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The Yellow Berry Problem in Kansas Hard Winter Wheats.

PART I.

ONE of the most serious problems which the wheat-growers of the Kansas hard wheat districts have to contend with is that of the so-called "yellow berry." The wheat of this region produces normally a hard, flinty, translucent grain, of medium size and of a clear dark reddish-amber color. By the term "yellow berry" is meant the appearance, in wheat of the above description, of grains of a light yellow color, opaque, soft and starchy. These opaque yellow grains, constituting what are called the "yellow berries,'' may have this character throughout; but sometimes from a small fraction to half of a grain will be yellow and starchy, while the remainder of the kernel will be hard, flinty and translucent. The difference in color between the flinty grains and the "yellow berries'' is due to difference in the structure and contents of the cells of the endosperm.

According to Hackel,[1] if the albuminoids so fill up the intervals between the starch grains that the latter seem to be imbedded in cement, the albumen appears translucent, and the fruit is called "corneous"; but if the union is less intimate there remain numerous small air-cavities, the albumen is opaque, and the fruit is mealy.

1. E. Hackel, "The True Grasses," p. 26.

Lyon and Keyser,[2] as the result of their studies on the internal structure of the wheat kernel, say (p. 35):

"The protoplasmic network of the cells in the sections from the very horny kernels showed only an occasional vacuole; sections from the markedly yellow kernels showed very much more numerous and larger vacuoles, measuring on the average less than 0.001 millimeter. Medium yellow berry kernels had fewer and smaller vacuoles than the markedly yellow kernels."

These writers also found that in the yellow berries the starch grains in the cells were larger in diameter than in the flinty kernels, although not so large as in the typical starchy wheats. The following table indicates the range:

TABLE I.

VARIETY.	Size of larger starch grains, mm.	Size of smaller starch grains, mm.
Sonora (a soft, starchy wheat)	0.02817	0.005634
Turkish Red (yellow berry)	0.01704	0 003081
Turkish Red (flinty kernels)	0.01409	0 002817

This agrees with Cobb, who says[3]: "It is noticeable that when the grain is rich in nitrogenous matter the number of large starch granules is smaller."

The yellow berry may then possibly be regarded as an imperfect product, in which the spaces in the cells which are normally filled with proteids (gluten) contain merely water, which, drying out with the ripening of the kernel, leave air-spaces which are responsible for the opaque appearance of the kernel. In addition to this fact is the further one that per unit of volume of the yellow berry kernel there may be a smaller amount of starch than in the flinty grains, on account of the greater size of the individual starch grains. From the standpoint, therefore, of both gluten and starch, the yellow berry is probably an inferior kernel, and from the economic standpoint it may be regarded as a degenerate product.

It should further be emphasized that the bleached opaque grains, due to weathering, are not "yellow berries.'' In weathered kernels the grain has an opaque and rather dirty grayish-yellow aspect, which appearance affects the grading of the grain adversely, but is not necessarily associated with an in-

2. Winter Wheat. T. L. Lyon and A. Keyser, Nebraska Experiment Station, Bull. 89 (June, 1905).

3. Cobb, N. A., in *Agricultural Gazette,* New South Wales, Vol. XV, part 6, p. 512.

ferior condition of the kernel, although such frequently is the result of exposure to the weather.

This distinction between weathered grains and yellow berry has been dwelt upon, because, to judge from the literature upon the subject, much confusion concerning these characters exists, not only among farmers but also among experiment station men.

The yellow berry, then, appears to be distinctly a physiological growth product, due to certain conditions thus far not clearly analyzed or satisfactorily explained in any of the experiment station publications, and the causes of which have constituted the object of the investigations which this bulletin reports.

PHYSICAL CHARACTERS OF THE YELLOW BERRIES.

In addition to, and in consequence of, the structural characters alluded to, viz., the presence of numerous vacuoles in the endosperm-cells, filled with air, which in the corresponding flinty grains of the same variety are filled with gluten (proteids), there are found to exist some interesting and important conditions with respect to weight and specific gravity. The presence of air-vacuoles doubtless accounts for the lighter weight and the uniformly lower specific gravity of the yellow berry kernels. Owing to the higher specific gravity of the carbohydrates in the wheat kernel (starch 1.53, sugar 1.60, cellulose 1.53), as compared with the proteids (gluten 1.297),[4] it would necessarily follow that the true starchy wheats are the heaviest wheats and possess the highest specific gravity.

TABLE II.*

	Average. pounds per bushel.	Average weight of 100 grains.	Average per cent. of carbo-hydrates, fat and crude fiber.	Average per cent. of nitrogen.
Hard spring, hard winter and semi-hard winter wheat districts	57.1	3.368	75.06	2.01
Soft wheats and Southern wheat districts	57.5	3.433	76.06	1.86
Irrigation and Pacific Coast wheat districts	58.9	4.045	78.03	1.62

* Compiled from reports of the U. S. Dept. of Agriculture.

The degree of correspondence that there may be between the particular kind of starchy grain appearing in hard wheat and

4. Körnicke und Werner, Handbuch des Getreidebaues, vol. 2, p. 120 (1884).

Known as "yellow berry," and the ordinary soft and starchy wheats proper of the Middle states and the Pacific coast, is not known. So far as the present meager physical data admit of comment, it would appear that the starchy wheats of the Pacific coast, and to a less degree the starchy wheats of the Middle and Southern states, average somewhat higher in pounds per bushel than the hard winter and spring wheats. Whether the data available will be substantiated by more rigid methods of determination is uncertain. Whatever may be true of the soft wheats of the Middle and Southern states in this respect, concerning which there is the most doubt, it certainly appears true that in some parts of California soft, starchy white wheat grows which is heavier in pounds per bushel than the hard winter and spring wheats. (See table 11.)

Now the yellow berry does not resemble this type of soft wheat in respect to weight, since the yellow berries, in weight and in specific gravity, fall below the flinty kernels of the same variety. The question therefore remains open, to what extent the yellow berry is a varietal trait, and to what extent merely a condition brought about by seasonal influences, whereby it can be considered a degeneration product, containing not only, as is known, less protein than the flinty kernels, but also less starch per unit of volume. This latter point is an interesting and critical one, upon which the writers are now working. There are data on hand which support both views of the nature of the yellow berry, but they are too incomplete to warrant any statement whatever at the present time.

The essential thing, from the practical standpoint, is to discover whether pure stocks of wheat can be found which produce constantly a minimum amount of yellow berry in the hard wheat region in seasons and localities in which the yellow berry ordinarily occurs.

In twenty-one varieties investigated for yellow berry at this Station by the Botanical Department, the results, with respect to weight and specific gravity, are shown in table III.

The data embodied in this table were obtained as follows: The weight and volume were determined for 200-grain lots each of yellow berry and of flinty kernels, taken from the same variety; and this for each of the twenty-one sorts of wheat. The volume was determined by the amount of 95 per cent. alcohol displaced by 200 grains in a 50 cc. specific-gravity

TABLE III.

NUMBER.	Average weight, gms.		Specific gravity.	
	Yellow berry (100 grains).	Flinty kernels (100 grains).	Yellow berries.	Flinty grains.
1	2.767	2.824	1.306	1.356
2	2.543	2.546	1.320	1.337
3	2.616	2.636	1.318	1.368
4	2.614	2.762	1.331	1.353
5	2.720	2.582	1.299	1.348
6	2.616	2.729	1.309	1.389
7	2.721	2.891	1.319	1.341
8	2.483	2.555	1.302	1.328
9	2.846	3.167	1.311	1.343
10	2.710	2.664	1.311	1.319
11	3.384	3.492	1.273	1.327
12	2.881	2.995	1.273	1.312
13	2.735	3.273	1.268	1.317
14	2.246	2.818	1.254	1.304
15	2.749	3.034	1.291	1.310
16	2.398	2.429	1.307	1.328
17	2.041	2.225	1.307	1.315
18	2.002	2.149	1.316	1.322
19	2.464	2.647	1.314	1.354
20	2.584	2.732	1.322	1.337
21	2.405	2.395	1.333	1.346
Averages	2.596	2.740	1.304	1.336

bottle. From the table above, it is seen that the average weight of the yellow berries per hundred was 2.596 grams, as against 2.740 grams for the hard, flinty grains. There were, however, three cases in which the absolute weight of the yellow berries was greater.

For the specific gravity there were no exceptions to the rule that the flinty grains have a higher specific gravity than the yellow berry grains of the same variety. In the above-mentioned twenty-one sorts, where the average specific gravity of the yellow berries was 1.304 while that of the flinty grains was 1.336, there can be no escaping the conclusion that the yellow berries, in all probability, owe this lesser specific gravity largely to the presence of numerous air-cavities, although to what an extent an actual diminution of the carbohydrates and the inorganic salts of high specific gravity may accompany this is not known. The actual loss of protein involved in the production of yellow berries may be gathered from table IV, taken from bulletin 89 of the Nebraska Experiment Station, to which reference has already been made.

TABLE IV.

Bull. 89, Neb. Exp. Sta., p. 80 (1905).

No.	Description.	Nitrogen.
40	Horny red (lightest light), 1901	2.23%
41	Yellow berry (lightest light), 1901	1.83
42	Horny red (heaviest heavy), 1901	2.32
43	Yellow berry (heaviest heavy), 1901	1.70
44	Horny red (lightest light), 1902	3.20
45	Yellow berry (lightest light), 1902	3 10
46	Horny red (heaviest heavy) 1902	3.40
47	Yellow berry (heaviest heavy), 1902	2.90

Average for Horny red, 2.79 per cent.; average for yellow berry, 2.38 per cent.

Now it is a clearly defined fact that loss of protein (gluten) content in the wheat grains means diminution in flour-making value; and the fact that grain inspectors reduce the grade of a hard wheat containing yellow berry is practical evidence to this point.

Snyder[6] explains the matter as follows :

"It is generally considered that the more amber and glutenous wheats yield a higher percentage of the patent flours and less of the clear and lower grades, while the lighter-colored or starchy wheats show a tendency to produce a higher percentage of total flour, but less is recovered as patent graded. . . . These physical characteristics are closely associated with, and dependent upon, chemical composition. . . . When two types of seed, light and dark, were selected from the same lot of wheat, the darker seeds in all samples analyzed were found to be richer in protein. . . . This difference is observed in illustration No. 120, showing the flinty character of the dark-colored grains and the starchy nature of the light-colored ones."

IMPORTANCE OF THE YELLOW BERRY PROBLEM.

Because of the fact that in central and northern Kansas is produced the best milling wheat in the United States, on account of the very high per cent. of a gluten of excellent quality and texture which this wheat yields in the flour, any factor that brings about deterioration in the grade of this wheat calls for serious investigation.

As has been shown, the yellow berry is such a factor, inferior certainly in protein content and probably also in starch; lower in specific gravity and generally also in absolute weight per bushel. The presence of the yellow berry in any quantity in our hard wheat affects unfavorably its commercial grading and its market price. It therefore seems to the writers that the

5. Harry Snyder, Bull. 90, Minn. Exp. Sta. (Jan., 1905), pp. 83-185.

yellow berry problem is one of first importance in connection with wheat-breeding; since if by any means wheat races can be produced in which the physical changes resulting in the yellow berry type of kernel will not take place under any conditions, the value of such races will be inestimable to this state and to the hard winter wheat district in general.

THE INFLUENCE OF CLIMATE.

It has long been known that in cool, moist climates, such as the maritime regions of Western Europe and of our north Pacific coast, the wheats there grown have larger grains, are softer, and lower in percentage of proteid nitrogen than the wheats grown in the continental areas, such as the interior of Russia, the Balkan states, Hungary and the central western states in this country.

Schindler,[6] the most extensive investigator hitherto of the relation of wheat to climatic factors, says, page 75:

> "With the length of the vegetative period, especially with the extent of the interval between blossoming and ripening, not only the dimensions of the kernel increase, but also the quantity of the carbohydrates stored therein, while the protein content diminishes."

Again, page 32:

> "It is not justifiable to speak of the size of the kernel and the protein content of the berry as 'race characters.' They may be such to a certain limited extent, but the influence of the race will in this connection be far exceeded by the influence of climate, and partly also by that of soil and cultivation. . . . The mode and the abundance of deposit of starch in the endosperm depends possibly upon the climate or upon the weather phenomena, as the case may be, especially during the period of the 'milk.' In regions with moist warm climates and a long vegetative period, the interval from fertilization to maturity is likewise a long one, and during this period abundant quantities of starch can be formed in the large leaf surfaces which the wheat endemic to such a climate is apt to produce, and which, in the course of the slow development of the grain, can be completely transported thither. Externally, the extensive storage of starch is indicated in the broad form of the kernel. The protein content is diminished when wheat native to such a climate is transported to a hotter, dryer region. At a time when, in its native home, it continued undisturbed in the transportation, of starch formed in the leaves to the ovary, here lack of water and high temperature combine to bring the growth to a close prematurely. The time is accordingly shortened for the passage of starch into the kernels, and even though the intensity of assimilation in warmer regions be greater, yet, on account of the time limitations, this factor cannot wait for a variety which is not adapted to a more rapid development. . . . From these considerations it un-

6. Franz Schindler, "Der Weizen," Berlin, 1895.

disputably follows that, even in one and the same locality, and with the same variety, the relation between protein and starch must be a variable one, according to the weather conditions; even though it is to be admitted that individual sorts or races, as the case may be, may possess for themselves an especially different energy of assimilation. It is certain, however, that this latter, in its final effect, stands far behind that of climate and of the weather."

We have quoted thus extensively from Schindler's work, because, with one or two exceptions, it is practically the only study of the wheat question that deals with the problems in at all a fundamental way.

It has long been known among scientific agronomists that regions characterized by a hot, dry climate of limited rainfall, and in which the final maturing of the wheat hastens fast upon the blossoming, are the regions in which the wheat grain is hardest and highest in protein content. Such regions are the "black soil" district of Russia, much of the Mediterranean coast region, the table-lands of Hungary, and the central and northern plains region of the United States.

It is, moreover, well known that seasonal differences in the same region bring about marked changes; that a hot, dry growing season results in a lower yield of wheat, which is harder and of higher protein content; while a moist, cool growing season results in the production of larger, softer grains of lower protein content.

So much for the general phenomenon. However, the yellow berry problem is not solved by reference to the above conditions. As has been said, the yellow berry is not simply a special phase of the general phenomenon of a relatively greater proportion of starch to protein deposited in the grain in consequence of a longer growing season. It is a case not merely of failure to form the normal amount of gluten *but probably also of a corresponding failure on the part of the plant to compensate by a relative increase in the starch content.*

The yellow berry problem is therefore a decidedly special one. Since the climatic factors are, above all others, prominent in determining the composition of the wheat grain, it remains to search out the critical period in the plant's life-history when its susceptibility to the formation of the yellow berry is greatest, and to ascertain what relation the climatic or seasonal factors may have thereto. It is clear that such knowledge will suggest means for avoiding the economic loss involved in the production of the yellow berry.

NATURE OF THE EXPERIMENTS.

In order to throw more light on this phase of the subject, it was determined to discover, if possible, the relation between the amount of yellow berry produced and the climatic conditions for the growing season concered. During the years 1906-'07, 128 varieties of wheat were grown for the special purpose of investigating the yellow berry problem. For each variety, careful records were kept of the date of planting, the date of coming up, the stand, vigor of the plants, extent of winter-killing, time of first and full heading, date of ripening and date of harvesting. The plots were very closely watched, and each was harvested immediately after it was considered fully ripe. In harvesting, the heads, after being cut off, were put into loose cloth sacks and taken to the laboratory the same day as that on which they were gathered. After drying out thoroughly under cover, the product from each plot was threshed separately with a flail and was carefully winnowed by hand. It is thus seen that each sample of wheat was subjected to exactly the same manipulation and mode of treatment during each of the two years of the experiment. The existence of yellow berry in any of the samples could not, therefore, be attributed either to overripeness or to exposure to the weather after the grain had been cut, but could only be ascribable to the influence of the weather conditions upon the growing or ripening grain or to inherent hereditary tendencies in the varieties themselves, or to both.

Each lot of air-dry grain, after cleaning, was thoroughly mixed, and a representative sample of 100 grains was taken out. Each of these samples was then separated by inspection into two lots, containing the flinty grains and the "yellow berries," respectively. As a criterion for classification, it was determined to consider as the "flinty grains" only those that were of a clear, reddish-amber color *throughout.* If a kernel bore even one or two small opaque starchy spots, it was classified among the "yellow berries."

After separation, the number of grains in each lot were counted, and the percentage of yellow berry recorded. To guard against the influence of the personal equation, and to insure all of the results being comparable with one another, all of the work of separation was done by one person. Further to safeguard the results, the operator was careful not to notice the label borne by any sample until after finishing the separation and counting the grains.

CLIMATOLOGICAL DATA.

These were obtained from the records of the Physics Department. The data are derived from self-registering instruments on the college campus, located about one-fourth mile from the wheat-breeding plots of the Department of Botany.

For purposes of comparison, the mean temperatures and precipitation for each month during the wheat vegetative season, and for the two crop years of 1905-'06 and 1906-'07, are given in table V.

TABLE V.

MONTH.	Mean temperature, Fahrenheit.		Precipitation, inches.	
	1905-'06.	1906-'07.	1905-'06.	1906-'07.
September	72.10°	71.88°	4.32	4.62
October	54.20	55.00	2.19	0.83
November	45.60	40.09	3.60	2.18
December	33.15	35.76	0.00	0.64
January	38.82	29.69	0.89	1.38
February	35.65	31.21	1.60	1.62
March	32.80	51.19	2.12	1.37
April	59.60	46.07	2.26	1.30
May	66.74	59.24	2.00	1.10
June	74.60	70.90	6.73	6.07
July	76.13	78.58	5.28	6.46
Averages and totals, excluding July	51.33°	49.10°	25.72	21.11

The wheat varieties included in the experiment were planted from one to nineteen days earlier in the fall of 1906 than in the fall of 1905; and the mean autumn temperature and the amount and distribution of the rainfall were slightly more favorable in 1906. We may therefore reason that the wheats probably entered the spring vegetative period of 1907 in slightly better condition than the spring period of 1906. The early part of March, 1907, was extremely warm, but the subsequent return of cold weather brought the mean temperature of April, May and June much lower than for the corresponding months of 1906.

The general effect of these conditions, and of the respective dates of the planting, upon the length of the spring vegetative period and the percentage of yellow berry, may be seen in the following table:

TABLE VI.

	1906.	1907.	Differences.
Number days from planting to January 1	90	95	5
Number days from March 1 till ripe	118	125	7
Average total vegetative season, days	267	279	12
Average per cent. of yellow berry	33	39	6

INFLUENCE OF INDIVIDUAL CLIMATIC FACTORS; CRITICAL PERIODS.

In endeavoring to analyze individually the influence of each of the chief climatic factors — temperature, light, air movements and precipitation — in relation to the growth of the wheat plant, and especially in endeavoring to ascertain the share of each factor in determining the changes resulting in the "yellow berry," we find that we are dealing with problems of the most extreme complexity and intricacy. Only by means of adequate meteorological apparatus, by the preservation of full and accurate records, by using a large number of varieties, and by the extension of the experiments over a number of years, can we expect to overcome the influence of special conditions and obtain representative averages.

So far as our investigation is concerned, while it covers but two years of experimental work, and while, by increase in the range of the meteorological data, and especially by the extension of the experiments over a number of years, the writers hope to obtain more satisfactory averages, yet the results thus far are so striking and significant in certain features that in our judgment they merit publication as far as completed.

It should, however, be realized that the results thus far obtained must of necessity be treated as qualitative rather than quantitative, and as preparing the way for the more detailed quantitative researches which are to follow. This bulletin therefore stands as a preliminary report of the work in progress, and not as a final announcement of ultimate results.

RELATION BETWEEN DATE OF PLANTING, AUTUMN VEGETATIVE CONDITIONS AND THE PERCENTAGES OF YELLOW BERRY.

For the purposes of this investigation, the autumn vegetative period is taken, roughly, to extend from the date of planting to January 1. The latter date is arbitrarily selected on account of the fact that in the Kansas hard wheat regions there are frequently rather prolonged warm periods extending through much of November and December, during which time the extent of root growth and the amount of stooling or tillering may be considerable. From January 1 to March 1, however, and frequently later, the wheat usually remains almost entirely dormant.

The differences in the fall vegetative conditions of the wheat in the autumn of 1905, as resulting from differences in the date of planting, and the extension of these effects into the spring of 1906 in respect to the percentage of yellow berry, are indicated in table VII. Here it will be seen that the fall vegetative period varied from ninety-four to seventy-six days for different plots, which involved a variation in the mean temperature for the period of from 45.5° to 41.1° F. The percentages of yellow berry produced from the different plantings are seen, with but one very slight exception, to decrease directly with the decrease in the mean temperature for the fall vegetative period; or, in other words, with the diminution of, the sum total of the achieved autumn growth.

TABLE VII. Relation of the date of planting and the duration of the fall vegetative period to the percentages of yellow berry—1905-'06.

Date of planting.	No. of cases.	No. days fall vegetative period.	Mean temperature, deg. F.	Total rainfall, Sep. 1 to Jan. 1, inches.	Rainfall three weeks before planting, inches.	Rainfall three weeks after planting, inches.	Average per cent. of yellow berry.
Sep. 28 ...	9	94	45 47	10.11	2 19	0 72	53 80*
Sep. 29 ...	15	93	44.91	10.11	2.19	0 72	45.43*
Sep. 30 ...	25	92	44 84	10.11	2 21	0.70	27.20*
Oct. 2 ...	51	90	44 53	10.11	2.04	0.73	35 74*
Oct. 11 ...	4	81	42 09	10 11	0.35	1.86	22.25†
Oct. 16 ...	24	76	41.07	10.11	0.73	3.95	19.58†
Averages,	128	89 9	43.98	10.11	1.80	1.36	33.00

* Planted in moist soil; germination rapid.
† Planted in dry soil; germination slow.

So far as the rainfall for the period is concerned, in its effect upon the young plants, the differences in these amounts are small. The plantings from September 28 to October 2, however, went into moist soil, while the plantings of October 11 to 16 were in rather dry soil, with consequent delay of germination and retardation of the initial growth of the seedlings. For the season of 1905-'06, then, it seems that the minimum of yellow berry appeared in the plantings in which there was a minimum opportunity for development in the fall. Just what relation there may exist by way of cause and effect between these two sets of phenomena will appear later.

In table VIII is seen a similar tabulation for the season 1906-'07:

TABLE VIII. Relation of date of planting and duration of the fall vegetative period to the percentages of yellow berry—1906-'07.

Date of planting.	Number of cases.	Number of days in fall vegetative period.	Mean temperature, Fahrenheit.	Total rainfall, Sep. 1 to Jan. 1, inches.	Rainfall three weeks before planting, inches.	Rainfall three weeks after planting, inches.	Average per cent. of yellow berry.
September 26	39	96	44.54°	8.27	4.62	0 45	44 33
" 27	53	95	44 28	8.27	4 62	0 45	37.22
" 28	14	94	44 14	8.27	4.62	0.45	36.16
" 29	22	93	43 98	8 27	4.62	0 45	32.63
Averages	128	94 8	44 30	8 27	4.62	0.45	39.00

A comparison of the data for the two years shows the same diminution in the percentage of the yellow berry with the shortening of the total time of the fall vegetative period, and a corresponding decline in the mean temperature for that period. It must be noted, however, that the planting season of 1905-'06 lasted over nineteen days, corresponding with which there was a decrease in the average amount of yellow berry of from 54 per cent. in the highest to 20 per cent. in the lowest case.

On the other hand, the planting season of 1906-'07 covered a period of but four days, and there was a correspondingly lower range to the average percentage of yellow berry from the different plantings of from 44 per cent. in the highest to 33 per cent. in the lowest case.

The average fall vegetative season of 1905-'06 was five days shorter than that of 1906-'07, and whereas the rainfall was slightly more favorable in the former period the temperature was somewhat higher in the latter. It may therefore fairly be concluded that, disregarding the date of planting, the fall growing season was equally favorable in all respects, except in that of mean temperature, for the two years. It may therefore be assumed that the reduction in the total length of the growing period with the later plantings, the consequent lower mean temperature for the period of fall growth, and the necessarily retarded and diminished development of the plants, is in direct correspondence with the subsequent development of yellow berry in the spring, at least so far as the data for the two years are concerned.

RELATION BETWEEN THE SPRING VEGETATIVE CONDITIONS AND THE PERCENTAGE OF YELLOW BERRY.

The spring vegetative period for wheat in this region is taken to be the time from March 1 to the date of ripening of the grain. By reference to the following table, it will be seen that this period in 1907 was twelve days longer than in 1906, and that this difference was accompanied by an average increase in yellow berry for 1907 of six per cent. over the average for 1906. The extent to which the lengthening of the spring vegetative period was due to the later planting in 1907 is shown in table IX, which also shows the relation between the date of planting and the date of ripening:

TABLE IX. Relation of length of spring vegetative period to length of fall vegetative period.

1906.

Length of fall vegetative period, days	94	93	92	90	81	76
Number of cases	9	15	25	47	4	27
Average length of spring vegetative period	110.3	110.5	119.6	119.8	119.0	118.1

1907.

Length of fall vegetative period, days	96	95	94	93		
Number of cases	40	52	14	22		
Average length of spring vegetative period	125.7	124.6	126.7	128.8		

In spite of the fact, previously mentioned, that the fall seasons of 1905-'06 and 1906-'07 were equally favorable, except for the disadvantages entailed by different dates of planting, it is seen nevertheless that plantings of the same date in the two years did not mature in equal periods, but that the spring vegetative period in the latter year was, on the average, sixteen days longer than in the year before for the same period. This fact can only be explained by the differences which might have obtained during the winter or spring. Now, since the wheat plants are practically dormant throughout the winter, it is more than probable that the conditions which, independent of the date of planting, caused the longer spring growing period of 1907, must be sought in the weather conditions between the time of resumption of active growth in the spring and the time of ripening.

By referring to table V, and by considering the spring season as a whole, it will be noted that during March, 1906, the weather was cold, but that with April more favorable weather came, both as to temperature and rainfall, and that these improved conditions prevailed until the time of ripening.

In 1907, on the other hand, March was abnormally warm, which brought about an early rapid growth in the wheat plants. This favorable weather was, however, followed by cold, dry weather in the latter part of March and the early part of April, which moreover persisted throughout April and May. June, the first really favorable month for plant growth, was itself colder than the same month of the previous year. The effect of these conditions as a whole has already been mentioned and is shown in table VI.

It remains to analyze the seasonal conditions in the spring vegetative period in detail, and to discover, if possible, from such evidence, the critical time in the growth of the plants when the influence of the external conditions on the production of yellow berry is most decisive.

Assuming the two weeks preceding ripening as the critical period in question, the mean temperature for the two weeks before ripening of each variety was calculated; the varieties were arranged in groups according to their mean temperatures, and the average percentage of yellow berry in each group was determined:

TABLE X. Relation of mean temperature for two weeks before ripening to percentage of yellow berry.

	Mean temperature, Fahrenheit.					
	73°	74°	75°	76°	77°	78°
1906.						
Number of cases	41	20	53	7	0	7
Average per cent. of yellow berry	23	48	35	23	0	32
1907.						
Number of cases	60	28	8	21	0	11
Average per cent. of yellow berry	45	32	25	28	0	47

Total average mean temperature: 1906, 75.06° F.; 1907, 74.84° F.
Total average per cent. of yellow berry: 1906, 33; 1907, 39.

A close scrutiny of the above table does not disclose any definite relationship between the mean temperature for two weeks before ripening and the production of yellow berry. If, therefore, there be any such relationship, it has been obscured, for these two years at least, by other factors. If, however, we make a similar study of the relationship of the mean temperature for three weeks before ripening to the production of yellow berry, we find results which are more uniform:

TABLE XI. Relation of mean temperature for three weeks before ripening to percentage of yellow berry.

	Mean temperature, Fahrenheit.			
	72.6° to 73.5°	73.6° to 74 5°	74.6° to 75.5°	75.6° to 76.5°
1906.				
Number of cases	52	40	21	15
Average per cent. of yellow berry	44	25	22	35
1907.				
Number of cases	2	28	82	16
Average per cent. of yellow berry	73	50	32	47

Total average mean temperature: 1906, 74 13° F.; 1907, 75.66°. F
Total average per cent. of yellow berry: 1906, 33; 1907, 39.

Table XI seems to indicate that, in general, higher mean temperatures for three weeks before ripening are correlated with lower percentages. of yellow berry, although there are several exceptions.

It will be noted that as the mean temperature rises there is a steady decline in the percentage of yellow berry in both years, until the highest mean temperature is reached (last column); and that here, for both years, the percentage of yellow berry has increased. In this last column fall those wheats which ripen late, after the hot weather of midsummer begins.

A further apparent contradiction to what seems the general rule, as exhibited by table XI, that the higher the mean temperature for the three weeks before ripening the lower the percentage of yellow berry, is seen in the fact that whereas the mean temperature for three weeks before ripening was lower in 1906 and in 1907, yet the higher percentage production of yellow berry was not in the former year, but in the latter.

Although little or no influence in the formation of the yellow berry seemed to be traceable to the mean temperature for the two weeks preceding ripening, yet, when a corresponding period of three weeks was taken, more influence seemed evident. On this account it was decided to trace the possible influence of the mean temperature even farther back from the date of ripening—to the date of the first appearance of the spike. The data were computed in the same manner as for tables X and XI:

TABLE XII. Relation of mean temperature to percentage of yellow berry, from time of first heading to maturity.

Mean temperature, Fahrenheit.	1906. No. cases...	1906. Av. per cent. yellow berry.	1907. No. cases...	1907. Av. per cent. yellow berry.
68.5° to 68.9°	......	......	1	62.0
69.0 to 69.4	......	....	20	46.0
69.5 to 69.9	......	......	52	40.3
70.0 to 70.4	......	......	17	28.5
70.5 to 70.9	......	.....	9	19.6
71.0 to 71.4	......	.....	10	42.4
71.5 to 71.9	39	44.7	1	71.0
72.0 to 72.4	40	26.7	0	......
72.5 to 72.9	18	29.0	3	57.0
73.0 to 73.4	30	28.9	5	34.2
73.5 to 73.9	1	0	9	41.4
74.0 to 74.4	......	......	0	......
74.5 to 74.9	......	......	0	......
75.0 to 75.4	......	.....	1	6.0

Total average mean temperature: 1906, 72.41° F.; 1907, 70.48° F.
Total average precipitation: 1906, 4.74 in.; 1907, 6.55 in.
Total average per cent. of yellow berry: 1906, 33; 1907, 39.

It will be noted that the results within the individual years are not so uniform here as in the preceding case (table XI), but when the total averages for the two years are compared they harmonize with the theory that high temperatures are correlated with a minimum of yellow berry in the crop.

Taking also into consideration the amount of the rainfall from the sixth day before heading to the fourth day before ripening, no relation becomes apparent between the precipitation and the production of yellow berry.

The data to this point are given in the following table, in which the wheat varieties grown in 1906-'07 are arranged in groups, according to the amount of rainfall occurring within the dates previously mentioned; the average percentage of yellow berry being calculated for each group:

TABLE XIII. Relation of precipitation to percentage of yellow berry.

	Precipitation, inches. 1 to 1.9	2 to 2.9	7 to 7.9	8 to 8.9	9 to 9.9
Number of cases...........	31	39	51	5	2
Average per cent. of yellow berry....................	50.31	23.59	27.94	32.80	59.50

A similar study was not made for the year 1907, for the reason that all of the varieties received very nearly the same amount of precipitation between the growth dates previously mentioned.

RELATION OF THE TIME, FROM FIRST HEADING UNTIL RIPENING, TO THE PRODUCTION OF YELLOW BERRY.

Considering the length of time between the dates of first heading and of ripening, in relation to the production of yellow berry, it is seen that, as between the averages for *different* years, those years in which the ripening was slow produced the greatest percentage of yellow berry. When, however, this principle is sought to be applied to the different rates of ripening discoverable among the many varieties grown during the *same* year, it is found that it does not hold. Indeed, with some exceptions, there seems to be a slight *decrease* in the percentage of yellow berry, corresponding to the increase in the number of days between the first heading and the ripening of the varieties:

TABLE XIV. Relation between the number of days from first heading to ripening and the production of yellow berry.

	Number of days from date of first heading to ripening.							
	29 to 31	32 to 34	35 to 37	38 to 40	41 to 43	44 to 46	47 to 49	50 to 52
1906.								
Number of cases.......	1	30	34	28	27	6	0	2
Average per cent. of yellow berry..........	23	46	26	26	34	25	......	60
1907.								
Number of cases.......	1	1	6	28	69	16	5	2
Average per cent. of yellow berry..........	6	51	48	42	39	23	45	42

Total average number of days: 1906, 38; 1907, 42.
Total average per cent. of yellow berry: 1906, 33; 1907, 39.

From table XII we may note that the total average mean temperature was about two degrees higher and the rainfall about two inches less in 1906 than in 1907 for the time between first heading and ripening. It is very probable that this might easily account for the fact that the average ripening period was four days shorter in the former year, and might also, at least partially, account for the greater percentage of yellow berry in 1907. The average date of first heading was May 20, in 1906, while in 1907 it was three days later. Since the wheats were planted on an average five days earlier in 1907, we should expect, other things being equal, that the time of first heading would itself be earlier in 1907. Some climatic agency must therefore be sought which would have been able to counteract the effects of late planting in 1906, and which would in addition have been responsible for causing the wheats to come into head three days earlier in 1906 than in 1907. This fact is easily discernable in the sum total of the weather conditions for April and May, which may be briefly summarized as follows:

TABLE XV.

	Precipitation.		Number of cloudy days.		Mean temperature.	
	1906.	1907.	1906.	1907.	1906.	1907.
April	2.76	1.30	13	10	59 60°	46.07°
May	2.00	1.10	14	13	66.70	59.45
Total and averages	4.76	2.50	27	23	63.23	52.87

From this table it becomes clear that the rapidity of growth in general, including the time of coming into head and of reaching final maturity, as well as the percentage of yellow berry produced, are the resultants of at least several combined seasonal factors of which the most important are those which obtain in the spring. The length of time duration for the autumn growth, as determined by the date of planting, and the climatic factors of the fall vegetative period, are merely of underlying importance as deciding the stage of growth and the general condition of the plants on their resumption of activity in the spring. If we attempt to interpret the effect of these combined influences in terms of the rapidity of growth of the plants and of the ripening of the grain, and to correlate them with the percentage production of yellow berry, we shall find, as previously stated, that the prevalent idea that slow ripening is correlated with high percentages of yellow berry is apparently justified by the data collected from our wheat cultures for 1906-'07, *when the total averages for the two years are compared.* (Table XIV.)

When, however, the data for the different varieties *within* a given season are considered, this rule does not hold. (See, also, table XIV.) Now, since it is improbable that influences that would operate as ***between*** different seasons to bring about such a result would fail to operate ***in*** a given season, there must therefore be other factors, or combinations of factors, which complicate the results, and which are not without taking into consideration data with reference not alone to climatological conditions but also to the hereditary tendencies of the varieties concerned.

TABLE XVI. Relation between length of spring vegetative period and the percentage of yellow berry.

1906.

	Number of days from March 1 until ripe.					
	106 to 110	111 to 115	116 to 120	121 to 125	126 to 130	
Average mean temperature, first head until ripe, Fahrenheit,	71.86°	71.97°	72.23°	73.23°	73.25°	
Number of cases..	29	6	58	28	7	
Average per cent. of yellow berry,	51 86	46 33	24.89	24.53	40.43	

1907.

	Number of days from March 1 until ripe.					
	116 to 119	120 to 123	124 to 127	128 to 131	132 to 135	136 to 139
Average mean temperature, first head until ripe, Fahrenheit,	68.78°	69.47°	70.07°	71.66°	72.48°	73 93°
Number of cases..	1	31	64	21	10	1
Average per cent. of yellow berry,	62.00	50.29	35 68	27.90	50 00	21 00

Total average number of days from March 1 to maturity: 1906, 118; 1907, 125.

Total average per cent. of yellow berry: 1906, 33; 1907, 39.

Examination of the data for both years, in table XVI, when taken with reference to the spring growing season, would seem to indicate that those wheats which ripened slowly, and which therefore had a long growing season, have a lower percentage of yellow berry. This *is* directly contrary to the generally prevalent idea as heretofore expressed, and also to the results obtained from the total averages of the two years, as taken separately.

If, however, we examine the column in table XVI giving the average of the mean temperatures from date of first heading to date of ripening for the different groups, we shall find that the wheats ripening later *ripened under the higher temperatures.* This fact confirms the conclusion previously drawn, and indicates that the later wheats, by the fact that their ripening period is brought over into the warmer season, are thus subjected to temperatures the effect of which appears to be to overcome any effect ascribable to a slow ripening period, with the net result, at any rate, that they have a lower percentage of yellow berry than the wheats ripening earlier.

In the last column for 1906 (table XVI), the next to the last for 1907 in the same table, there appears a group of slow-ripening wheats which, despite the higher mean temperatures prevailing from first heading to ripening, have yet varied from the rule in the production of high percentages of yellow berry.

An attempt to explain these apparently anomalous cases will be found in the second part of this bulletin.

PART II.

INDIVIDUAL AND VARIETAL INHERITANCE OF YELLOW BERRY.

One of the most desirable achievements in wheat-breeding would be the origination of a strain of hard glutenous winter wheat which under no conditions would produce grains of the inferior "yellow berry'' type. Attempts to secure such strains by importation from the hard wheat districts of Russia, Hungary and the Balkan states have been made. In a way the same end has been sought by the efforts of different breeders to improve the gluten content of wheat by various systems of selection, based upon chemical analyses of the grain and upon milling and baking tests of the flour. In some cases the results of such efforts have been promising.

There exists, however, to the knowledge of the authors, no attempt hitherto at the improvement of wheat through the selection of pedigree strains or pure cultures, in which the tendency to produce the yellow berry has been followed satisfactorily through more than one generation of pure-bred plants; and this particular investigation, in the writers' opinion, is of fundamental importance in dealing with the problem.

It is certain that the yellow berry is an inferior type of kernel, and it is not unreasonable to suppose that strains comparatively free from a tendency to produce such grains might exist, just as, by analogy, strains or families have been found, of various economic plants, whose cell characters render them immune to the attacks of certain species of fungi which ordinarily beset the species.

Manifestly, the elimination of the yellow berry by such a method *is wholly dependent upon the extent to which the yellow berry is distinctively a heritable product* and not a fluctuating variation common to all the strains of glutenous wheats when grown under certain seasonal conditions. That the appearance of the yellow berry in hard wheats is indeed a phenomenon in which the climatic conditions play an important part has long been recognized, and to the further and more particular knowledge of this fact part I of this bulletin is a contribution.

Nevertheless, that the appearance of the yellow berry is by no means due to climatic factors alone is proven by the following fact:

Among our mass-variety cultures, those wheats were examined *which were planted side by side on the same day, and which ripened on the same date. Among these, the percentages of yellow berry were found to vary widely.* A few illustrative examples to the point are given in the following table:

TABLE XVII.

No.	Year.	Date planted.	Date ripe	Per cent. of yellow berry.
527	1905–'06	October 2	July 4	1
510	1905–'06	October 2	July 4	22
484	1905–'06	October 2	June 26	2
462	1905–'06	October 2	June 26	38
248	1906–'07	September 27	July 2	17
256	1906–'07	September 27	July 2	54
527	1906–'07	October 2	July 8	16
506	1906–'07	October 2	July 8	66

It may, moreover, be shown that most of the so-called "varieties," as they appear on the market, are really mixtures of wheats, which when separated are found to produce widely different amounts of yellow berry. For a few instances of these mixed varieties see table XVIII. What these examples so strikingly show is probably true, to a greater or less degree, of all commercial varieties of wheat.

By "segregation number" in the above table is meant that, from an original lot of seed bearing the name of a commercial "variety," distinct and different types of wheats—"segregates"—were selected out, and a serial number assigned to

TABLE XVIII.

Original number.	VARIETY NAME.	Segregation number.	Per cent. of yellow berry.
494	....	1338....................	47
		1339....................	17
543......	Hungarian Red..........	1348....................	10
		1349....................	51
627......	Japanese................	1362....................	48
		1363....................	21
147......	Pedigree Early Genesee Giant.........	1366....................	62
		1367....................	38

each. Here also it is clear that within a given so-called "variety," as it appears on the market, are found strains of different type which show distinct physiological differences so far as the production of yellow berry is concerned.

Since here, too, the different "segregates" chosen for illustration *were all planted on the same day, side by side, and matured their seed on the same date,* it is evident that the soil and climatic factors operative must have been exactly the same for all.

The question of the extent to which the tendency to produce the yellow berry may be an heritable one, independently of seasonal conditions, has been examined into for the wheat varieties under experiment, and for the two years 1905-'06 and 1906-'07.

For this purpose the varieties grown in 1906 were separated into four groups, according to the percentage amount of yellow berry produced by each. Group I contained those wheats in which from 1 to 25 per cent. of yellow berry was produced; group 11, from 25 to 50 per cent.; group111,51to 75 per cent., and group IV, from 76 to 100 per cent. The average percentage of yellow berry produced by the wheat varieties of each group was determined. Table XIX gives a summary of these analyses, from which it will be observed that, with one very minor exception, the averages of the amount of yellow berry for each group take the same relative position in 1907 that they occupy in 1906.

It will be noted, by reference to the preceding table, that the wheats of 1907, with respect to the total average percentage amounts of yellow berry produced by each group as a whole, appear in every case, with one exception (column 4, group IV), when arranged in successive order, *to have been derived from groups having the same successive order in 1906.*

TABLE XIX.

Group No.	Number of varieties included.	1	2	3	4
		Range of percentages of yellow berry within the groups, 1906.	Average percentage of yellow berry for each group, 1906.	Range of percentages of yellow berry within the groups, 1907.	Average percentage of yellow berry for each group, 1907.
I..............	61	1.25	12.78	0.83	36.95
II..............	38	26.50	38.34	0.89	38.68
III..............	26	51.75	61.65	17.72	45.84
IV..............	9	76.10	81.55	22.72	42.55

It is true that the group range of the offspring of 1907 (column 3) is wider than the original group range of those groups from which they sprang. It is highly probable that this is due, in part at least, to the mixed character of most of the commercial varieties under experiment. Were the varieties all purebred, it is unlikely, if the yellow berry tendency be inheritable at all, that the range of the offspring would be as wide as in the table.

However, allowing for the crude and imperfect materials, it at least appears as a fact that the location of the *minimum range of yellow berry in the varieties lies in those groups of 1907 that came from the minimum groups of 1906.* It will furthermore be noted that, when the averages are considered (column 4), while the minimum average is not so low in 1907 as in the corresponding parent groups for 1906, it is easy to see that the groups of 1907 fall into the same relative order as those of 1906 from which they sprang, in regard to percentage of the yellow berry. The minor exception, referred to previously, is the reversal of the order of the last two groups in column 4. The difference between them, however, of only 3.29 per cent., is negligible, as is also the difference 'between the first two groups, of 1.73 per cent.

What stands out very clearly, however, is the fact that from the ninety-nine varieties grown in 1906 which had 50 per cent, of yellow berry or under, with an average of 25.56 per cent., came offspring whose average percentage of yellow berry was 37.81 per cent. And, on the other hand, from thirty-five varieties in 1906 in which the yellow berry percentage lay between 50 and 100, with an average of 71.60 per cent., came offspring with an average percentage of yellow berry of only 44.19 per cent., although the group range was wider than that from which the selection came. The general conclusion from the data may be stated thus:

While on the one hand the vareties *low* in yellow berry (groups I and II) had progeny in 1907 which averaged 12.25 per cent. *higher* than the average of the corresponding parental groups for 1906, yet, on the other hand, the varieties *high* in yellow berry (groups 111and IV) had progeny which averaged 27.41 per cent. *lower* than the average of the corresponding parental groups for 1906.

Without undertaking to use the materials at hand for constructing a regression table for the character in question, it will suffice to say that the data, as they stand, point strongly to a certain degree of actual inheritance of the yellow berry tendency, even as exhibited by such impure cultures as the commercial mass-varieties necessarily are.

It may be recalled that in table XVI there was a group of wheats which, in spite of their late ripening, produced high percentages of the yellow berry during both of the years covered by the experiment. This fact is opposed to the conclusions heretofore drawn that within a given season those wheats which ripen late, and which therefore carry their ripening period over into the warmer weather, produce less yellow berry.

As an explanation of this apparently contradictory evidence, it may be suggested that with the hereditary long growing period of those wheats, there may also coexist a strong hereditary tendency toward the production of the yellow berry, which physiological tendency persists despite the hotter weather of midsummer, resulting in a higher percentage of the yellow berry than is the case even with many of the earlier-ripening wheats.

That the length of the growing season in wheat varieties is itself a character that is strongly heritable may be seen from the following table, in which the wheats grown in 1906 are arranged in groups according to the length of their respective spring growing periods, with the offspring for 1907 arranged in groups corresponding to their respective parents, and with the averages determined as before. From this table, indicating the inheritance of length of vegetative period, and from table XIX, and tables XXII and XXIII (below), showing the inheritance of the tendency to produce yellow berry, there exists, in our judgment, a sufficient basis of evidence for the assumption that these two tendencies may occasionally occur together in the same individual.

TABLE XX. Length of spring vegetative period for parent varieties, 1906, and offspring, 1907.

No. of cases........	29	6	58	28	7
Spring vegetative period, 1906 (days)..	106 to 110	111 to 115	116 to 120	121 to 125	126 to 130
Average for progeny, 1907 (days).......	124.2	124.5	124.8	129.7	128 0

In the preceding table, the varieties under experiment are grouped according to the duration of their respective spring vegetative periods. Beneath this grouping is given the average length of the spring vegetative period of the progeny of the several groups.

CULTURE TEST OF HARD WHEAT GRAINS AND YELLOW BERRIES.

From each of eight apparently pure varieties which contained a mixture of flinty and starchy kernels, 200 grains of each of these types were carefully selected. While of course there were present, many intermediate types in the mass, only the extremely hard and the completely starchy grains were actually taken. Two thirty-foot rows including each of these types were planted side by side, on the same date in the fall of 1906, and were promptly harvested on the day when they were apparently ripe. The spikes were cut off, placed in loose sacks, and were immediately brought in and allowed to dry under cover. The grain was thrashed by hand, and the yield in gram weight of each row was carefully determined. All percentages of the yellow berry in the grain were then found, and by the same person.

In table XXI, following, appear the results of the study of the progeny of the hard and soft grains, and a close scrutiny of the table brings out the following facts:

1. The hard grains planted in 1906 were much heavier than the soft ones.

2. The yields from the heavy hard grains were greater than those from the lighter, softer kernels, with the exception of the case of No. 241, where the row of the soft wheat was on the outside of the plot, having therefore the advantage of additional growing space, and that of No. 501, which was a Poulard wheat.

The results as to yield are in accordance with those usually obtained from similar tests, and are probably due to the fact

TABLE XXI.

Serial number.	Character of grains planted.	Average air-dry weight of 100 grains.	Date ripe and harvested.	Characters of crop harvested.			
				Average weight of 100 grains.	Yield.	Specific gravity.	Per cent. of yellow berry.
		Grams.		*Grams.*	*Grams.*		
241........	Soft*..	3.054	July 13	2.531	514	1.358	1.6
	Hard..	3.214	"	2.612	269	1.335	6.6
246........	Soft...	3.008	"	2.601	344	1.334	14.0
	Hard..	3.114	"	2.546	360	1.336	8.7
249........	Soft..	2.775	"	2.032	224	1.325	8.0
	Hard..	3.221	"	1.940	281	1.318	4.6
254........	Soft...	3.008	"	2.335	250	1.333	2.7
	Hard..	3.353	"	2.434	329	1.340	2.5
466........	Soft...	3.168	"	2.647	328	1.305	4.0
	Hard..	3.579	"	2.673	474	1.318	5.2
501........	Soft†.	3.688	July 19	2.934	112	1.288	63.1
	Hard†.	3.989	"	2.403	71	1.270	72.5
534........	Soft...	2.987	July 13	2.191	169	1.314	18.7
	Hard..	3.436	"	2.127	187	1.320	14.8
1303........	Soft...	2.685	"	2.396	303	1.344	13.0
	Hard‡.	3.007	"	2.327	356	1.366	8.3
Total av'gs,	Soft...	3.046	July 13	2.458	280	1.325	16.71
	Hard..	3.363	"	2.392	291	1.325	15.40

* Disregard yield on account of outside row.
† Poulard wheat.
‡ Not an outside row.

Average yield: Soft, 270 grains; hard, 331 grains.
Average yellow berry: Soft, 10.1 per cent.; hard, 7.4 per cent.

that large, heavy seeds contain more reserve food material, enabling the plants to start more vigorously than those from lighter and smaller grains.

With the exception of Nos. 241 and 501, before referred to, and one other—No. 466—the offspring of the hard grains showed a slightly higher percentage of yellow berry than did the progeny of the soft grains.

That the percentages of yellow berry obtained in the crop from hard seeds should average very little less than the percentages of yellow berry in the crop from the soft grains may be explained as follows:

Since yellow berry kernels may sometimes occur on the same spike with normal hard kernels, and since all the grains on the head have practically the same set of elementary characters, a selection of such yellow berry kernels for planting would not constitute a selection of a family of plants predisposed to the production of yellow berry at all. The offspring in such cases of the yellow berry and of the normal kernels would inherit like characters; and offspring of both sorts would possess the same ratio of hard to soft kernels.

As an explanation of the slight advantage of the hard grains in giving harvests which contained somewhat less of the yellow berry, the suggestion may be offered that the varieties used were not pure cultures of pedigree wheats, but were the usual mass-varieties of commerce, and consequently in all probability not homogeneous in point of descent. It may have been that these "varieties" were mixtures containing several sub-varieties, some of which, under identical conditions with others, would produce less of the yellow berry. It is plain that if such a mixture of the hard and soft grains were selected from at random, the selected hard grains would be apt to contain a slightly larger relative proportion of seeds from the harder sorts in the mixture, while the selected soft wheats or yellow berries would be apt to be, in large proportion, grains from those sorts in the mixture that naturally and normally produce a larger percentage of the yellow berry. The outcome would be that the progeny of the hard grains would verge slightly more *away* from the yellow berry tendency and the progeny of the soft or yellow berry grains would verge slightly more *towards* it. As a result of such selection, if long continued, a gradual and at last a considerable elimination of the sorts that tended toward the production of much yellow berry would follow. The improvement would be slow, because blindly achieved, and in all probability would never be permanent, on account of the almost practical impossibility of securing *total* elimination of the undesirable races in this way.

DEGREE OF INHERITANCE OF YELLOW BERRY IN PURE-BRED (PEDIGREE) WHEATS.

In the summer of 1906 a large number of spikes of wheat were selected from among the mass-varieties growing in the plots of the Department of Botany of this Experiment Station. These spikes or heads were chosen on account of certain apparently promising characters possessed by the plants which bore them, and they were intended to furnish the seed for other plants of pure "pedigreed" races of superior stocks. The reason that more than one head was not selected from any single plant was because of the fact that the plants grew close together in the row, and in the consequent tangle of roots and stems it is always impossible to ascertain with certainty where

PLANT BREEDING RECORDS

DEPARTMENT OF BOTANY, KANSAS EXPERIMENT STATION, 19____

TRITICUM SHEET, FORM 1, PEDIGREE SERIES, MATURE PLANTS.

Serial No.	958
Plant No.	3
Total no. culms	13
Culm No.	11

Name	Golden Drop
Origin	No. 504 Haage & Schmidt 1902
Remarks	

Culm Characters.

Length, cm	52
Structure, solid	
Structure, semi-solid	
Structure, hollow	+
Color	br

Spike Characters.

Structure	b
Rigidity	
Flattened across spikelets	+
Flattened with spikelets	
Square	
Conical	+
Fusiform	
Clavate	
Awns, position	S
Awns, arrangement	S
Awns, color	br
Length, cm	8.7
Width, mm	12
No. of spikelets	25
Ratio length to no. spikelets	.38
Grains visible	
Grains not visible	+

Glume Character. (Empty Glume.)

Color	br
Pubescent	
Not pubescent	+
Tooth, blunt	
Tooth, acute	+
Tooth, length, mm	+2
Shoulder	R
Auricle notch	S
Glume of apical spikelet	S.

(Flowering Glume.)

Color	br
Pubescent	
Not pubescent	+
Awns, color	br
Awns, length, mm	+30
Total no. sterile spikelets	4
Total no. bearing spikelets	21
Ratio sterile to bearing "	5.25
Total no. sterile flowers	26
Total no. bearing flowers	36
Ratio sterile to bearing flow.	1.38

Distribution of Flowers and Seeds in Spikelets.

Sp. No.	Fls.	Sds.
1	1	0
2	2	1
3	3	1
4	3	1
5	3	2
6	3	2
7	4	3
8	3	3
9	4	3
10	3	1
11	3	2
12	4	3
13	3	2
14	3	2
15	2	1
16	3	1
17	2	2
18	2	2
19	3	1
20	2	1
21	2	1
22	1	0
23	1	1
24	1	0
25	1	0
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		

Grain Characters.

Total no. grains	36	Av. crushing point, g.	
Color		Av. volume, cc.	
Form		Specific gravity	
Av. length, mm.	6.52	Total weight, g.	1.100
Av. width, mm	3.11	Av. weight, mg.	30.55

PLATE 1. Wheat-breeding record-sheet, showing the manner in which the data are recorded.

one plant ends and another begins. One is therefore compelled to commence with single heads unless the individuals are growing in nursery plots.

All of the visible morphological characters of these heads, of their grains, and of the culms which bore them, were carefully entered on a special set of blanks which are now on file in the records of this department. Plate I is an illustration of such a record sheet, in which some fifty characters are accounted for.

An examination of the grain from each of the heads was made with especial reference to the presence or absence of the yellow berry, and, while it is very true that a single spike is not a perfect index to the character of all of the other spikes on the plant, and while the character of the grains may vary somewhat even within the same plant, yet when enough cases are considered, the writers believe, as the following table will indicate, that at least extremely suggestive data appear with reference to inheritance of the tendency to produce the yellow berry. For this reason, a comparative study was made of the percentage amounts of yellow berry produced in the original heads selected, and in their progeny harvested in 1907. For convenience, the original selections are here thrown into groups, according to the percentage amounts of yellow berry produced in each spike.

TABLE XXII. Inheritance of yellow berry in pure races of (pedigree) wheat.

	Group number—				
	I.	II.	III.	IV.	V.
Number of cases	35	38	17	9	6
Percentage range of yellow berry in parentage, 1906	0	1–25	26–50	51–75	76–100
Percentage range of yellow berry in progeny of the foregoing groups, 1907	0–20	0–30	0–68	1–38	0–49
Mean percentage of yellow berry in 1907	3.9	7.9	17.1	14.9	23 5

An inspection of the above table leads to some interesting inferences. It will be noted that while the progeny of each of the 1906 groups have a lower range limit of zero, yet when the higher range limit is considered the effect of selection becomes manifest in the fact that the progeny in the high-range groups of 1906 are also high in 1907, in respect to maximum amount of yellow berry; while the progeny of the low-range groups of

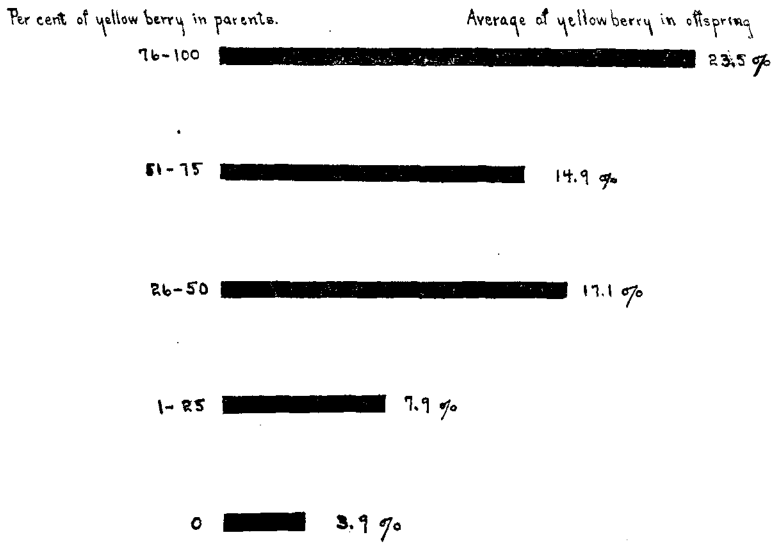

PLATE 2. Showing graphically the degree of inheritance of the tendency to produce yellow berry in pedigree races of wheat.

1906 are low in 1907. That groups III and IV, in 1907, are not in the same relative order with respect to the maximum as their parentage of 1906 may be ascribable in part to the small number of cases involved, with a consequent undue influence of occasional erratic variants.

Reference to the mean per cents. in the last column brings even these irregular numbers almost completely into the relative order of the parentage of 1906. As a matter of fact, the high average and the excessively high range of group III (1907) was caused by the presence of one case, which produced 68 per cent. of yellow berry, and which markedly modified the mean. Were this case excluded, the group would fall into its correct position.

Although it is a fact that many of those parental spikes in which no yellow berries were found produced yellow berries in their 1907 offspring, and while those parents, which, as in group IV, contained a high percentage of yellow berry, produced much smaller amounts in the offspring, yet the regression toward a common race mean is not so marked in the case of the pedigree wheat cultures (table XXII) as when mass-varieties are used.

This fact is strikingly shown in table XXIII:

TABLE XXIII. Distribution of parents and offspring with respect to the production of the yellow berry, as exhibited by mass-variety cultures, pedigree cultures, and selected hard and soft grains from mass-varieties.

Number and distribution of cases.							Per cent of yellow berry—			
							In parents.	Average in offspring.		
1	2	3	4	5	6	7	8	9	10	11
Group No.......	Number of mass-variety cultures..	Per cent. of all cases..........	Number of pedigree cultures....	Per cent. of all cases.........	Selections of hard and soft from mass-varieties...	Per cent. of all cases.........	Percentage range of yellow berry in parents, 1906..	Mass-variety cultures........	Pedigree cultures.	Selected hard and soft grains from mass-varieties...
I	0	0	35	33	8	50	0	0	3.9	15.40
II	61	46	38	36	0	0	1–25	36 95	7.9	
III	38	28	17	18	0	0	26–50	38.68	17.1	
IV	26	19	9	9	0	0	51–75	45.84	14 9	
V	9	7	6	6	8	50	76–100	42.55	23.5	15.7

From the table it is seen that the difference between the averages for the highest and the lowest groups in the mass-varieties was only about 8 per cent.; in the selections of hard and soft grains from certain mass-varieties it was but 0.3 per cent.; while in the pedigree heads the difference between the highest and lowest averages was 20 per cent. Moreover, in the first progeny group of the pedigree wheats for 1907, *a little over one-third of the cases produced no yellow berry at all* (a fact which the general table does not show), *while the average ofall the cases was* ***but*** *3.9 per cent.* On the other hand, by the other method of selection, *there were no cases whatever where the offspring were free from yellow berry;* and the averages for the lowest groups in the case of the mass-varieties, and of the selected hard and soft grains, were 36.95 per cent. and 15.40 per cent., respectively.

This conclusively demonstrates the superiority of the pedigree method as compared with other methods of selection, due to the evident fact that the pedigree cultures represent isolated stable races, instead of the congeries of mixtures of strains which form the commercial varieties.

Table XXIII, however, calls for some further explanation. Taking the mass-variety cultures (common commercial varieties) for 1906, the cultures of hard and soft (yellow berry) grains separated out from a number of such varieties, and the pure (pedigree) cultures of our wheats for 1906, including 134, 16 and 105 cases in each category, respectively, a careful determination was made of the percentage amount of yellow berry in each. The wheats of each category were then thrown into five groups, according to the amounts of yellow berry found.

Owing to the small number of grains available in many cases in the parental groups of the pedigree cultures, it was decided not to attempt to calculate the mean for yellow berry percentage *within* each group, but simply to present the total range of the groups. That the distribution within each group was sufficiently normal was ascertained by inspection. It is further indicated by the fact that, if the distribution of the number of cases be taken in their order from groups I to V, no irregularities will appear.

Now the fact that the original pedigree heads fall into the mode of distribution that they do with respect to the yellow berry is, of course, necessarily a matter of chance. That the *offspring,* however, of the pedigree lots, follows the distribution of the parents to such a high degree in respect to the percentage composition of yellow berry is remarkable. That the mass-variety and selected hard and soft lots follow the same law, although less rigidly, is what would be expected of such lots if the yellow berry tendency is heritable at all in the constituent units which taken together form the group called a "variety."

On examination of table XXIII, columns 8, 9 and 10, it is seen that the *mean percentages* of yellow berry in the mass-variety and pedigree cultures fall almost exactly into the same relative order as the groups of percentage ranges of the parents (column 8). While it is to be inferred that there is regression here, the data were not thought suitable for presentation in the form of a regression table, especially since the means within the two groups of parents could not be calculated to advantage. Therefore, while it is, strictly speaking, incorrect to compare the mean percentage of the progeny with the group range of the parents for a given character, yet, given a uniform and normal distribution *within* the parental groups, such a comparison has practical value, in the absence of the possibility for the more exact analysis of a regression table. It appears, in plain words, in columns 8, 9, 10, table XXII, *that with the percentage increase of yellow berry in the parents follows a mean percentage increase of yellow berry in the offspring.* What is decidedly of supreme importance, so far as this investigation is concerned, is the *very evident fact of the superiority of the pedigree-cultwe method so far as the elimination of the yellow berry is concerned.* For example, while there were no cases of mass-variety lots of parents containing no yellow berry, there were sixty-one cases (46 per cent. of the total) in which the percentage of yellow berry ranged from 1 to 25 per cent. From these came progeny in 1907 in which the *mean percentage of the yellow berry was nearly* 37. On the other hand, among the pedigree cultures, there were thirty-eight in all, or 36 per cent. of the total examined, which fell into the 1 to 25 per cent. class of the parents, but which in 1907 had a *mean percentage of yellow berry of only 7.9.*

Still more striking is the fact that the *minimum or zero class of the parents gave rise also to the minimum class of the offspring (3.9 per cent.) in the case of the pedigree wheats.*

In view of the fact that but one head from each plant of the pedigree parent stocks had to furnish the grains on which an estimate of the percentage yield of yellow berry in the plant as a whole was based, the result is really surprisingly confirmatory of our hypothesis that the yellow berry is a, "tendency," which finds expression in certain strains or races more markedly than in others, *and is heritable.*

In so far as this is the case, the yellow berry problem is one which is capable of being handled by the breeder with a view to the propagation of pure strains of wheat which may be found free from the yellow berry under all conditions. It therefore seems reasonable to hope that from a group of pure strains of pedigree wheats producing no yellow berry for two successive years—which we have—a race of wheat may be derived which will go entirely wide of this tendency to deterioration in the product. If the next few years' work confirms the results of the past two, the outcome, so far as the Kansas hard wheat interest is concerned, will be a distinctively valuable one.

The results thus far, at all events, brilliantly demonstrate the fact that the pedigree system of cereal breeding is the only one whereby definite and permanent results may be effected in breeding improved races of the grains, since by the pedigree method alone can the improved strains be isolated and separated from those of inferior character.