at Fargo in 1933. On any one plant, in the hybrids studied, the black-point kernels generally were definitely heavier than the kernels showing no evidences of infection.

This difference in weight can be ascribed in part to a difference in infection of kernels differing normally in size because of position in the spike. Third-floret kernels and end-spike kernels carried less infection than the heavier mid-spike kernels.

Within any kernel group of the spike, such as the third-floret group, the black-point kernels were significantly heavier than the noninfected kernels. The obvious conclusion seems to be that a portion of the weight differences results from a stimulation of the development of the endosperm following the entrance of the fungus into the developing ovule.

In one experiment, a coefficient of correlation of 0.22 ± 0.04 was found between the percentage of black point and the yield in 5-foot rows and a coefficient of 0.32 ± 0.04 was found between black point and weight of 1,000 kernels. In a study of individual plants resulting from a different cross, a correlation of -0.09 ± 0.04 was secured between the percentage of black point and the weight of the grain per plant and a correlation of 0.32 ± 0.03 was obtained between percentage of black point and the weight per 1,000 kernels.