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Breeding for Type of Kernel in Wheat.

BY

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Breeding for Type of Kernel in Wheat, and Its Relation to the Grading and Milling of the Grain.

By H. F. ROBERTS.

Pure races of wheat, even of the same general type, show great diversities among themselves with respect to the form of the kernel. This is the case even among wheat races in which the kernel is in all instances hard and of high protein content. It therefore becomes necessary to distinguish, for breeding purposes, those races which show the most desirable types of kernel. In the improvement of the form of the wheat kernel two purposes have to be reckoned with:

First, the production of such a type of wheat berry as will mill to the greatest advantage—that is to say, which will yield a maximum amount of flour in proportion to the bran. It may be remarked that in the breeding of pure races of wheat—*i. e.,* "pure lines" in the sense used by Johannsen—we find great differences in the types of grain, even among the hard red winter wheats, with respect to this important matter of milling-quality alone.

So far as the miller is concerned, there are certain well-defined preferences with respect to a desirable wheat for milling purposes. Leaving out the primary necessity, in our region at least, of a hard, semitranslucent wheat rich in gluten, and preferably a winter wheat of a dark reddish-amber color, we find that, so far as the form of the wheat kernel is concerned, the millers and grain dealers desire a full plump berry in preference to a slender berry, on account of the relatively less amount of bran to the flour which such a kernel produces, and, for the same reason, a berry with a shallow crease is preferable to one with a deep crease. The deep crease is also an objectionable feature because of the considerable quantity of dirt that it holds, and which must be cleaned out in the scouring process as thoroughly as possible. Manifestly, a kernel with a deep crease will carry more dirt to the rolls than one with a shallow crease. A type of kernel devoid, so far as possible, of the mass of hairs surmounting the ovary, and called the "brush," is likewise desirable because of its lesser liability to carry dirt particles. So much for the preferred type of kernel for milling purposes. Following are illustrations of desirable and undesirable types of kernels. Plates I, II, III, IV and V.

Second, the breeder should endeavor to produce such a type of berry as will, by its superior packing quality in the grain tester, make a maximum weight in pounds to the bushel, and thus secure for the grain as sold a higher grading, and consequently a better price, than another type of berry equally good in other respects but testing at a lower pound rate per bushel.

The present investigation was directed, so far as the data to be herein presented are concerned, toward the relation of the form-factors of the wheat kernel to the volume-weight of the grain.

Wheat, before being sold, is "tested" by means of a standard "grain tester" in order to ascertain the number of pounds per bushel it will average. Upon this average bushel-weight and upon other considerations affecting the quality of the grain, as judged by its appearance, hardness, etc., the grain is "graded" according to a system of standards prescribed by the grain exchange or the state inspection department, as the case may be. The grade as thus fixed for any lot of wheat determines its market price. Wheat is, to be sure, sold entirely by weight in our market; but if, say, two lots of hard winter wheat weigh 1000 pounds each, and if one tests at 56 and the other at 62 pounds to the bushel, the latter will, other things being equal, go into a higher grade and bring a better price than the other.

Under the grading system of the Kansas and of the Minnesota State Grain Inspection Departments, for example, No. 1 Hard winter wheat must weigh not less than 61 pounds to the bushel, while No. 3 must weigh not less than 56 pounds. This weight requirement alone would finally determine the classification, although, of course, other factors of quality almost invariably accompany such differences in weight. Our experiments show that this is not necessarily the case, and that wheats equally good in all other respects may, on account of the form-factors of the kernel, give widely different test weights. Assuming two lots of wheat, testing at 62 pounds and 56 pounds, respectively, and grading No. 1 Hard and No. 3 Hard, the average spread between the prices of these two grades would run from about three cents on the bushel for

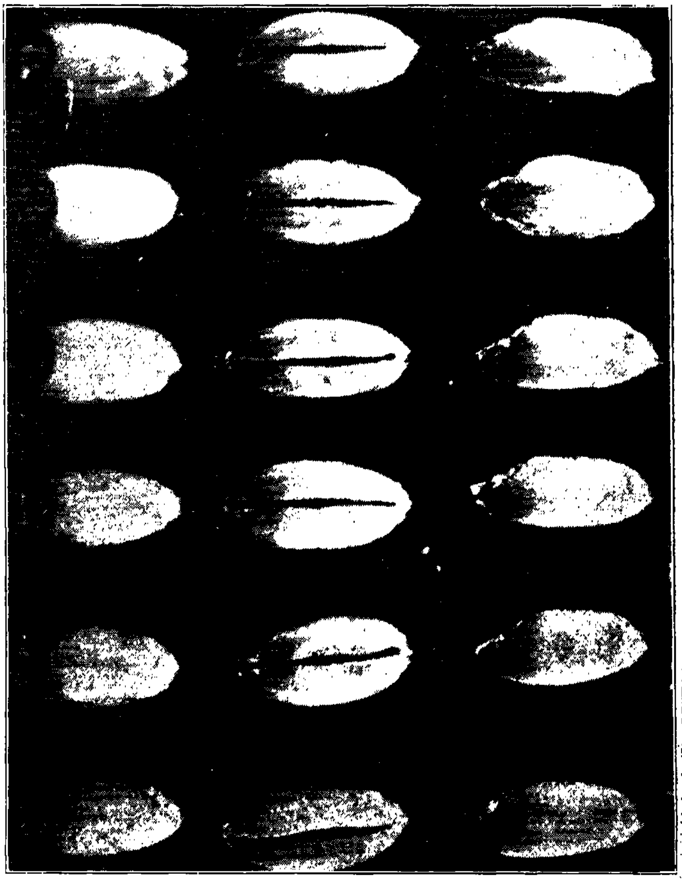

PLATE I. Pedigree No. 1064 × 3 dia.
Superior type of the wheat kernel to breed for: Pure-bred varieties having kernels of the type of this and of No. 1066 have been produced by breeding.

good years when the grades crowd closely together, to about five cents in bad years, when the differences between the upper and lower grades become more sharply marked. In the case supposed, the difference possible to be arrived at in the grading, due to differences in the test weight per bushel, would involve differences in market value of from thirty to fifty dollars on each 1000-bushel lot. It is possible, as will be demonstrated, to secure for wheat a considerably higher test reading by attention to the breeding of a type of kernel that will have superior packing qualities; along with which fact it is also the case that a superior type of kernel as regards shape for milling purposes is simultaneously secured. There is no question that

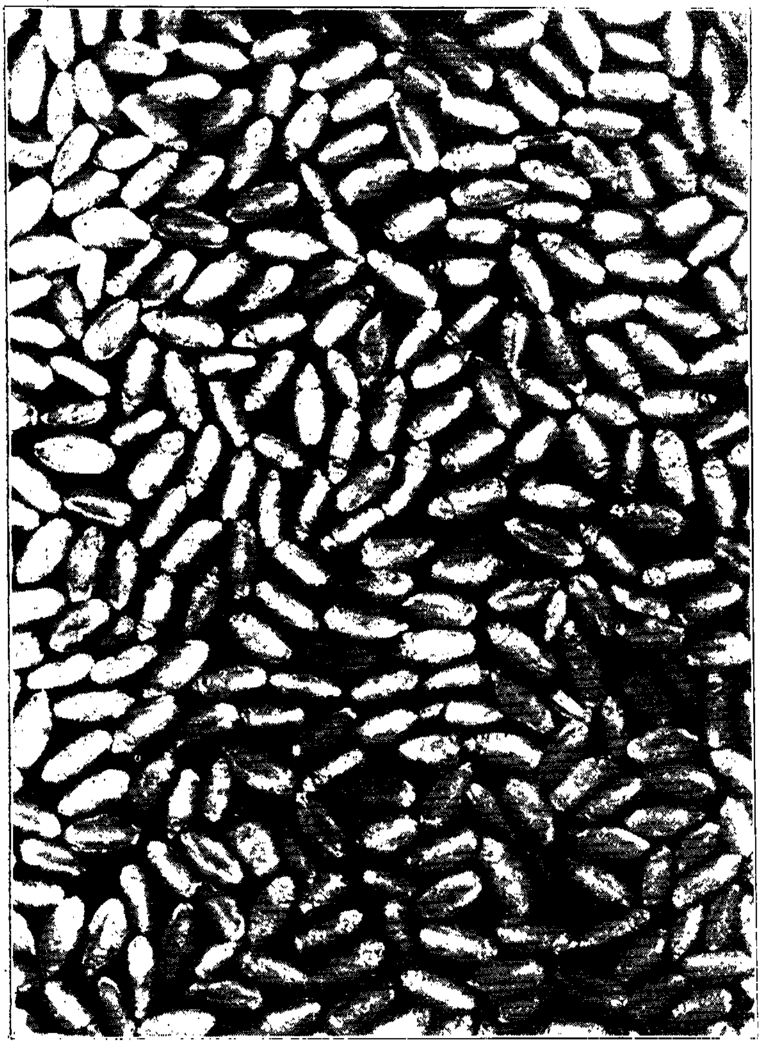

PLATE II. Pedigree No. 1066 × 1½ dia.

One of the most desirable types of the wheat kernel. The grain rather short, thick, blunt at both ends; full, with a very shallow crease. Wheat having this type of kernel will mill to the greatest advantage, yielding a minimum amount of bran.

PLATE III. Pedigree No. 1066 × 3 dia.
Showing details of type of kernel characteristic of this variety—a hard red winter wheat of superior type.

the breeding of a specific type of kernel in wheat is, for these two reasons alone, of equal importance with that of the breeding of a specific type of kernel in corn; which latter has long since been recognized and settled upon. The relative smallness of the wheat kernel has obscured the fact of the importance of the form-factors in this grain, and no quantitative investigations along just these lines seem to have been undertaken hitherto.

What factors determine the differences in volume-weight which thus affect the grade and the market price of wheat? On first consideration, it would naturally be assumed that the

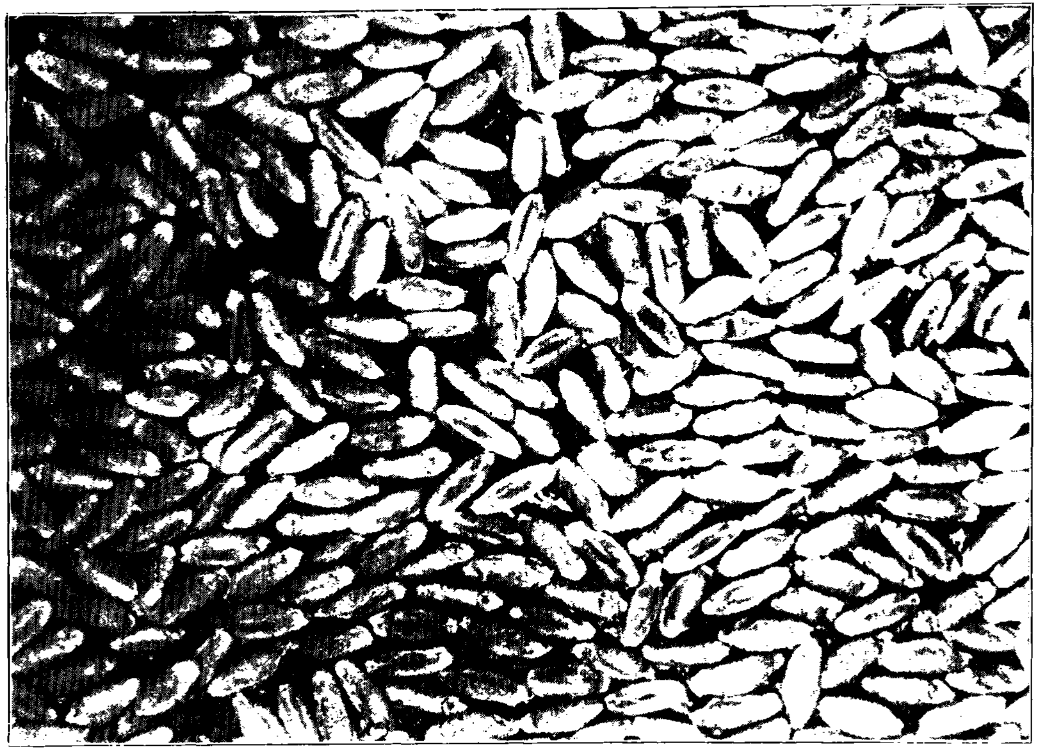

PLATE IV. Pedigree No. 722 × 1½ dia.

An inferior and undesirable type of kernel in wheat; the grain long, narrow, tapering, with a very deep crease. The crease of this type is not due to shrivelling, but is characteristic of certain types of wheat.

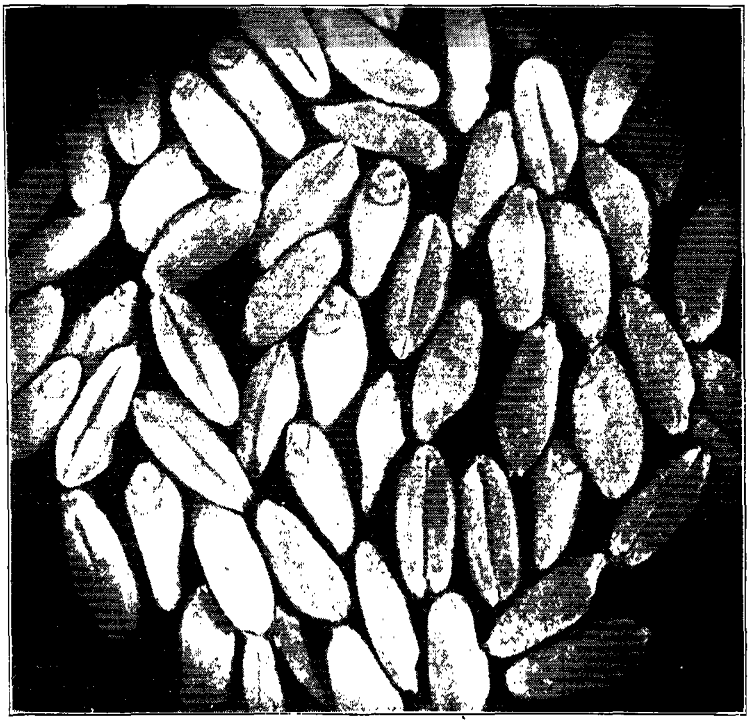

PLATE V. Pedigree No. 722 × 3 dia.
A bad type of milling wheat; kernel long, narrow, with deep crease, producing a maximum of bran.

specific gravity of the kernels would be the most important factor.

However, it was noticed that, among several hundred pure races ("pure lines") of wheat harvested in 1908 at the Kansas Experiment Station, in the breeding grounds of the department of botany, certain distinctive types of kernel existed, which seemed to pack more closely into a given volume than did others, and an investigation was instituted to determine the optimum type of wheat kernel in this regard.

It is sufficiently evident that, in the filling of any physical measure of volume, the number of units that can be gotten into it depends considerably upon their geometrical form, in cases where the volume of the individual kernels is identical; that is to say, for example, whether they are approximately spherical, egg-shaped, oblong, or the like.

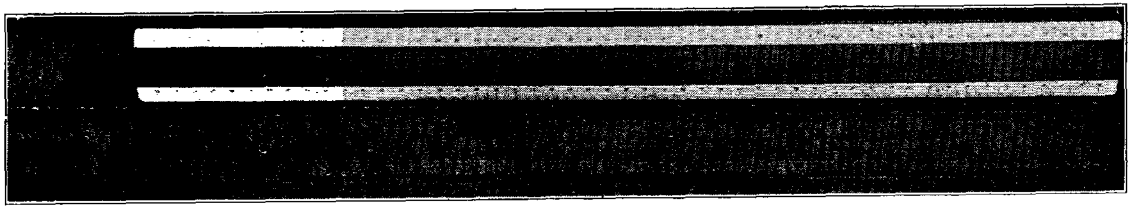

PLATE VI. Measuring board for determining average lengths of kernels.

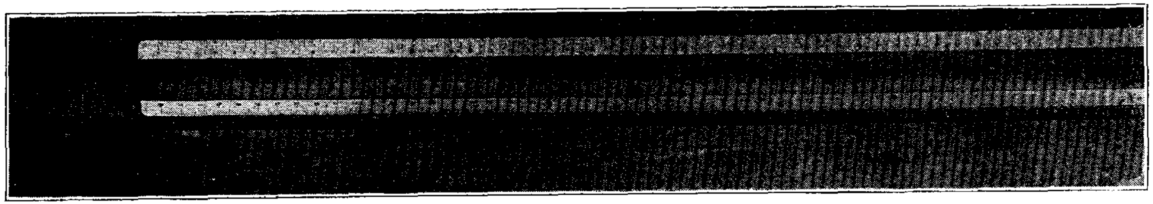

PLATE VII. Measuring board for determining average widths of kernels.

Manifestly, the bushel-weight is the sum of the weights of all the 900,000 to 1,400,000 individual kernels contained in it, and therefore the purpose of the wheat breeder in aiming to influence the bushel-weight for the benefit of the grower should be to select for breeding that race of wheat adapted to his region, which, in addition to having the highest average kernel-weight, also possesses a type of kernel that will admit of the greatest possible number of grains in a bushel measure.

In order to arrive at an unprejudiced judgment in the matter of the particular type of kernel to breed for, an investigation was conducted as follows:

Fifty-two pure races of wheat, showing amongst themselves a great diversity of types of kernel in respect to apparent length, width, contour and volume of the individual grains, and all of which had been growing for two successive years in our breeding grounds, were chosen for experiment, without regard to the economic value of the types of wheat selected.

Kernels of each of these races were subjected to a series of measurements in the following manner:

The average *length* of the kernels of each race was determined by taking, by random sampling, five lots of kernels, amounting by estimate to above 100 grains each, and from which in succession, and without choice, 100 kernels were taken and measured, by laying them end to end upon a measuring board designed by the writer (plate VI), making the number to be measured up to 100 by additional random samplings where necessary. The total length of such 100 kernels in millimeters, divided by the number of individual grains, gave an average that ran exceedingly close for each of the five samples of 100 chosen throughout the fifty-two different races. The total average length for each 500 kernels was therefore taken as the average or mean kernel-length of the race for the given season and locality.

Reference to the following table will indicate how accurate these averages are:

TABLE I.

No.	No. grains.	Av. length (mm.)........	Av. width (mm.)........	Ratio length to width....	Av. volume (cu. mm.)...	Av. weight (g.)..........	Av. specific gravity......	Av. volume-weight.			Packing quality.	
								Grams per 100 cc..	Lbs. per (packed) bushel........	Lbs. per (struck) bushel........	Per cent vol. in 100 cc. not occupied by grain...	Per cent vol. of grain in 100 cc..
418-8	1st 100	5.05	2.66	1.90	16.1	0.021	1.298					
	2d 100	5.03	2.59	1 94	16.0	.020	1.305					
	3d 100	5.15	2.67	1.93	16.5	.021	1.335					
	4th 100	5.16	2.64	1.95	15.5	.020	1.301					
	5th 100	5.16	2.70	1.91	16.0	.021	1.305					
Av.....	500	5.11	2.65	1.92	16.0	0.021	1.309	84.99	66.03	62.26	34.64	65.36
748	1st 100	6.19	2.50	2.47	18.0	0.025	1.358					
	2d 100	6.12	2.50	2.44	17.5	.024	1.386					
	3d 100	6.05	2.44	2.47	17.0	.023	1.377					
	4th 100	6.12	2.45	2.50	17.0	.023	1.375					
	5th 100	6.11	2.45	2.49	17.0	.023	1.371					
Av.....	500	6.12	2.47	2.47	17.3	0.024	1.373	83.77	65.08	58.11	37.60	62.40
778	1st 100	6.20	2.79	2.23	17.5	0.024	1.351					
	2d 100	6.00	2.80	2.14	17.5	.023	1.369					
	3d 100	6.20	2.76	2.24	17.0	.022	1.371					
	4th 100	5.90	2.75	2.14	16.5	.022	1.345					
	5th 100	5.50	2.76	2.00	16.5	.023	1.343					
Av.....	500	5.96	2.77	2.15	17.0	0.023	1.356	86.17	66.94	60.77	37.13	62.87
800	1st 100	5.82	2.78	2.09	18.0	0.025	1.355					
	2d 100	5.82	2.26	2.10	19.0	.025	1.348					
	3d 100	5.79	2.76	2.10	19.3	.025	1.350					
	4th 100	5.80	2.74	2.12	18.0	.025	1.353					
	5th 100	5.78	2.75	2.10	18.5	.025	1.355					
Av.....	500	5 80	2.76	2.10	18.6	0.025	1.352	86.08	66.87	62.75	36.60	63.40
819	1st 100	6.16	2.79	2.20	19.0	0.026	1.322					
	2d 100	6.16	2.76	2.23	19.5	.026	1.315					
	3d 100	6.19	2.76	2.24	20 0	.026	1.311					
	4th 100	6.18	2.79	2.21	20.5	.027	1.314					
	5th 100	6.21	2.81	2.21	20.5	.028	1.310					
Av.....	500	6.18	2.78	2.22	19.9	0.027	1.314	83.53	64.89	59.48	36.52	63.48
854	1st 100	6.06	2.93	2.06	21.5	0.028	1.334					
	2d 100	6.07	2.89	2.10	21.0	.028	1.341					
	3d 100	6.05	2.88	2.10	20.5	.028	1.341					
	4th 100	6.10	2.88	2.11	20.5	.028	1.330					
	5th 100	6.09	2.89	2.10	21.0	.029	1.332					
Av.....	500	6.07	2.89	2.10	20.9	0.028	1.336	83.70	65.02	59.21	37.47	62.53
860	1st 100	5.95	2.56	2.32	16.7	0.022	1.227					
	2d 100	5.88	2.59	2.27	16.5	.023	1.323					
	3d 100	5.90	2.59	2.27	16.0	.022	1.313					
	4th 100	5.89	2.60	2.26	17.0	.022	1.319					
	5th 100	5.88	2.57	2.28	16.0	.022	1.321					
Av.....	500	5 90	2 58	2.28	16.4	0.022	1.301	83.89	65.17	59.69	36.51	63.49
861	1st 100	5.95	2.68	2.22	18.5	0.025	1.338					
	2d 100	5.93	2.68	2.21	18.5	.025	1.345					
	3d 100	5.91	2.63	2.24	17.5	.024	1.341					
	4th 100	5.90	2.65	2.22	18.5	.024	1.336					
	5th 100	5.91	2.61	2.26	17.5	.024	1.336					
Av.....	500	5.92	2 65	2.23	18.1	0.024	1.339	84.16	65.38	59.16	37 17	62.83

TABLE I—*Continued.*

No.	No. grains.	Av. length (mm.).....	Av. width (mm.)......	Ratio length to width....	Av. volume (cu. mm.)...	Av. weight (g.).........	Av. specific gravity......	Av. volume-weight. Grams per 100 cc..	Av. volume-weight. Lbs. per (packed) bushel	Av. volume-weight. Lbs. per (struck) bushel........	Packing quality. Per cent vol. in 100 cc. not occupied by grain...	Packing quality. Per cent vol. of grain in 100 cc...
893	1st 100	6.26	2.68	2.33	20.0	0.026	1.264					
	2d 100	6.30	2.67	2.35	20.0	.027	1.258					
	3d 100	6.28	2.72	2.30	21.5	.028	1.270					
	4th 100	6.30	2.71	2.32	20.5	.027	1.273					
	5th 100	6.27	2.73	2.29	22.5	.028	1.271					
Av.....	500	6.28	2.70	2.32	20.9	0.027	1.267	83.01	64.49	59.33	35.85	64.15
907	1st 100	5.14	2.67	1.92	15.0	0.020	1.327					
	2d 100	5.14	2.64	1.94	14.5	.019	1.313					
	3d 100	5.14	2.75	1.86	15.5	.020	1.313					
	4th 100	5.11	2.69	1.90	15.0	.020	1.310					
	5th 100	5.10	2.68	1.90	15.0	.020	1.316					
Av.....	500	5.13	2 69	1.90	15.0	0.020	1 316	84.21	65.42	57.41	36.76	63.24
921	1st 100	5.69	2 74	2.07	17.0	0.024	1.306					
	2d 100	5.65	2.78	2.03	18.0	.024	1.315					
	3d 100	5.67	2.76	2.05	17 0	.023	1.297					
	4th 100	5.63	2.75	2.04	18.0	.023	1.304					
	5th 100	5.64	2.76	2.04	18.4	.024	1.322					
Av.....	500	5.66	2.76	2.05	18.0	0.024	1.309	78.64	61.09	56.48	38.36	61.64
927	1st 100	6.13	2.88	2.12	21.5	0.029	1.325					
	2d 100	6.12	2.92	2.09	22.0	.030	1.830					
	3d 100	6.10	2.89	2.11	22.5	.029	1.322					
	4th 100	6.11	2.91	2.10	22.5	.031	1.324					
	5th 100	6.10	2.93	2.08	23.5	.030	1.332					
Av.....	500	6.11	2.91	2.10	22.4	0.030	1.325	85.41	66.35	60.31	35.48	64.52
932	1st 100	6.17	3.01	2.04	25.5	0.034	1.381					
	2d 100	6.17	3.02	2.04	24.5	.034	1.331					
	3d 100	6.18	3.01	2.05	24.5	.033	1.322					
	4th 100	6.19	3.00	2.06	24.5	.033	1.331					
	5th 100	6.21	3.02	2.05	25.5	.035	1.318					
Av.....	500	6.18	3.01	2.05	24.9	0.034	1.337	88.77	68.96	64.07	34.52	65.48
935	1st 100	5.57	2.52	2.21	16.5	0.023	1.350					
	2d 100	5.60	2.51	2.23	16.5	.023	1.353					
	3d 100	5.61	2.56	2.19	16.0	.024	1.366					
	4th 100	5.59	2.54	2.20	17.5	.024	1.359					
	5th 100	5.58	2.56	2.17	17.0	.023	1.358					
Av.....	500	5.59	2.54	2.20	16.7	0.023	1.357	88.27	68.58	63.39	35.08	64.92
940	1st 100	6.33	2.37	2.67	26.5	0.037	1.329					
	2d 100	6.31	2.35	2.68	26.5	.037	1.331					
	3d 100	6.34	2.33	2.72	26.5	.037	1.326					
	4th 100	6.31	2.35	2.68	26.2	.037	1.324					
	5th 100	6.32	2.32	2.72	26.0	.036	1.302					
Av.....	500	6.32	2.34	2.70	26.3	0.037	1.322	88.88	69.05	63.23	35.17	64.83
951	1st 100	6.11	2.82	2.16	21.4	0.029	1.311					
	2d 100	6.10	2.78	2 19	20.5	.028	1.336					
	3d 100	6.09	2.78	2.19	21.0	.029	1.330					
	4th 100	6.06	2.78	2.18	20.2	.028	1.322					
	5th 100	6.05	2.78	2.17	22.0	.028	1.326					
Av.....	500	6.08	2.79	2.17	21.0	0.028	1.325	87.33	67.84	58.94	37.51	62.49

TABLE I—*Continued.*

No.	No. grains.		Av. length (mm.)........	Av. width (mm.)........	Ratio length to width....	Av. volume (cu. mm.)....	Av. weight (g.)..........	Av specific gravity	Av. volume-weight. Grams per 100 cc..	Lbs. per (packed) bushel........	Lbs per (struck) bushel........	Packing quality. Per cent vol. in 100 cc. not occupied by grain...	Per cent vol. of grain in 100 cc..
983	1st	100	6.02	2.63	2.28	18.5	0.025	1.337					
	2d	100	5.96	2.62	2.27	18.0	.026	1.336					
	3d	100	5.94	2.57	2.31	17.5	.023	1.328					
	4th	100	5.97	2.63	2.27	18.0	.025	1.333					
	5th	100	5.94	2 56	2.32	17.5	.023	1.338					
Av.....		500	5.97	2.60	2.29	17.9	0.024	1.334	86.17	66.94	60.69	35.52	64.48
994	1st	100	5.83	2.86	2.03	21.0	0 028	1.278					
	2d	100	5.81	2.87	2.02	20.5	.027	1.290					
	3d	100	5.80	2 84	2.04	20.5	.027	1.313					
	4th	100	5.81	2.84	2.04	20 0	.026	1.289					
	5th	100	5.83	2.82	2.06	19.5	.026	1.289					
Av.....		500	5.82	2.85	2 04	20.3	0.027	1.292	82.18	63.84	58.06	36.66	63.34
1008	1st	100	5.97	2.91	2.05	21.5	0.024	1.351					
	2d	100	6.01	2.90	2.07	22.0	.024	1.335					
	3d	100	5.96	2.86	2.08	21.0	.024	1.350					
	4th	100	6.00	2.87	2.09	22.0	.024	1.350					
	5th	100	5.93	2.88	2.07	21.5	.025	1.352					
Av....		500	5.98	2.88	2.07	21.6	0.024	1.349	86.06	66.86	61.86	36.20	63.80
1014	1st	100	5.89	2.74	2.15	19.0	0.025	1.284					
	2d	100	5.95	2.79	2.13	19.5	.025	1.283					
	3d	100	5.94	2.79	2.13	19.0	.025	1.276					
	4th	100	5.90	2.74	2.15	19 5	025	1 278					
	5th	100	5.89	2.74	2.15	19.0	.024	1 270					
Av.....		500	5.91	2.76	2.14	19.2	0.025	1.278	79.27	61.58	55.50	37.88	62.12
1016	1st	100	5.91	2.82	2.09	20.5	0.028	1.355					
	2d	100	5.89	2.78	2.11	19.5	.027	1.356					
	3d	100	5 93	2.79	2.12	20.5	.028	1.346					
	4th	100	5.93	2.80	2.11	21.0	.028	1.338					
	5th	100	5.95	2.83	2.10	21.0	.029	1.328					
Av		500	5.92	2.80	2.11	20 5	0.028	1.345	80.78	62.76	56.43	37.94	62.06
1018	1st	100	5.77	2.72	2.12	18.5	0.025	1.331					
	2d	100	5.82	2.69	2.16	18.0	.025	1.33					
	3d	100	5.77	2.74	2.10	19.0	.026	1.346					
	4th	100	5.77	2.69	2.14	18.0	.025	1.332					
	5th	100	5.78	2.69	2.14	18.0	.025	1.322					
Av.....		500	5.78	2 71	2 13	18.3	0.025	1.33[illegible]	85.41	66.35	60.63	36.64	63.36
1023	1st	100	6.70	2.33	2.87	18.0	0.024	1.31[illegible]					
	2d	100	6.75	2.38	2.83	18 0	.026	1.319					
	3d	100	6.75	2.37	2.84	18.0	.025	1.319					
	4th	100	6.75	2.37	2.84	19.0	.025	1.321					
	5th	10[illegible]	6.70	2.37	2.82	18.0	.025	1.329					
Av.....		500	6.73	2.36	2 84	18.0	0.025	1.32[illegible]	79.04	61.40	53 37	41 09	58.91
1040	1st	100	6.89	2.91	2.36	26.5	0.035	1.295					
	2d	100	6.89	2.94	2.34	25.5	.036	1.306					
	3d	100	6.86	2.89	2.37	25.5	.033	1.302					
	4th	100	6.86	2 91	2.35	26.5	.034	1.297					
	5th	100	6.85	2.86	2.39	25.0	.0[illegible]3	1.296					
Av.....		500	6.87	2.90	2.36	25.8	0.034	1.300	80.53	65.18	54.78	39.60	60.40

TABLE I—*Continued.*

No.	No. grains.	Av. length (mm.)........	Av. width (mm.)........	Ratio length to width....	Av. volume (cu. mm.)	Av. weight (g.)........	Av. specific gravity......	Av. volume-weight. Grams per 100 cc..	Av. volume-weight. Lbs. per (packed) bushel........	Av. volume-weight. Lbs. per (struck) bushel........	Packing quality. Per cent vol. in 100 cc. not occupied by grain...	Packing quality. Per cent vol. of grain in 100 cc..
1059-1	1st 100	5.78	2.63	2.19	17.5	0.024	1.302					
	2d 100	5.76	2.56	2.25	17.5	.023	1.298					
	3d 100	5.75	2.56	2.24	17.5	.023	1.296					
	4th 100	5.73	2.57	2.22	17.5	.023	1.302					
	5th 100	5.76	2.57	2.24	17.5	.023	1.296					
Av....	500	5.76	2.58	2.23	17.5	0.023	1.299	81.15	63 04	57.05	39.23	60.77
1064	1st 100	5.91	2.87	2.05	21.0	0.029	1.341					
	2d 100	5.94	2.85	2.08	21.4	.030	1.354					
	3d 100	5.97	2.85	2.09	21.0	.030	1.346					
	4th 100	5.97	2.84	2.10	20.0	.030	1.365					
	5th 100	5.91	2.83	2.08	21.0	.029	1.345					
Av....	500	5.94	2.85	2.08	20.9	0.030	1.350	88.00	68.37	62.05	36.67	63.33
1066	1st 100	5.97	2 93	2.03	23.0	0.032	1.338					
	2d 100	5.98	2.96	2.02	24.0	.033	1.334					
	3d 100	6.02	2.97	2.02	24.0	.033	1.335					
	4th 100	5.99	2.95	2.03	23.0	.032	1.337					
	5th 100	5.98	2.96	2.02	24.0	.033	1.338					
Av....	500	5.98	2.95	2.02	23.6	0.033	1.336	91.36	70.98	65.25	34.90	65.10
1069	1st 100	5.80	2.40	2.41	14.5	0.019	1.323					
	2d 100	5.77	2.42	2.38	15.0	.020	1 297					
	3d 100	5.74	2.43	2.36	14.5	.019	1.320					
	4th 100	5.74	2.43	2 36	16.0	.021	1.329					
	5th 100	5.75	2.43	2.36	15.0	.021	1.325					
Av....	500	5.76	2.42	2.38	15.0	0.020	1.320	80.86	62.82	58.82	38.08	61.92
1071	1st 100	5.50	2.36	2.33	13.5	0.018	1.277					
	2d 100	5.54	2.39	2.31	15.0	.019	1.281					
	3d 100	5.52	2.37	2.32	14.5	.019	1.285					
	4th 100	5.50	2.42	2 27	15.0	.020	1.276					
	5th 100	5.55	2.44	2 27	15.0	.021	1.286					
Av....	500	5.52	2.40	2.30	14.6	0.019	1.281	80.57	62.59	55.99	38.48	61.52
1074	1st 100	5.76	2.84	2.02	20.0	0.028	1.331					
	2d 100	5.73	2.82	2.03	20.0	.027	1.320					
	3d 100	5.76	2.84	2.02	21.0	.028	1.349					
	4th 100	5.78	2.86	2 02	21.0	.029	1.341					
	5th 100	5.73	2.82	2.03	20.0	.028	1.337					
Av....	500	5.75	2.84	2.02	20.0	0 028	1.336	88.59	68.82	62.31	35.84	64.16
1078	1st 100	6.42	2.77	2.31	22.0	0.029	1.304					
	2d 100	6.41	2.72	2.35	20.5	.028	1.307					
	3d 100	6 42	2.74	2.34	21.5	.029	1 310					
	4th 100	6.37	2.72	2.34	21.0	.028	1.292					
	5th 100	6.44	2.72	2.36	20.5	.028	1 300					
Av.	500	6.41	2 73	2 34	21.1	0.028	1.303	83.35	64.75	57.56	37 52	62.48
1080	st 100	6.10	2.60	2.34	19.0	0.025	1.345					
	2d 100	6.11	2.60	2.35	19.0	.026	1.339					
	3d 100	6.09	2.57	2 36	18.5	.025	1.340					
	4th 100	6.11	2 55	2.39	18.5	.025	1.344					
	5th 100	6.05	2.58	2.34	18.0	.025	1.338					
Av....	500	6.09	2.58	2 36	18.6	0.025	1.341	85.99	66.80	57.78	37.84	62.16

TABLE I—*Continued.*

No.	No. grains.	Av. length (mm.)........	Av. width (mm.)........	Ratio length to width....	Av. volume (cu. mm.)...	Av. weight (g.)........	Av. specific gravity......	Av. volume-weight.			Packing quality.	
								Grams per 100 cc.	Lbs. per (packed) bushel........	Lbs. per (struck) bushel........	Per cent vol. in 100 cc. not occupied by grain...	Per cent vol. of grain in 100 cc..
1081	1st 100	6.01	2.69	2.23	20.5	0.026	1.350					
	2d 100	5.99	2.69	2.22	19.0	.026	1.353					
	3d 100	6 01	2.69	2.23	20.0	.027	1.352					
	4th 100	5.98	2.68	2.23	19.0	.026	1.351					
	5th 100	6.01	2.65	2.26	20.0	.026	1.344					
Av.....	500	6.00	2.68	2.23	19.7	0.026	1.350	86.32	67.06	62.55	37.94	62.06
1082-1	1st 100	5.96	2.43	2.45	16.5	0.022	1.326					
	2d 100	6.01	2.39	2.51	16.5	.021	1.320					
	3d 100	6.00	2.38	2.52	16.0	.021	1.322					
	4th 100	5 99	2.40	2 49	16.0	.021	1.324					
	5th 100	5.96	2.39	2.49	15.5	.021	1.323					
Av.....	500	5.98	2.40	2.49	16.1	0.021	1.323	82.99	64.47	57.76	38.64	61.36
1105	1st 100	6.47	2.87	2.25	24.5	0.034	1.305					
	2d 100	6.53	2.90	2.25	24.5	.034	1.302					
	3d 100	6.47	2.87	2.25	25.0	.033	1.304					
	4th 100	6.48	2.89	2.24	25.5	.034	1.307					
	5th 100	6.50	2.88	2.26	25.0	.034	1.303					
Av.....	500	6.49	2.88	2.25	24.9	0.034	1.304	87.62	68.07	63.21	34.12	65.88
1108	1st 100	6.32	2.50	2.52	18.0	0.024	1.330					
	2d 100	6.32	2.50	2.52	18.5	.024	1.329					
	3d 100	6.29	2.49	2.52	18.0	.024	1.322					
	4th 100	6.30	2.48	2.54	17.0	.024	1.328					
	5th 100	6.34	2.50	2.53	18.0	.025	1.315					
Av.....	500	6.31	2.49	2.52	17.0	0.024	1.325	88.31	63.95	57.73	38.30	61.70
1110	1st 100	5.97	2.79	2.04	20.0	0.026	1.308					
	2d 100	5.96	2.78	2.14	19.0	.026	1.310					
	3d 100	5.95	2.81	2.12	20.2	.028	1.309					
	4th 100	5.98	2.80	2.13	20.0	.028	1.315					
	5th 100	5.94	2.79	2.13	20.0	.026	1.303					
Av.....	500	5.96	2.79	2.13	19.8	0.027	1.309	83.66	64.99	59.30	37.23	62.77
1111	1st 100	5.78	3.06	1.88	23.0	0.032	1.301					
	2d 100	5.81	3.05	1.90	24.0	.032	1.295					
	3d 100	5.80	3.12	1.86	25.0	.034	1.295					
	4th 100	5.81	3.11	1.87	24.5	.033	1.300					
	5th 100	5.84	3.11	1.87	25.0	.033	1.297					
Av.....	500	5.81	3.09	1.88	24.3	0.033	1.298	86.81	67.44	62.47	34.68	65.32
1112	1st 100	6.15	2.85	2.15	23.0	0 032	1.337					
	2d 100	6.13	2.89	2.12	22.5	.032	1.345					
	3d 100	6.10	2.84	2.14	22.5	.030	1.360					
	4th 100	6.18	2.89	2.13	23.0	.032	1.347					
	5th 100	6.13	2.89	2.12	22.5	.032	1 340					
Av.....	500	6.14	2 87	2.13	22.7	0.032	1.346	88.64	68.87	62.84	35.76	64.24
1113	1st 100	6.11	2.89	2.11	21.0	0.029	1.345					
	2d 100	6.15	2.95	2.08	22.5	.030	1.334					
	3d 100	6.12	2.93	2.08	21.5	.030	1.326					
	4th 100	6.19	2.96	2.09	22 5	.031	1.334					
	5th 100	6.17	2.94	2.09	21.5	.030	1.327					
Av.....	500	6.15	2.93	2.09	21.8	0.030	1.333	85.93	66.76	61.22	36.87	63.13

TABLE I—*Continued.*

No.	No. grains.	Av. length (mm.)......	Av. width (mm.)........	Ratio length to width....	Av. volume (cu. mm.)....	Av. weight (g.)..........	Av. specific gravity......	Av. volume-weight. Grams per 100 cc..	Av. volume-weight. Lbs. per (packed) bushel........	Av. volume-weight. Lbs. per (struck) bushel........	Packing quality. Per cent vol. in 100 cc. not occupied by grain...	Packing quality. Per cent vol. of grain in 100 cc..
1114	1st 100	5.68	2.69	2.11	18.5	0.023	1.293					
	2d 100	5.70	2.70	2.11	19.1	.024	1.300					
	3d 100	5.68	2.67	2.12	17.5	.023	1.300					
	4th 100	5.71	2.70	2.11	18.4	.024	1.300					
	5th 100	5.67	2.70	2.10	17.7	.023	1.295					
Av.....	500	5.69	2.69	2.11	18.2	0.023	1.298	84.89	65.95	60.16	36.10	63.90
1115	1st 100	6.16	3.05	2 02	25.5	0.034	1.306					
	2d 100	6.19	3.05	2.03	25.0	.033	1.290					
	3d 100	6.22	3.06	2.03	25.0	.034	1.300					
	4th 100	6.16	3.03	2.03	25.5	.034	1.302					
	5th 100	6.24	3.04	2.05	25.5	.034	1.311					
Av.....	500	6.19	3.05	2.03	25 3	0.034	1.302	84.64	65.75	60.45	35.50	64.50
1116	1st 100	6.26	2.90	2.15	24.0	0.032	1 284					
	2d 100	6.21	2.91	2.13	24.0	.032	1.300					
	3d 100	6.22	2.90	2.14	24.5	.033	1.284					
	4th 100	6.25	2.90	2.15	24.5	.033	1.295					
	5th 100	6.22	2.88	2.16	26 0	.033	1.300					
Av.....	500	6.23	2.90	2.14	24 6	0.033	1.295	85.59	66.49	61.00	35.84	64.16
1119	1st 100	6.09	2.89	2.12	23.0	0.031	1.302					
	2d 100	6.10	2.90	2.10	24.0	.032	1.313					
	3d 100	6.07	2.90	2.09	23.0	.031	1.324					
	4th 100	6.10	2 89	2.11	24.0	.032	1.335					
	5th 100	6.13	2.88	2.12	23.0	.032	1.306					
Av.....	500	6.10	2.89	2.11	23.4	0.032	1.316	89.17	69.27	67.34	35.82	64.18
1121	1st 100	6.07	2.85	2.13	21.5	0.028	1.301					
	2d 100	6.01	2.84	2.11	21.0	.028	1.308					
	3d 100	6.08	2.92	2.08	22.5	.030	1.302					
	4th 100	6.00	2.86	2.10	22.0	.028	1.297					
	5th 100	6.03	2.88	2.09	22.5	.029	1.306					
Av.....	500	6.04	2.87	2.10	21.9	0.029	1.303	82.95	64.45	60.84	35.96	64.04
1125	1st 100	6.24	3.03	2.06	23.5	0.033	1.359					
	2d 100	6.27	2.99	2.10	24.0	.032	1.348					
	3d 100	6.26	3.01	2.08	24.0	.032	1.358					
	4th 100	6.30	3.00	2.10	24.0	.033	1.357					
	5th 100	6.32	3.01	2.10	25.0	.033	1.368					
Av.....	500	6.28	3.01	2.09	24.1	0.033	1.358	86.81	67.44	61.93	35.84	64.16
1145	1st 100	6.41	3.19	2.00	28.0	0.036	1.218					
	2d 100	6.41	3.16	2.02	29.5	.034	1.222					
	3d 100	6.40	3.18	2 01	27.7	.035	1 231					
	4th 100	6.41	3.17	2.02	27.5	.035	1.227					
	5th 100	6.45	3.15	2.04	28.9	.036	1.227					
Av.....	500	6 42	3 17	2.09	28.3	0.035	1.225	81.67	63.45	58.14	35.12	64.88
1149	1st 100	6.02	2.88	2.09	23.0	0.031	1.361					
	2d 100	6.02	2.85	2.11	21.5	.031	1.361					
	3d 100	5.99	2.85	2.10	21.5	.030	1.258					
	4th 100	6.00	2.85	2.10	22.0	.031	1.358					
	5th 100	6.00	2.87	2.09	22.0	.031	1.362					
Av.....	500	6.01	2.86	2.10	22.0	0.031	1.360	89.91	69.85	63.58	35.04	64.96

TABLE I—*Concluded.*

No.	No. grains.	Av. length (mm.)	Av. width (mm.)	Ratio length to width	Av. volume (cu. mm.)....	Av. weight (g.)	Av. specific gravity	Av. volume-weight. Grams per 100 cc..	Lbs. per (packed) bushel	Lbs. per (struck) bushel	Packing quality. Per cent vol. in 100 cc. not occupied by grain....	Per cent vol. of grain in 100 cc..
1150	1st 100	6.23	2.85	2.18	23.5	0.032	1.362					
	2d 100	6.24	2.88	2.16	23.5	.032	1.331					
	3d 100	6.26	2.88	2.17	24.0	.033	1.358					
	4th 100	6.21	2.90	2.14	23.5	.033	1.342					
	5th 100	6.27	2.89	2.16	23.9	.033	1.358					
Av.....	500	6.24	2.88	2.16	23.7	0.033	1.350	87.84	67.64	62.33	35.64	64.36
1151	1st 100	6.04	2.81	2.15	18.5	0.024	1.283					
	2d 100	6.01	2.77	2.17	18.1	.024	1.284					
	3d 100	5.99	2.78	2.15	18.5	.023	1.290					
	4th 100	6.04	2.81	2.15	18.5	.023	1.280					
	5th 100	6.03	2.83	2.14	18.0	.023	1.272					
Av.....	500	6.02	2.80	2.15	18.3	0.023	1.282	77.02	59.84	53.37	40.28	59.72
1152	1st 100	6.10	2.62	2.33	19.0	0.026	1.359					
	2d 100	6.10	2.59	2.35	18.0	.026	1.357					
	3d 100	6.11	2.60	2.35	18.5	.026	1.362					
	4th 100	6.08	2.62	2.32	19.0	.026	1.365					
	5th 100	6.10	2.58	2.36	18.5	.025	1.373					
Av.....	500	6.10	2.60	2.34	18.6	0.026	1.363	88.74	68.94	63.55	35.24	64.76
1068-2	1st 100	6.34	2.89	2.19	21.0	0.029	1.344					
	2d 100	6.29	2.88	2.18	20.9	.028	1.343					
	3d 100	6.34	2.89	2.21	20.7	.028	1.350					
	4th 100	6.30	2.86	2.20	20.1	.029	1.337					
	5th 100	6.33	2.90	2.18	22.0	.030	1.341					
Av.....	500	6.32	2.88	2.19	20.9	0.029	1.343	81.45	63.28	62.15	36.24	63.76

In a similar way, the mean kernel-width for each race was also determined, upon another slightly differently constructed measuring board. (Plate VII.) It was found that the variations in averages among the five different hundreds of each lot were so slight that in general a lesser number than 500 would have sufficed. However, this number was adhered to in the determination of the averages in question for the entire series of fifty-two races.

These length and breadth measurements were then combined in the form of the ratio of length to width for each race, and taken as a form-factor — a large ratio denoting a long grain and a small ratio a short grain, as a matter of course.

Each separate lot, for which mean lengths and widths of the grain had been determined, was also used in the determination of mean kernel volume. This was done by pouring each lot of 100 kernels into a very accurately calibrated burette, previously filled with 95 per cent alcohol up to an observed point. The volume of displacement of the alcohol gave the data for determining the average kernel volume, expressed in cubic milli-. meters, and furnished a means of differentiating, say, two races having the same $\frac{\text{length}}{\text{width}}$ ratios, but in which the kernels were of different average sizes. Here also the mean volumes for each of the 500-kernel lots in the different races are exceedingly uniform. (See table I.)

Other factors in the form of kernel, such as the third dimension, or the distance from the plane of the "crease" or groove, perpendicularly to the point of greatest thickness of the kernel, and the form and dimensions of the crease itself, were not determined, owing to special difficulties in the way of ascertaining them. Nor was any way found for quantitatively measuring, without too laborious detail, the outline of the kernel, which varied from broad-oval, tapering equally toward both ends, to linear-oblong, or an obovate form, tapering toward one end. All of these differences in the shape of the kernel were left to be expressed by mean $\frac{\text{length}}{\text{width}}$ ratios and by mean volumes.

The volume-weight of the kernels of each race was then determined by weighing as much grain as could possibly be packed into a 250 cc. graduate, the packing being effected by vigorous tamping of the graduate a given number of times for each fractional portion of its contents as the same was put in. This volume-weight in grams per 100 cc. will be taken converted into terms of pounds per bushel for the purpose of this paper.

The amount of unoccupied air space left among the kernels of the packed grain was then determined in the case of each of the fifty-two cases in the experiment, by filling the graduate in which the grain had been packed as described, with 95 per cent alcohol. The amount of alcohol thus delivered from the burette, and necessary to exactly cover the grain, reduced to a basis of 100 cc. and subtracted from 100, gave exactly the volume in percentage of 100 cc. of actual solid grain material in each instance.

There were thus at hand data for determining the relation between any specific type of kernel as expressed in terms of the $\frac{\text{length}}{\text{width}}$ ratio and the average kernel-volume on the one hand, and the percentage volume of grain in 100 cc. on the other; and between all of these factors on the one hand and the bushel-weight on the other.

Assembling the data given in table I in such manner as to bring out these relationships, we have:

TABLE II.

Pedigree No.	Average kernel volume (cu. mm).	Average kernel weight (grams).	Volume-weight of grain.			Packing quality.	
			Grams per 100 cc.	Lbs. per bushel (packed).	Lbs. per bushel (struck).	Air space in 100 cc. unoccupied by grain.	Per cent vol. of grain in 100 cc.
1071	14.6	0.019	80.57	62.59	55.99	38.48	61.52
907	**15.0**	**.020**	**84.21**	**65.42**	**57.41**	**36.76**	**63.24**
1069	**15.0**	**.020**	**80.86**	**62.82**	**58.82**	**38.08**	**61.92**
418-8	16.0	.021	84.99	66.03	62.26	34.64	65.36
1082-1	16.1	.021	82.99	64.47	57.76	38.64	61.36
860	16.4	.022	83.89	65.17	59.69	36.51	63.49
935	16.7	.023	88.27	68.58	63.39	35.08	64.92
778	17.0	.023	86.17	66.94	60.77	37.13	62.87
748	17.3	.024	83.77	65.08	58.11	37.60	62.40
1059-1	17.5	.023	81.15	63.04	57.05	39.23	60.77
983	**17.9**	**.024**	**86.17**	**66.94**	**60.69**	**35.52**	**64.48**
1108	**17.9**	**.024**	**82.31**	**63.95**	**57.73**	**38.30**	**61.70**
921	18.0	.024	78.64	61.09	56.48	38.36	61.64
1023	18.0	.025	79.04	61.40	53.37	41.09	58.91
861	18.1	.024	84.16	65.38	59.16	37.17	62.83
1114	18.2	.023	84.89	65.95	60.16	36.10	63.90
1018	18.3	.025	85.41	66.35	60.63	36.64	63.36
1151	18.3	.023	77.02	59.84	53.37	40.28	59.72
800	**18.6**	**.025**	**86.08**	**66.87**	**62.75**	**36.60**	**63.40**
1080	**18.6**	**.025**	**85.99**	**66.80**	**57.78**	**37.84**	**62.16**
1152	18.6	.026	88.74	68.94	63.55	35.24	64.76
1014	19.2	.025	79.27	61.58	55.50	37.88	62.12
1081	19.7	.026	86.32	67.06	62.55	37.94	62.06
1110	19.8	.027	83.66	64.99	59.30	37.23	62.77
819	19.9	.027	83.53	64.84	59.48	36.52	63.48
893	20.0	.027	83.01	64.49	59.33	35.85	64.15
1074	20.0	.028	88.59	68.82	62.31	35.84	64.16
994	20.3	.027	82.18	63.84	58.06	36.66	63.[illegible]4
1016	20.5	.028	80.78	62.76	56.43	37.94	62.06
854	20.9	.028	83.70	65.02	59.21	37.47	62.53
1064	20.9	.030	88.00	68.37	62.05	36.67	63.33
1068-2	20.9	.029	81.45	63.28	62.15	36.24	63.76
951	21.0	.028	87.33	67.84	58.94	37.51	62.49
1078	21.1	.028	85.35	64.75	57.56	37.52	62.48
1008	21.6	.024	86.06	66.86	61.86	36.20	63.80
1113	21.8	.030	85.93	66.76	61.22	36.87	63.13
1121	21.9	.029	82.95	64.45	60.84	35.96	64.04
1149	22.0	.031	89.91	69.85	63.58	35.04	64.96
927	22.4	.030	85.41	66.35	60.31	35.48	64.52
1112	22.7	.032	88.64	68.87	62.84	35.76	64.24
1119	23.4	.032	89.17	69.27	67.34	35.82	64.18
1066	23.6	.033	91.36	70.98	65.25	34.90	65.10
1150	23.7	.033	87.84	67.64	62.33	35.64	64.36
1125	24.1	.033	86.81	67.44	61.93	35.84	64.16
1111	24.3	.033	86.81	67.44	62.47	34.68	65.32
1116	24.6	.033	85.59	66.49	61.00	35.84	64.16
932	**24.9**	**.034**	**88.77**	**68.96**	**64.07**	**34.52**	**65.48**
1105	**24.9**	**.034**	**87.62**	**68.07**	**63.21**	**34.12**	**65.88**
1115	25.3	.034	84.63	65.75	60.45	35.50	64.50
1040	25.8	.034	80.53	65.18	54.78	39.60	60.40
940	26.3	.037	88.88	69.05	63.23	35.17	64.83
1145	28.3	.035	81.67	63.45	58.14	35.12	64.88

In the table (11) we have the races under investigation arranged in the order of increase of their average kernel-volumes. By reference to the data in the succeeding columns of this table, the relation is shown between the average individual kernel-volume on the one hand, and on the other the volume-weight of grain, and what for lack of a better term is designated as "packing quality." The gross bearing of average kernel-volume upon the "packing quality" of the grain, as expressed by the percentage volume of grain capable of being packed into 100 cc., is shown in plate VIII. Taking as abscissæ the average kernel-volumes, and as ordinates the percentage volume of grain in 100 cc., it is clearly shown that, without reference to the $\frac{\text{length}}{\text{width}}$ ratios of the kernels, and without regard to the average kernel-weights, there is a steady and uniform rise in the percentage of solid grain material that will go into a given cubic volume of space, as the average kernel-volumes rise from 14 to 28 cubic millimeters.

The data plotted are shown in two groups, those races (twenty-seven in number) having $\frac{\text{length}}{\text{width}}$ ratios of from 1.88 to 2.14 millimeters being designated by circles, and those races (twenty-five in number) having $\frac{\text{length}}{\text{width}}$ ratios of from 2.15 to 2.84 millimeters being indicated by crosses. By thus differentiating the races having kernels with low ratios (short kernels) from those with high ratios (long kernels), it is readily seen that the combination of short kernels with large volumes is the more frequent one, and that there is a more uniform rise in the packing quality of the grain where the increasing kernel-volumes are accompanied by low $\frac{\text{length}}{\text{width}}$ ratios. It is sufficiently apparent from this plotting alone that the type of kernel to breed for is one having a low $\frac{\text{length}}{\text{width}}$ ratio combined with a maximum average kernel-volume. Considering now the relation between the $\frac{\text{length}}{\text{width}}$ ratio of the kernels and the packing quality of the grain, we have the data of table I plotted in plate IX. No attempt has been made to calculate an equation to express the curve according to which these individual

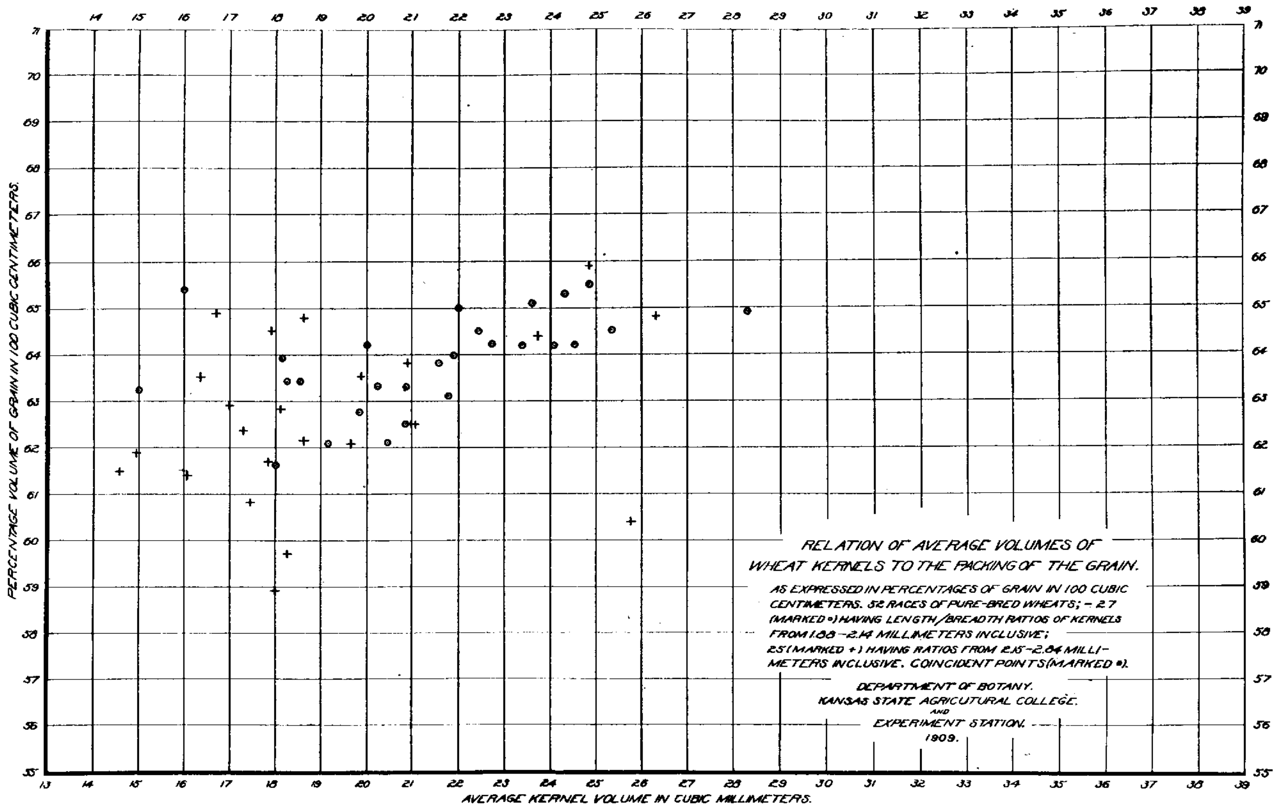

PLATE VIII. Relation of average volumes of wheat kernels to the packing of the grain.

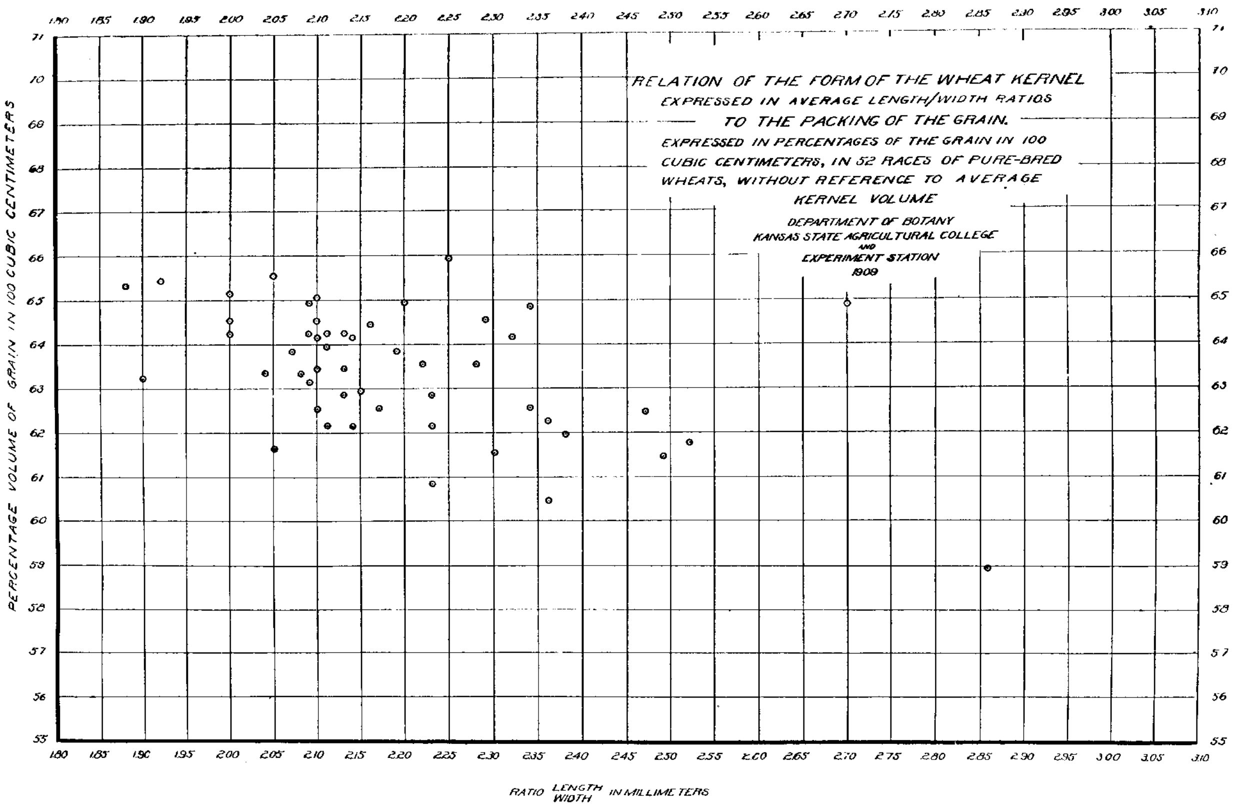

PLATE IX. Relation of the form of the wheat kernel to the packing of the grain.

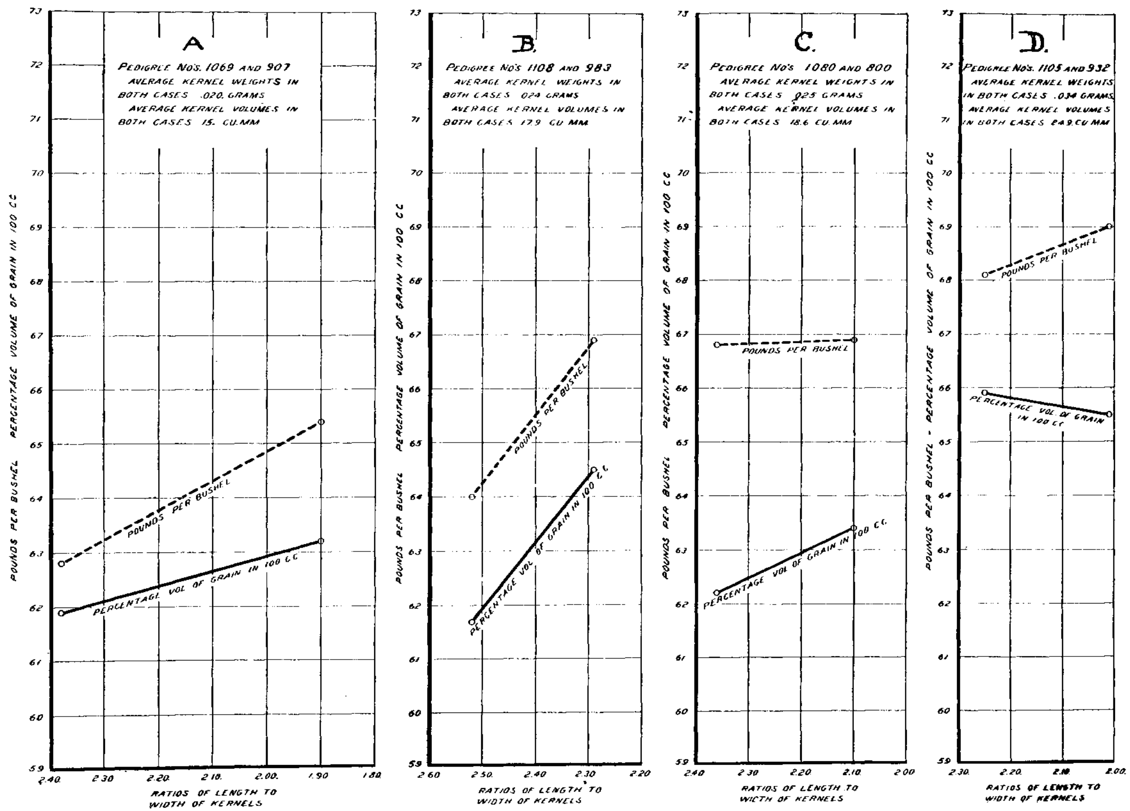

PLATE X. Relation of cubic volume of grain to bushel-weight.

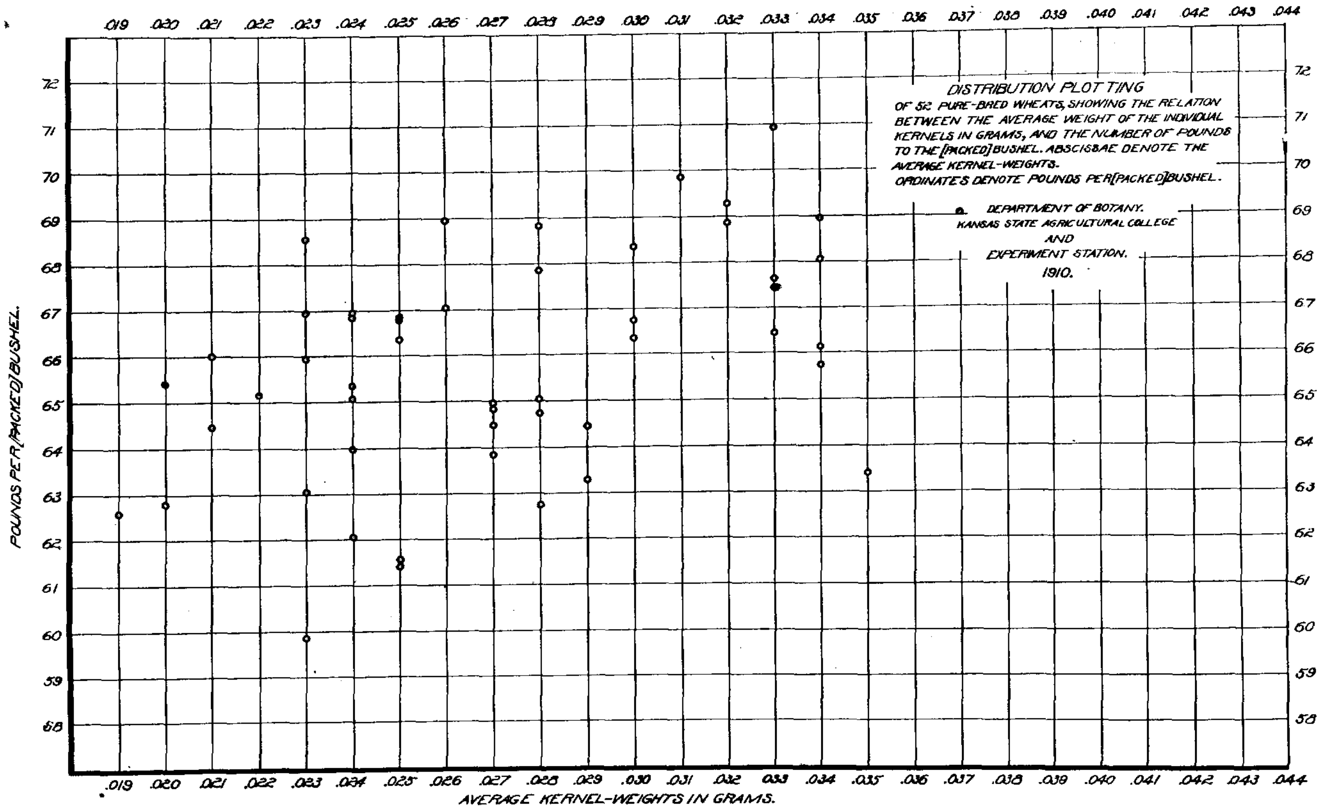

PLATE XI. Relation of kernel-weight to bushel-weight.

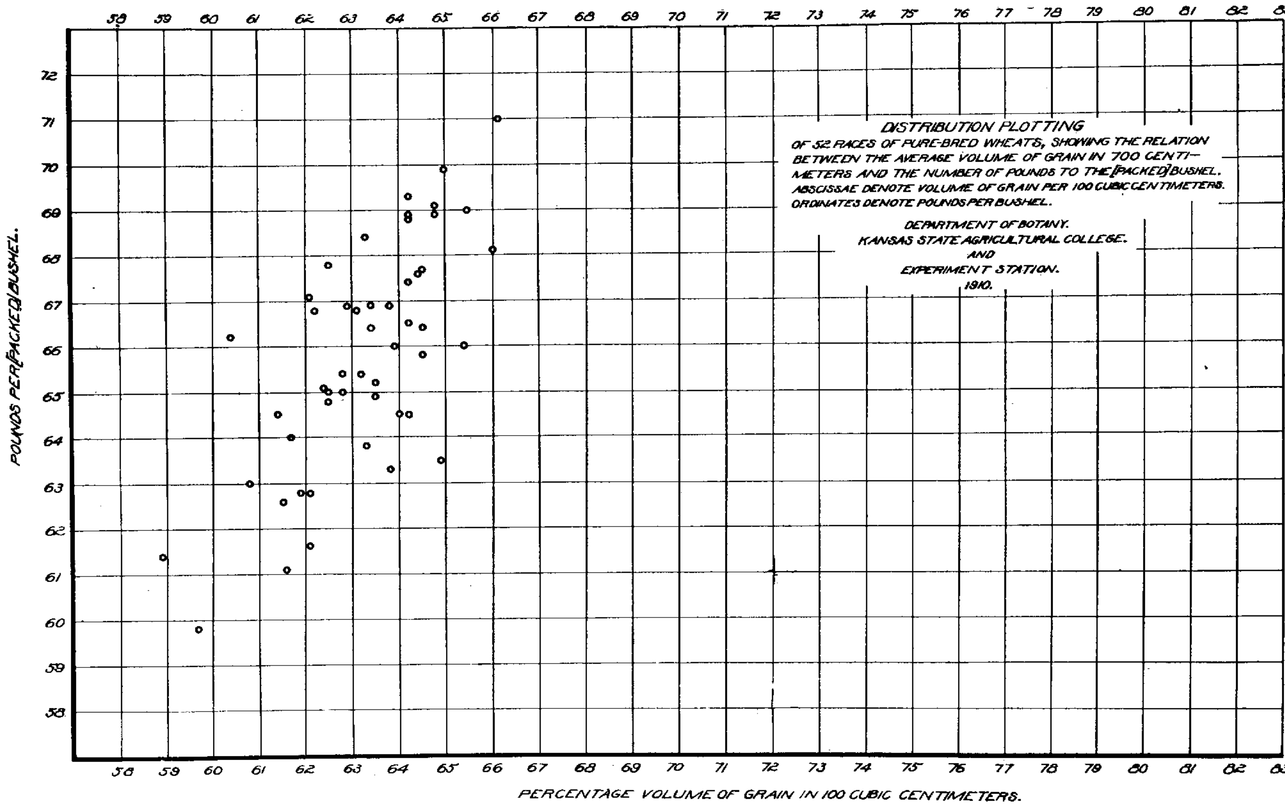

PLATE XII. Relation of percentage volume of grain to bushel-weight.

data fall, but simple inspection shows that such an equation would be for a straight line, and that the curve falls from the low to the high ratios. In other words, the plot clearly shows that with an increased $\frac{\text{length}}{\text{width}}$ ratio—*i. e.,* a larger kernel—the percentage volume of grain in 100 cc. falls off absolutely, and irrespective of the average kernel-volumes, thus corroborating the conclusion derived from the data in plate VIII.

Referring again to table II, it will be noted that four pairs of wheat races occur, indicated in black-face type, in which, for each pair, identical kernel-volumes and identical kernel-weights exist. By having thus eliminated the variables of weight and volume, it is possible to analyze more exactly the relation between $\frac{\text{length}}{\text{width}}$ ratios of the kernels on the one hand, and both volume-weight (pounds per bushel) and percentage volume of grain in 100 cc. (packing quality) on the other. This relation is exhibited by the plotting in plate X.

In plate X we have the four pairs of cases given in table II, where identical kernel-volumes and kernel-weights occur in each pair, respectively. These pairs are arranged in four successive plots on the plate in the order of increasing average volume of the kernels of the pairs. The abscissæ indicate the $\frac{\text{length}}{\text{width}}$ ratios of the kernels in decreasing order for each pair. The ordinate figures express conveniently two relations, viz., pounds per bushel and percentage volume of grain in 100 cc. The effect of high and low $\frac{\text{length}}{\text{width}}$ ratios upon each of these factors is expressed separately by the two groups of each plot. It will be seen that in three out of the four pairs of cases, where identical kernel-volumes and kernel-weights exist for each pair, that increased percentages of grain in 100 cc. follow the progression from high to low ratios. It also appears that increased bushel-weight accompanies without exception that member of each of the four pairs having the lower ratio. The general shifting of the pairs up on the ordinate scale from plot A to plot D may be due in part to progressively increasing average kernel-weights, since the latter run in an increasing series 0.020, 0.025, and 0.034 for the plots from A to D. It is more likely, however, that the predominant influence is that of average kernel-volume. The demonstration of the general importance of this factor in plate VIII leads to the conclusion that in the four pairs exhibited here, where a rise from A to D is indicated with practically no exception, when each member of the pair is followed successively through the four plots for both percentage volume of grain and pounds per bushel, that this is largely to be charged to the rise in kernel-volume from 15 cu. mm. in A to 24.9 cu. mm. in D. This rise in the kernel-volume is moreover much more rapid than the corresponding rise in kernel-weight.

In table III, which follows, the data of averages given in table I are again rearranged, to show the absolute relation between average weight of individual kernels in the different races under experiment and the volume-weight and packing quality of the grain, the arrangement being in the order of increasing average weights of the kernels.

TABLE III.

Pedigree No.	Av. kernel-weight (g.).	Volume-weight of grain. Grams per 100 cc.	Volume-weight of grain. Lbs. per bushel (packed).	Volume-weight of grain. Lbs. per bushel (struck).	Packing quality of the grain. Air space in 100 cc. unoccupied by grain.	Packing quality of the grain. Per cent vol. of grain in 100 cc.
1071	0.019	80.57	62.59	55.99	38.48	61.52
907	.020	84.21	65.42	57.41	36.76	63.24
1069	.020	80.86	62.82	58.82	38.08	61.92
418-8	.021	84.99	66.03	62.26	34.64	65.36
1082-1	.021	82.99	64.47	57.76	38.64	61.3[illegible]
860	.022	83.89	65.17	59.69	36.51	63.49
778	.023	86.17	66.94	60.77	37.13	62.87
935	.023	88.27	68.58	63.39	35.08	64.92
1059-1	.023	81.15	63.04	57.05	39.23	60.77
1114	.023	84.89	65.95	60.16	36.10	63.90
1151	.023	77.02	59.84	53.37	40.28	59.72
748	.024	83.77	65.08	58.11	37.60	62.40
861	.024	84.16	65.38	59.16	37.17	62.83
921	.024	78.64	61.09	56.48	38.36	61.64
983	.024	86.17	66.94	60.69	35.52	64.48
1008	.024	86.06	66.86	61.86	36.20	63.80
1108	.024	82.31	63.95	57.73	38.30	61.70
800	.025	86.08	66.87	62.75	36.60	63.40
1014	.025	79.27	61.58	55.[illegible]0	37.88	62.12
1018	.025	85.41	66.35	60.63	36.6[illegible]	63.36
1023	.025	79.04	61.40	53.37	41.09	58.91
1080	.025	85.99	66.80	57.78	37.84	62.16
1081	.026	86.32	67.06	62.55	37.94	62.06
1152	.026	88.74	68.94	63.55	35.24	64.76
819	.027	83.53	64.89	59.48	36.52	63.48
893	.027	83.01	64.49	59.33	35.85	64.15
994	.027	82.18	63.84	58.06	36.66	63.34
1110	.027	83.66	64.99	59.30	37.23	62.77
854	.028	83.70	65.02	59.21	37.47	62.53
951	.028	87.33	67.84	58.94	37.51	62.49
1016	.028	80.78	62.76	56.43	37.94	62.0[illegible]
1074	.028	88.59	68.82	62.31	35.84	64.16
1078	.028	83.35	64.75	57.56	37.52	62.48
1068-2	.029	81.45	63.28	62.15	36.24	63.76
1121	.029	82.95	64.45	60.84	35.96	64.04
927	.030	85.41	66.35	60.31	35.48	64.52
1064	.030	88.00	68.37	62.05	36.07	63.33
1113	.030	85.93	66.76	61.22	36.87	63.1[illegible]
1149	.031	89.91	69.85	63.58	35.04	64.96
1112	.032	88.64	68.87	62.84	35.76	64.24
1119	.032	89.17	69.27	67.34	35.82	64.18
1066	.033	91.36	70.9[illegible]	65.25	34.90	65.10
1111	.033	86.81	67.44	62.4[illegible]	34.68	65.32
1116	.033	85.59	66.49	61.00	35.84	64.16
1125	.033	86.81	67.44	61.93	35.84	64.16
1150	.033	87.84	67.64	62.33	35.64	64.36
932	.034	88.77	68.96	64.07	34.52	65.48
1105	.034	87.62	68.07	63.21	34.12	65.88
1040	.034	80.53	65.18	54.78	39.60	60.40
1115	.034	84.63	65.75	60.45	35.50	64.50
1145	.035	81.67	63.45	58.14	35.12	64.88
940	.037	88.88	69.05	63.23	35.17	64.83

The degree of influence exercised by the average kernel-weight in the gross upon the bushel-weight, may be inferred to some extent from plate XI, in which the abscissæ denote the average kernel-weight in grams and the ordinates indicate the number of pounds to the (packed) bushel. It should be remembered, however, that the variable of increasing volume is also present, and that the plotting therefore cannot show the absolute relation between kernel-weight alone and volume-weight. It is sufficient to call attention to the fact that the relation here is not as close as between kernel-volume and volume-weight as shown in plate VIII.

The prime importance of a well packing type of grain in wheat, so far as the test bushel-weight is concerned, is shown most strikingly in plate XII, where the percentage volumes of grain in 100 cc. are plotted as abscissæ, and the bushel-weights as ordinates. The sharp and close coincidence of good packing quality with high bushel-weight, irrespective of individual kernel-weights, is here strikingly shown.

Finally, in table IV, the fifty-two races of wheat under investigation stand arranged in the increasing order of their $\frac{\text{length}}{\text{width}}$ ratios, Amongst these, the races having coincident ratios are printed throughout in black-face type.

TABLE IV.

Pedigree No.	Av. ratio length to breadth of kernels.	Av. kernel volume (cu. mm.)	Packing quality of grain.		Volume-weight of grain.		
			Air space in 100 cc. unoccupied by grain.	Per cent vol. of grain in 100 cc.	Grams per 100 cc.	Lbs. per bu. (packed).	Lbs. per bu. (struck).
1111	1.88	24.3	34.68	65.32	86.81	67.44	62.47
907	1.90	15.0	36.76	63.24	84.21	65.42	57.41
418-8	1.92	16.0	34.64	65.36	84.99	66.03	62.26
1074	2.02	20.0	35.84	64.16	88.59	68.82	62.31
1066	2.02	23.6	34.90	65.10	91.36	70.98	65.25
1115	2.03	25.3	35.50	64.50	84.63	65.75	60.45
994	2.04	20.3	36.66	63.34	82.18	63.84	58.06
921	2.05	18.0	38.36	61.64	78.64	61.09	56.48
932	2.05	24.9	34.52	65.48	88.77	68.96	64.07
1008	2.07	21.6	36.20	63.80	86.06	66.86	61.86
1064	2.08	20.9	36.67	63.33	88.00	68.37	62.05
1113	2.09	21.8	36.87	63.13	85.93	66.76	61.22
1125	2.09	24.1	35.84	64.16	86.81	67.44	61.93
1145	2.09	28.3	35.12	64.88	81.67	63.45	58.14
800	2.10	18.6	36.60	63.40	86.08	66.87	62.75
854	2.10	20.9	37.47	62.53	83.70	65.02	59.21
1121	2.10	21.9	35.96	64.04	82.95	64.45	60.84
1149	2.10	22.0	35.04	64.96	89.91	69.85	63.58
927	2.10	22.4	35.48	64.52	85.41	66.35	60.31
1114	2.11	18.2	36.10	63.90	84.89	65.95	60.16
1016	2.11	20.5	37.94	62.06	80.78	62.76	56.43
1119	2.11	23.4	35.82	64.18	89.17	69.27	67.34
1018	2.13	18.3	36.64	63.36	85.41	66.35	60.63
1110	2.13	19.8	37.23	62.77	83.66	64.99	59.30
1112	2.13	22.7	35.76	64.24	88.64	68.87	62.84
1014	2.14	19.2	37.88	62.12	79.27	61.58	55.50
1116	2.14	24.6	35.84	64.16	85.59	66.49	61.00
778	2.15	17.0	37.13	62.87	86.17	66.94	60.77
1151	2.15	18.3	40.28	59.72	77.02	59.84	53.37
1150	2.16	23.7	35 64	64.36	87.84	67.64	62.33
951	2.17	21.0	37 51	62.49	87.33	67.84	58.94
1068-2	2.19	20.9	36.24	63.76	81.45	63.28	62.15
935	2.20	16.7	35.08	64.92	88.27	68.58	63.39
819	2.22	19.9	36.52	63.48	83.53	64.89	59.48
1059-1	2.23	17.5	39.23	60.77	81.15	63.04	57.05
861	2.23	18.1	37.17	62.83	84.16	65.38	59.16
1081	2.23	19.7	37.94	62.06	86.32	67.06	62.55
1105	2.25	24.9	34.12	65.88	87.62	68.07	63.21
860	2.28	16.4	36.51	63.49	83.89	65.17	59.69
983	2.29	17.9	35.52	64.48	86.17	66.94	60.69
1071	2.30	14.6	38.48	61.52	80.57	62.59	55 99
893	2.32	20.9	35.85	64.15	83.01	64.49	59.33
1152	2.34	18.6	35.24	64.76	88.74	68.94	63.55
1078	2.34	21.1	37.52	62.48	85.35	64.75	57.56
1080	2.36	18.6	37.84	62.16	85.99	66.80	57.78
1040	2.36	25.8	39.60	60.40	80.53	65.18	54.78
1069	2.38	15.0	38.08	61.92	80.86	62.82	58.82
748	2.47	17.3	37.60	62.40	83.77	65.08	58.11
1082-1	2.49	16.1	38.64	61.36	82.99	64.47	57.76
1108	2.52	17.9	38.30	61.70	82.31	63.95	57.73
940	2.70	26.3	35.17	64.83	88.88	69.05	63 23
1023	2.84	18.0	41 09	58.91	79 04	61.40	53.37

These eleven groups, having from two to five members each, having identical ratios within the group, are shown in succession on plates XIII, XIV, XV and XVI. In these plates the ratios run from 2.02 to 2.36. For each plate the average kernel-volumes in cubic millimeters are plotted as abscissæ while the ordinates are of three sets. The upper (integral) ordinates have a dual value, indicating throughout all of the plots in the four plates both pounds per bushel and percentage volume of grain in 100 cc. The lower (decimal) ordinates denote average kernel-weights in grams. We are thus enabled to present in each plot of the four plates three separate graphs, which exhibit side by side, under identical conditions as regards $\frac{\text{length}}{\text{width}}$ ratios, the relation which volume-weight, kernel-weight and percentage volume of grain in 100 cc. all bear to one another, where increasing kernel-volumes are denoted by the abscissæ

It will be understood, in explanation of these plates, that each individual case in each plot is treated as though it were a separate moment on an individual variation curve. Take, for example, the case of the lower graph in plate XIV, which gives the plotting of the percentage volume of grain in 100 cc. for five successive races of wheat—Nos. 800, 854, 1121, 1149 and 927—in the order of the increasing values of their kernel-volumes as denoted by the abscissæ Above this graph the same races follow in the same order in the other two graphs, but the ordinates denote average kernel-weight in grams and pounds per bushel in each case, respectively. It is manifestly impossible, without more data, to speak positively regarding the exact mathematical relation that may be found to exist in the case of wheat between the percentage volume of grain in a given cubic space and the volume-weight as expressed in pounds per bushel. It is sufficiently evident that an exceedingly close relation does exist between the two. (See plate XII.) A close inspection of the series of plates further reveals the fact that the rise and fall of the graph for bushel-weight, while generally accompanied by a closely corresponding rise and fall of the percentage volume of grain in 100 cc., is not accompanied by a similar deflection of the graph for individual kernel-weight. In plate XI the doubtful and uncertain bearing of the average individual kernel-weight upon the bushel-weight has been in-

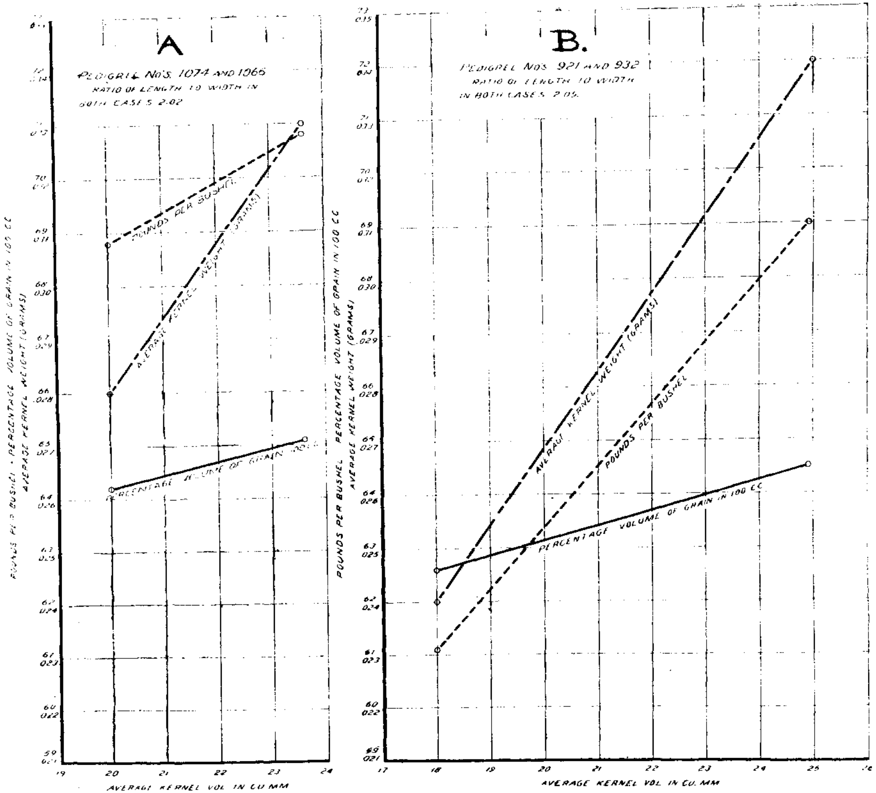
A
B.
POUNDS PER BUSHEL
AVERAGE KERNEL WEIGHT (GRAMS)
PERCENTAGE VOLUME OF GRAIN IN 100 CC
AVERAGE KERNEL VOL. IN CU. MM

PLATE XIII.

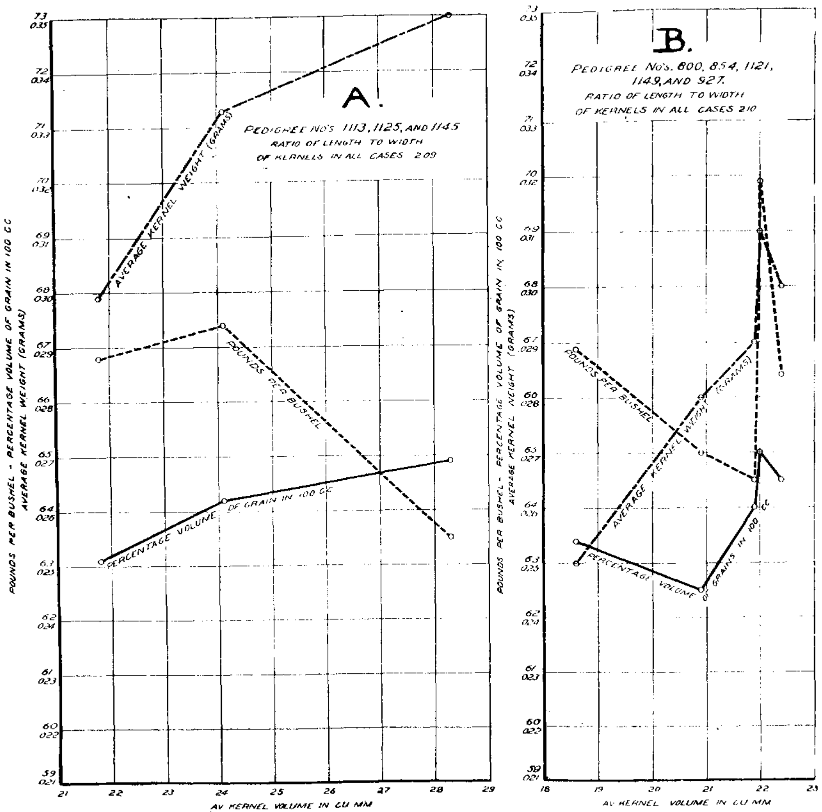
A.
PEDIGREE NO'S 1113, 1125, AND 1145
RATIO OF LENGTH TO WIDTH
OF KERNELS IN ALL CASES 2.09
AVERAGE KERNEL WEIGHT (GRAMS)
POUNDS PER BUSHEL
PERCENTAGE VOLUME OF GRAIN IN 100 CC
POUNDS PER BUSHEL - PERCENTAGE VOLUME OF GRAIN IN 100 CC
AVERAGE KERNEL WEIGHT (GRAMS)
AV KERNEL VOLUME IN CU MM
B.
PEDIGREE NO'S. 800, 854, 1121,
1149, AND 927.
RATIO OF LENGTH TO WIDTH
OF KERNELS IN ALL CASES 2.10
POUNDS PER BUSHEL
AVERAGE KERNEL WEIGHT (GRAMS)
PERCENTAGE VOLUME OF GRAINS IN 100 CC
AV KERNEL VOLUME IN CU MM

PLATE XIV.

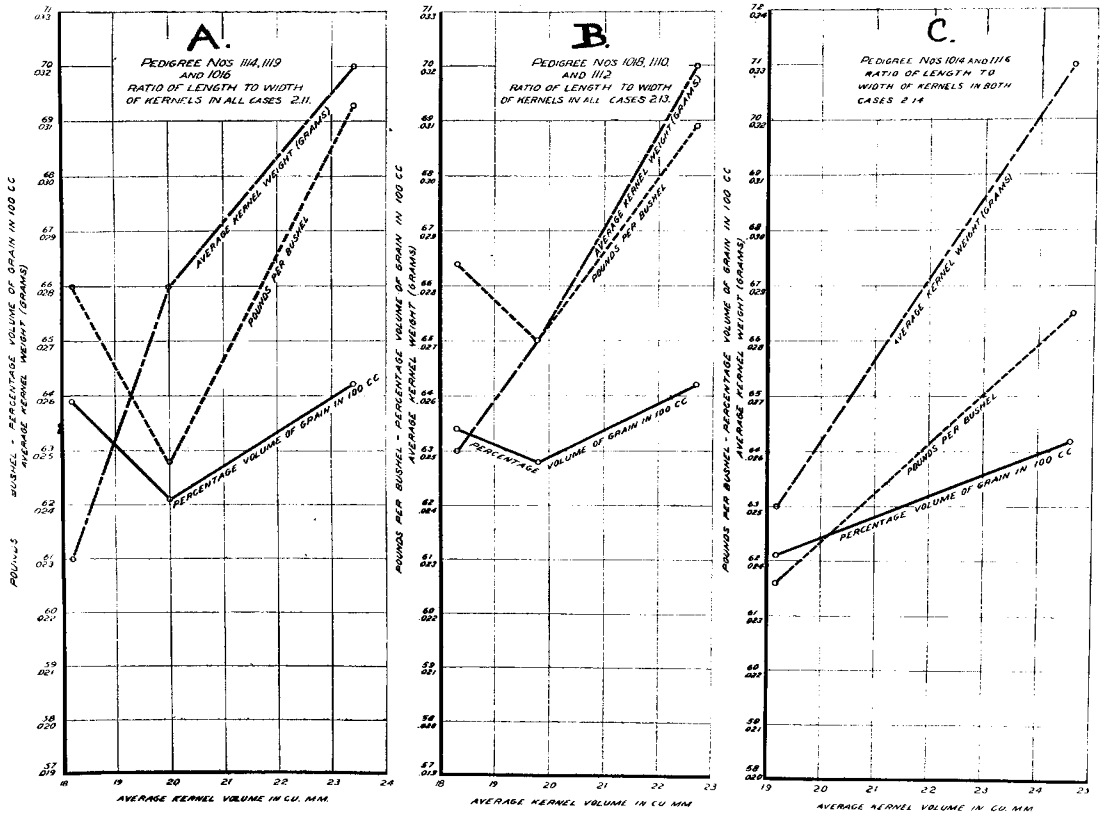
A.
PEDIGREE NOS 1114, 1119 AND 1016
RATIO OF LENGTH TO WIDTH OF KERNELS IN ALL CASES 2.11.
AVERAGE KERNEL WEIGHT (GRAMS)
POUNDS PER BUSHEL
PERCENTAGE VOLUME OF GRAIN IN 100 CC
POUNDS PER BUSHEL - PERCENTAGE VOLUME OF GRAIN IN 100 CC
AVERAGE KERNEL WEIGHT (GRAMS)
AVERAGE KERNEL VOLUME IN CU. MM.
B.
PEDIGREE NOS 1018, 1110, AND 1112
RATIO OF LENGTH TO WIDTH OF KERNELS IN ALL CASES 2.13.
AVERAGE KERNEL WEIGHT (GRAMS)
POUNDS PER BUSHEL
PERCENTAGE VOLUME OF GRAIN IN 100 CC
AVERAGE KERNEL VOLUME IN CU MM
C.
PEDIGREE NOS 1014 AND 1116
RATIO OF LENGTH TO WIDTH OF KERNELS IN BOTH CASES 2.14
AVERAGE KERNEL WEIGHT (GRAMS)
POUNDS PER BUSHEL
PERCENTAGE VOLUME OF GRAIN IN 100 CC
AVERAGE KERNEL VOLUME IN CU. MM

PLATE XV.

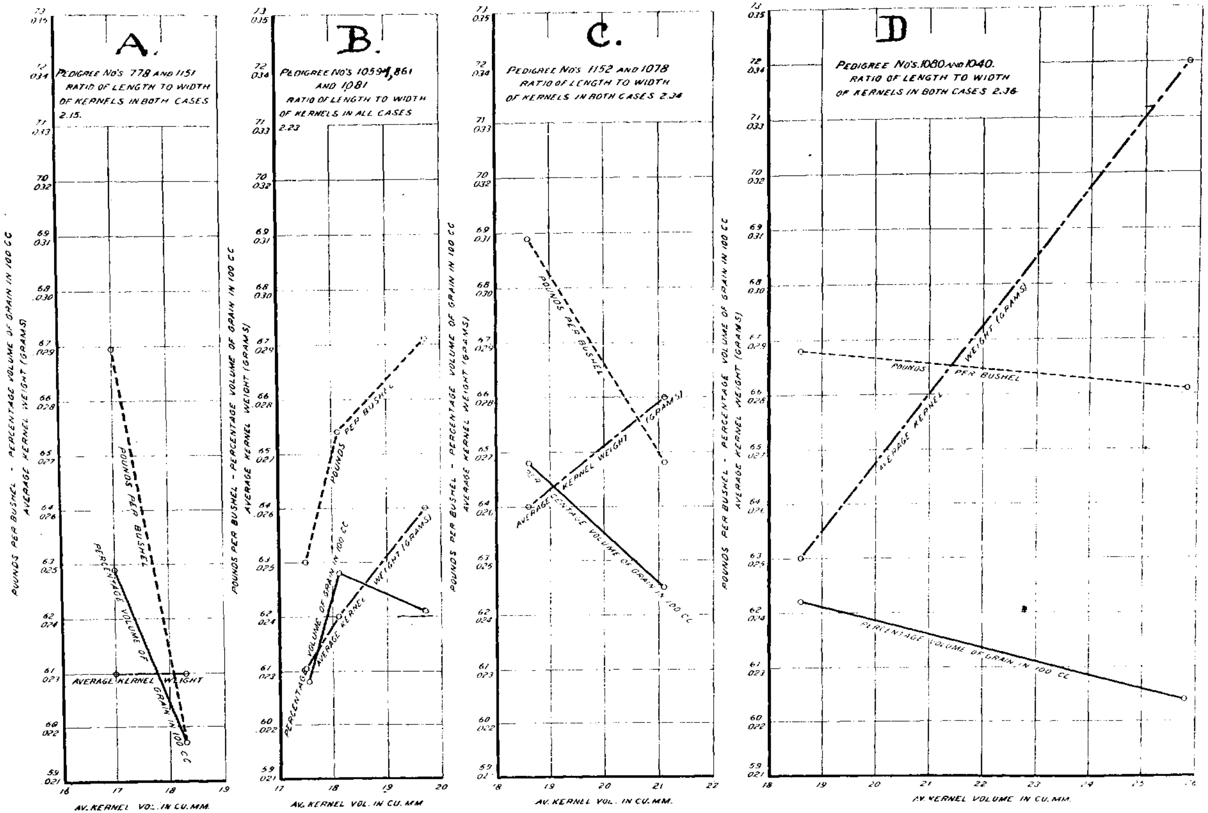
A.
PEDIGREE NO'S 778 AND 1151
RATIO OF LENGTH TO WIDTH OF KERNELS IN BOTH CASES 2.15.
POUNDS PER BUSHEL
PERCENTAGE VOLUME OF GRAIN IN 100 CC
AVERAGE KERNEL WEIGHT
AV. KERNEL VOL. IN CU. MM.
B.
PEDIGREE NO'S 1059, 861 AND 1081
RATIO OF LENGTH TO WIDTH OF KERNELS IN ALL CASES 2.23
POUNDS PER BUSHEL
PERCENTAGE VOLUME OF GRAIN IN 100 CC
AVERAGE KERNEL WEIGHT (GRAMS)
AV. KERNEL VOL. IN CU. MM
C.
PEDIGREE NO'S 1152 AND 1078
RATIO OF LENGTH TO WIDTH OF KERNELS IN BOTH CASES 2.34
POUNDS PER BUSHEL
AVERAGE KERNEL WEIGHT (GRAMS)
PERCENTAGE VOLUME OF GRAIN IN 100 CC
AV. KERNEL VOL. IN CU. MM.
D
PEDIGREE NO'S. 1080 AND 1040.
RATIO OF LENGTH TO WIDTH OF KERNELS IN BOTH CASES 2.36
AVERAGE KERNEL WEIGHT (GRAMS)
POUNDS PER BUSHEL
PERCENTAGE VOLUME OF GRAIN IN 100 CC
AV. KERNEL VOLUME IN CU. MM.
POUNDS PER BUSHEL - PERCENTAGE VOLUME OF GRAIN IN 100 CC
AVERAGE KERNEL WEIGHT (GRAMS)

PLATE XVI.

dicated. There seems, moreover, to be a rather general tendency for the percentage volume of the grain in 100 cc. and the bushel-weight to rise together with increasing volumes of the individual kernels in the plots for the low ratios (2.02 to 2.14), and to fall in the plots for the high ratios (2.15 to 2.36). This also is irrespective of the average kernel-weight, which latter practically uniformly rises with the increase in kernel-volume in the case of all the ratios, There are, of course, cases which conflict. So far as a general conclusion can be inferred from the data thus far, it is as follows:

Bushel-weight is closely correspondent to the percentage volume of grain contained in a cubic volume of space, with an exact mathematical relation to be established from further data. This relation is practically unaffected by the factor of average kernel-weight. There is a general tendency for both of the above factors to rise in value with increasing average volume of individual kernels, *where the* $\frac{\text{length}}{\text{width}}$ *ratios of kernels is low,* and to fall correspondingly where the same is high.

An investigation of some 250 additional pure races of wheat with respect to all of these relations is now nearly completed, and the data derived therefrom will be included in a future bulletin.

The final conclusions from all of the experimental work on the form-factors of the wheat kernel are:

1. A difference of at least as high as three pounds per bushel may exist between different pure-bred wheats *having identical average kernel-volume and kernel-weight,* and which is due entirely to the superior packing quality of one *type* of kernel over another. (See table II, cases of pairs 906-1069, 983-1108, and plate X, A and B.) In each of these cases the higher member of the pair *is the one having the lower* $\frac{\text{length}}{\text{width}}$ ratio. This indicates that, *all other conditions being equal,* a difference of at least three pounds to the bushel in the test weight can be gained by breeding for short-kernelled races of wheat. When other factors than ratio are considered, it has been found that as much as seven pounds per bushel may be gained by breeding for specific types of kernel.

This difference would unquestionably effect a difference in the grading in many instances. It is of course well known that the sort of manipulation given the grain tester may make a difference of as much as five pounds in the test reading. Even in cases where such manipulation is possible and is practiced to the disadvantage of the wheat grower, nevertheless he cannot but profit through having a variety of wheat which, by reason of the type of the kernel, will gain at least three pounds in the tester over other varieties and types of wheat, under any sort of manipulation whatever. Assuming perfect fairness in the handling of the tester, there is yet every reason for the grower to produce a wheat that will inevitably test high.

2. Where the $\frac{\text{length}}{\text{width}}$ ratios of the kernels remain the same, the higher bushel-weights generally follow the higher kernel-volumes, except in the higher ratios, where the reverse is the case. This indicates that the short type of kernel with high volume is the type to breed for to secure high grading, other things being equal.

3. In general, wheats having low $\frac{\text{length}}{\text{width}}$ ratios are the best packers, and give the highest test bushel-weights.

4. In general, wheats having high average kernel-volumes yield the highest bushel-weights; especially, as before stated, when combined with low ratios.

5. There is a very close dependence of the bushel-weight on the percentage volume of grain in the measure, irrespective of the average kernel-weights.

6. The writer's conclusion from the investigation herein presented, therefore, is that in a just and scientific system of market grading of wheat the percentage volume of grain in a packed measure would be superior, as a basis for establishing a grade, to the present system of grading by test bushel-weight.

In such a system, the grain should be run in a continuous and mechanically distributed stream into a standardized. liter measure, which, mounted on a mechanical shaker, would shake or tamp the grain down as it entered. Into this packed measure of grain, ordinary denatured alcohol should be run from a container above, until the surface of the alcohol reaches the level of the surface of the packed grain. Then the amount of alcohol required to cover the grain would be the equivalent of the cubic volume of air space displaced in the measure, and which the wheat itself did not fill. The difference between this amount of alcohol, in cubic centimeters, and 1000 cc.—the volume of the standard measure—would give the actual volume of wheat that had been packed into the measure. Upon the amount of solid grain as determined in this way, and expressed in percentages of 1000 cc., the grading of the grain would rest.

The grain should clearly be cleaned before being graded. This, however, even now, under the present test bushel-weight system, is practiced by the Minnesota State Grain Inspection Department for all grain officially graded there.

Other qualitative factors, such as color, bleached condition, etc., could be passed upon of course as usual, and would be included in the determination of the grade as at present.

The establishment of grades upon the actual percentage-volume of packed wheat in the standard measure would, as the writer's investigations show, inure to the mutual advantage of the wheat grower and of the miller. The wheat raiser would gain by eliminating the fluctuations in the bushel-weight as ascertained by the tester, due not merely to intentional manipulation but to a number of accidental causes.

When we consider that a packed bushel of wheat contains a million or more grains, the importance of such a neglected feature as the crease comes in for consideration. The writer finds that the width and depth of the crease in wheat, as well as its general contour, are characteristic and specific for different pure-bred races of wheat. Plainly, wheat that has a wide, deep crease in the kernel as a race characteristic, will give a lower percentage of solid grain in a measure than a race with a crease almost obliterated, such as some of our pure-bred races possess. Under the proposed system of grading, a grower of wheat with a shallow crease would receive in exact accordance with the superiority of his wheat in this respect. Wheat with a wide deep crease would fall off proportionately in the grading, as also would shrivelled wheat. Indeed, this method would give an exact quantitative measure of value for shrivelled wheat, forcing it automatically, by its lower percentage volume, into one of the lower grades.

So far as the miller is concerned, the proposed method of percentage-volume grading would be to his advantage. For milling purposes, a rather short plump kernel is preferred to a long slender one, on account of the greater amount of flour in proportion to the bran which such a type affords. Now since, as has been shown, the short-kernelled races—*i. e.*, those with low $\frac{\text{length}}{\text{width}}$ ratios—give the highest percentage volume, especially when taken combined with the feature of large average kernel-volume, it is clear that such types of wheat would inevitably grade highest according to this method. This would naturally lead to the growing of wheats with such a kernel to the exclusion of others, which certainly would be to the satisfaction of the mills, while being more profitable to the growers. So far as the matter of crease is concerned, it has already been stated that a type of wheat having a deep crease is undesirable to the millers, on account of the quantity of "crease dirt" that such a type of berry carries, as well as because of the fact that a berry with a deep crease gives more bran in proportion to the flour than does one with a shallow crease. For both of these reasons it is desirable to improve the wheat kernel by eliminating the crease so far as possible. Now, in the proposed method of grading on the basis of percentage volume of grain, a type of wheat with a deep or broad crease would grade lower than a type having a very shallow crease, because of the greater amount of waste air space in the measure. Consequently, such a method of grading as is herein proposed would put a premium on securing and growing types of wheat having a berry with a minimum amount of crease. In the writer's experience with pure-bred wheats at this Experiment Station, it has been found that different races are as distinctively marked in respect to the type of the crease as in respect to other characters of the grain or of the plant. It is therefore perfectly possible to separate out and grow for profit those races of hard winter wheats that have a very shallow crease, and to maintain them.

In the practical application of the principle of grading herein discussed, the element of cost is important. The cost of denatured alcohol at wholesale figures is forty-four cents per gallon in barrel lots f. o. b. place of manufacture; To ascertain. how much alcohol is used in this grading method, *i. e.*, how much is lost by absorption and adhesion to grain, a test was made as follows: An accurate 1000 cc. graduate was packed with grain, tamping in the usual manner. Alcohol was then poured in until it barely covered the top of the grain, the amount of the alcohol thus used being carefully measured. This amount, of course, indicated the volume of air expelled from around the kernels—the difference from 1000 cc. being the percentage volume of grain contained in one liter. The alcohol was then carefully drained off, and the amount recoverable in this way was also measured. In this manner the amount of alcohol lost in the operation was determined. The following table gives the results obtained with ten different varieties of wheat from the one-liter sample used of each:

TABLE V.

No.	Wt. (g.) of packed grain in 1000 cc.	Vol. (cc.) of air displaced by alcohol.	Percentage vol. of grain in one liter.	Vol. (cc.) of alcohol recovered.	Vol. (cc.) of alcohol lost.
1790	848.6	368.0	632.0	274	94 0
1802	848.6	365.4	634.6	281	84 4
1894	820.8	381.9	618.1	281	100.9
1817	858.9	360.6	639.4	272	88.6
1685	868.4	359.1	640.9	277	82 1
1645	883 0	358.7	641.3	277	81.7
1679	871.6	363.3	633.7	274	89.3
1687	896.3	361.0	639.0	292	69.0
1544	865.6	366 9	633 1	2-5	81.9
5192	841.6	374.8	625 2	277	97.8
Averages	860.3	366.0	634.0	279	87.0

From the ten cases above, it appears that on the average about 87 cc., or 0.087 liter, of alcohol was lost in each operation. A liter being 0.88 of a quart, the value of the alcohol lost, estimating the denatured alcohol at forty-four cents per gallon ($0.0968 per liter), the average cost of the alcohol lost in each operation would amount to $0,008, or 8 mills. This would be the cost where 95 per cent alcohol was used. A lower grade of alcohol can probably be used with equally satisfactory results. Experiments thus far made indicate that probably 70 per cent and possibly 50 per cent alcohol can be used.

In the practical use of commercial alcohol for determining the percentage volume of wheat in the proposed system of grading, a considerable portion of the alcohol lost in the grain could be recovered by distillation, provided it was found upon experiment to be profitable, as it probably would be in an important grain center, where a large aggregate volume of grading is done daily.