REPORT

of

COMMITTEE ON EXAMINATION

This is to certify that we the undersigned, as a Committee of the Graduate School, have given Ralph John Gerber final oral examination for the degree of Master of Science. We recommend that the degree of Master of Science be conferred upon the candidate.

Minneapolis, Minnesota

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Andrew Boss
Chairman

F. J. Alway

E. M. Freeman

REPORT

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Ralph John Garber for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

Andrew Boss
Chairman

E. J. Clucey

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A STUDY OF THE RELATION BETWEEN ENDOSPERM OF THE SEED AND RESULTANT CHARACTERS AS FOUND IN A VARIETY OF WHEAT

(Triticum sativum vulgare)

A THESIS

Presented to the Faculty of the Graduate School
of the University of Minnesota in partial
fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE.

By

RALPH JOHN GARBER

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INTRODUCTION.

While numerous investigations have been made during the last decade anent the correlation of characters of our various farm crops, comparatively few of them have dealt statistically with the possible relation that may exist between the weight of seed planted and the resultant plant characters, particularly those characters which have a direct bearing on the yield of grain. To the writer this seems of the greatest importance. It is true, frequent studies of this relation have been made, but, from a scientific viewpoint, the methods which were employed may rightfully be questioned. The present paper treats of an investigation concerning the possible influence, size of endosperm, may have on the succeeding generation, in the study of which the biometrical method was used thruout.

Seed selection is obviously an important factor in a research of this nature. Hand and machine selections are both inaccurate. When the former is used, one's criterion of size is likely to change from time to time and hence the resulting classes based on this criterion are more or less fluctuating. Machine selection does not carefully discriminate between large seed of a light specific gravity and small seed of a heavy specific gravity. All things considered, then, it would seem that by using only carefully weighed individual kernels as seed, the most reliable results may be obtained. Then too, methods other than the statistical which have been employed during the past in studying this problem, have not included an account of the exact number of seeds distributed per unit of area. Plants in a crowded condition are handicapped when compared with those growing in a less crowded condition. A method which insures a uniform distribution of plants over a given area obviates this difficulty. In view of the foregoing considerations and in the light of present day experimentation, the biometrical method seemed to promise most in the way of accurate information; consequently it was adopted in studying the problem at hand, namely, the relation between size of seed and yield, or, stated more specifically, to determine the possible influence the amount of endosperm may have on the plant characters of the next generation.

The variety studied, Marquis wheat, was chosen largely because of its growing importance in the spring wheat section. Then too, its habits of growth and characters are such as lend themselves readily to the determination of biometrical constants. Furthermore, previous investigations have shown that these constants do not differ radically in the different varieties. Hence, what is found to be true for Marquis is at least indicative of a tendency in the other spring wheat varieties.

RELATED INVESTIGATIONS.

Previous investigators have secured more or less conflicting evidence regarding the influence of such selection. Some have found positive correlations between certain characters where others have found just as decided negative correlations with similar characters. However, when one considers the fact that correlation coefficients themselves usually vary considerably, even in the same character of one variety under observation, and the fact that many things may influence correlation, such as, soil, disease, variety, climatic condition, etc., the apparently contradictory evidence becomes less surprising.

Love and Leighty (6)* working with oats found high positive correlations between the average height of the plant as subjective and each of the following characters as relative, total and average yield, total and average number of kernels produced and average number of spikelets per culm. A high positive correlation was also found between total yield and number of culms; also between total yield and number of kernels. The average kernel weight was not correlated closely with any other character considered except with the average culm yield. When development was arrested, the yield was reduced by a reduction of the number of kernels per plant, per culm, and per spike rather than in average weight of kernels and number of spikelets. They also found the biometrical constants --

* Number refers to bibliography.

correlation coefficients, means, standard deviations, and coefficients of variability -- to be more or less responsive to environmental condition such as exist in different years.

E. G. Montgomery (8) formerly of the Nebraska Station, isolated in the neighborhood of a thousand pure strains of Turkey Red wheat. In his investigation with these he found broad differences between strains in the shape and size of berry, in resistance to lodging, in ability to yield, and in quality of kernel. He concludes, "It is not possible to tell by the appearance of the grains or appearance of the heads which are likely to be good yielders and which poor. In fact some of the good yielders have a small berry while other good yielders have a large berry and the same may be said of the poor yielding strains."

In comparing biometrical constants of oats, Leighty (5) discovered that practically the same means and coefficients of correlation were obtained whether the plants or the culms were considered as the unit. This discovery was likewise made by Whitcomb (14) in his study of statistical methods with barley. The coefficients of variability and standard deviations both indicated consistently a greater amount of variability where the culms were used as the unit. Differences in correlation coefficients may result from the use of different varieties. A comparison of oats grown in hills and drills showed no radical difference of correlations for the two methods of planting. However, some rather large differences did occur in some instances. The effect of different degrees of crowding in the row produced striking differences in the correlation between certain characters of plants in the same pure line of oats. Lowest correlations were found when least crowded and usually the highest when most crowded; however, exceptions occurred. From the above facts the investigator concludes that differences in correlation due to different conditions of growth may amount to more than any differences due to varieties.

Hutcheson (4) employing the biometrical method in a study of oats found that heavier seed produced taller, stronger and broader leafed plants, and that this type of plants produced the largest yields of grain and straw. No correlation existed between the average weight of seed planted and the average weight of kernels harvested. This indicated that within a variety the amount of food stored in the endosperm is of more importance than inheritance.

Zavitz (17) in an experiment with hand selected, large, medium, and small seeds of each of the cereals -- oats, barley, spring wheat and winter wheat, found a direct relation between size of seed and yield; also that the largest seeds produced the heaviest kernels.

Improved American oats separated by the farming mill gave, according to Williams and Welton (16), an increase in yield both in the uniform and varied rates of seeding of 2.75 and 4.06 bushels, respectively, in favor of the large over the small seed. Between unscreened and large seed little difference appeared. This experiment was carried thruout a period of nine years and the results are the average for that time. The same investigators (15) separated with a machine Velvet Chaff winter wheat into three grades, first, second, and third, according to weight. Varied and uniform seeding was made from each grade and the resultant yields showed no appreciable differences.

In Nebraska Station Bulletin 104, Montgomery (7) describes an experiment with Turkey Red and Big Frame wheats which was conducted for eight successive years. He discovered practically no differences in yield as to quantity or quality, as the result of fanning mill separation. He used three grades of seed, lightest light, heaviest heavy, and ordinary seed as it comes from the thresher. In a similar experiment with Kherson oats carried on for a period of three years, practically the same results were obtained.

At the Kansas Station (3) in an experiment with oats separated with the fanning mill into three grades, light, heavy, and common; slight differences were found between the common and heavy grades but they each yielded about two bushels more per acre than the light grade. The common grade was made up of oats as they come from the thresher.

L. R. Waldron (12) in a statistical study of oats growing under field conditions obtained a distinct negative correlation between average weight of grain subjective and each of the following characters relative, number of kernels per head, length of head and total length of culms including length of heads. In other words plants with shorter culms, shorter heads and with a smaller number of grains, produced on the whole, grains of a greater average weight. He also found number of grains to be the most variable of the characters studied.

Atkinson (2) working with eight spring wheat varieties, Pringles Champion, Stanley, Marquis, Kubanka, Kufan, Red Fife, Minnesota 169, and Bart Tremenia, secured a high positive correlation between average weight of kernels and yield; a medium positive correlation between average weight of kernels and number of kernels, average weight of kernels and length of culm, total weight of kernels and length of culms; and a high negative correlation between total weight of kernels and number of rudimentary spikelets.

Meyers (9) conducted an investigation with a variety of wheat to determine the influence of soil fertility on correlations and variability. His conclusions were that increased fertility decreased variability and also amount of correlations.

Roberts' (10) biometrical studies with three pure strains of wheat revealed high positive correlations between yield and number of culms, and also culm length and number of grains. Little variation occurred in the latter over the two year period. A less high correlation was found between culm length and head length, also between number of culms per plant and both culm length and number of grains.

HISTORY OF THE EXPERIMENT.

The aim of this investigation was primarily to study the influence of the amount of endosperm in the wheat kernel on the resultant plant rather than to study this relation as it is manifested in the particular variety considered. From this view-point it becomes obvious that the various classes of seed according to the individual weight of the kernels planted should contain approximately equal numbers. In throwing correlation tables, for example, it would hardly be fair to compare a frequency class of 4 coming from the 12 milligram seeds with a frequency class of 25 grown from the 45 milligram seeds. Therefore, about equal numbers were selected to represent each class as to weight of seed planted. The writer is aware of his liability to be criticised for basing conclusions wholly on a study of the size of endosperm without considering fluctuations in the size of germ. However, the absolute variations in size of the latter are small compared with those of the endosperm; hence, the probability of error from this source is not great.

The growing season of 1916 was somewhat abnormal as a study of the following tables taken from the United States weather bureau report reveal. The rainfall during April and May was above the normal, while during June and July it was below. Temperature likewise showed some deviation. April, May and June were several degrees cooler than the average while July was about as many degrees warmer, a rather broad difference thus existing between them.

A table showing the precipitation in the vicinity of St. Paul, during the growing season of 1916, and the normal.

	1916 Inches	Normal* Inches	Deviation Inches	Percent Dev. from Normal
April	3.03	2.5	+ .53	21.2
May	5.89	3.3	+2.59	78.48
June	3.79	4.4	- .61	13.86
July	.75	3.6	-2.85	79.16
August	3.365	3.45	- .085	2.46

A table showing the mean temperature of the growing season of 1916 compared with the normal, 1873 to 1903.

	1916 Deg.F.	Normal* Deg.F.	Deviation Deg. F.	Percent Dev. from Normal
April	43.8	48.	-4.2	8.75
May	56.6	60.	-3.4	5.66
June	62.7	66.	-3.3	5.00
July	78.2	74.	+4.2	5.67
August	60.32	62.	-1.68	2.70

* The normal represents an average of 31 years, 1873 to 1903.

The soil on which the wheat plants were grown is mapped as Hempstead silt loam by the United States Soil Survey. This type of soil is described as follows, "The surface soil of Hempstead silt loam consists of about 10 to 18 inches of black to dark-brown silt loam, underlain by a subsoil consisting of brown to yellowish-brown silty clay, to silty clay loam, which extends to a depth of about 3 feet. . . . . Movement of ground water is reasonably free, but nevertheless the moisture-conserving qualities appear to be excellent. The substratum consist of a bed of rather clean gravel and sand. . . . The proportion of limestone origin is small." The particular plot used was of ordinary fertility and in first rate condition for grain production.

Marquis wheat was originated at the Central Experimental Farm, Ottawa, Canada, by Dr. A. P. Saunders. It is one of the types he produced by crossing Red Fife (male) with Hard Red Calcutta (female). In 1903 several of the resultant types were selected on a high gluten basis and one of these was afterward named Marquis. It was first grown separately in 1904. The seed which was used in this experiment was taken from the pure Marquis variety which has been grown for a period of four years on University Farm.

During February and March of 1916, 550 kernels were individually weighed in grams to the fourth decimal place. The seeds which ranged in weight from 12 to 43 milligrams, inclusive, were placed in separate envelopes previously numbered from 1 to 550 and the weights recorded both on the envelope and in a note book. For a supplementary experiment on the same plot, 198 seeds ranging from 33 to 45 milligrams, inclusive, were also carefully weighed after which varying amounts of endosperm were removed from the different berries by means of a sharp knife. Immediately after a kernel was mutilated, it was reweighed and the cut surface coated with grafting wax to prevent, as far as possible, physiological disturbances. These seeds were likewise placed in envelopes and the weights recorded as above.

The following spring the seeds were planted in their consecutive order according to number, 4 inches apart in rows which were separated by 4 inches. A small stake bearing the correct number was inserted at the same relative position beside each seed. In order to secure uniform growing conditions, if a kernel failed to grow or a young plant died, the space thus left vacant was filled by a transplanted wheat plant of the same variety. Of the 550 normal seeds planted, 479 developed into plants suitable for study. The entire plot was surrounded by two border rows of plants of the same variety.

About a week before harvesting, the culms of each individual were collectively tagged with their correct number, the number on the stake. To insure against possible loss of kernels in harvesting, the plants were pulled, individually wrapped in newspapers, and tied into bundles of fifty. In this condition they were allowed to hang in the laboratory until dry, after which the several determinations were made.

Data was collected on length of tallest culm, total length of culm, total weight of plant, total length of spikes, number of culms, number of kernels and total weight or yield of grain. The weighings, both for the grain and the entire plant, were made in grams; the former to two decimal places, the latter to one. Before the measurements were taken, all of which were made in centimeters, the culms were severed by means of shears immediately above the roots. Threshing was carefully done by hand. The calculations necessary in throwing the tables were done on a "millionaire" machine and every operation checked so that the writer feels reasonably certain that the results herewith presented are correct.

EXAMINATION OF THE PURITY OF THE LINE OF MARQUIS WHEAT USED.

While the writer was working on the correlation tables under consideration, it was suggested that the positive relations he was finding might be due to inherent qualities of the germ rather than the endosperm. A table was thrown using weight of seed planted subjective and average weight of kernels produced relative. No correlation was found. In other words, the size of seed planted did not determine the size of kernel produced. In some unpublished data of a similar experiment with seed from the same original stock carried on in 1914 and 1915, Arny finds the same lack of correlation between weight of seed planted and average weight of kernels produced. To demonstrate further that the Marquis worked with was a pure line, about eight plants which produced only plump kernels were selected from each class or weight of seed planted and a correlation table thrown. As before no correlation was found between the weight of seed planted and the average weight of kernels produced. This seems conclusive evidence of a pure line, at least in so far as weight of kernel is concerned. The relations which were found, then, must be largely due to environmental influences-- things outside the germ. While it is true that the size of embryo varies considerably, the absolute variation does not approach that found in the amount of endosperm.

Tables I and II which show the purity of the line worked with and table III showing all the constants determined, follow.

	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
11-13						1		1	2	3	1	5	7	4	2		3		29
13-15									3	1	3	9	4	8	2	2			32
15-17					1			1	3	1	3	5	3	5	10				32
17-19									1	3	4	2	6	7	6	2	1		32
19-21							1			3	4	5	5	4	2		1		25
21-23		1					1	2	4		4	6	9	2	2	1			32
23-25										2	1	6	7	5	7	1	3		32
25-27						1				2	3	3	8	7	5	1	2		32
27-29			1							2	5	4	7	7	3	2		1	32
29-31										1		9	7	6	3				26
31-33						1				2	2	2	4	3	5				19
33-35					1				1	2	1	6	7	7	1	1	1		28
35-37									1	2	3	7	9	9	1				32
37-39								1	1		6	6	6	7	2	2	1		32
39-41								1		4	6	4	5	5	5	2			32
41-43								2	1	2	2	6	9	5	4	1			32
		1	1		2	3	2	8	17	30	48	85	105	91	60	15	12	1	479

Table I. Weight of seed planted, subjective
Average weight of kernels in milligrams, relative
Coefficient of correlation = .013 ± .031

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
11-13								1				1	2	1		1		6
13-15										1	2		2		2			7
15-17										1	1	1	1	1				5
17-19									1		1	1	2	2	1	1		9
19-21									1	1	2	1	1	1				7
21-23												2	1	1				4
23-25											1			2		1		4
25-27												2	3	1	1			7
27-29										1	1	1		2	1			6
29-31											2	2		2				6
31-33												2	1	1				4
33-35												3	2	1		1		7
35-37											1	2	3					6
37-39										1	3	3	1	2				10
39-41										1	1	2	3	2	1			10
41-43							1					2	3	1	1			8
							1	1	2	6	15	25	25	20	7	4		106

Table II. Weight of seed in milligrams, subjective
Average weight of plump kernels in milligrams, relative.
Coefficient of correlation = .018 ±.063

Table III.

A table showing the correlation coefficients, standard deviations, means and coefficients of variability of the characters studied.

Relatives	Coefficient of Correlation	Standard Deviation	Mean	Coefficient of Variability
Wt. of individual kernels, mg. (479)		9.36± .204	26.96± .288	34.70± .842
Total length of spikes, cm.	.412 ± .026	6.64± .145	21.09± .205	31.49± .751
Average length of spikes, mm.	.158 ± .030	7.40± .161	79.33± .228	9.33± .203
Length of tallest culm at maturity, cm.	.292 ± .028	5.19± .113	91.57± .160	5.67± .124
Average length of culms, cm.	.176 ± .030	6.54± .142	85.10± .202	7.68± .167
Total length of culms, cm.	.410 ± .026	71.11±1.549	227.51±2.192	31.26± .745
Total weight of plant, cg.	.399 ± .026	153.88±3.353	479.18±4.742	32.11± .769
Weight of kernels or yield, cg.	.433 ± .025	57.08±1.244	172.99±1.759	32.99± .793
Av. weight of kernels per plant, mg.	.013 ±.031	2.16± .047	24.71± .066	8.73± .190
Weight of straw, cg.	.360 ± .027	97.81±2.131	309.67±3.014	32.37± .775
Number of kernels per plant	.459 ± .024	22.00± .480	69.15± .678	31.82± .760
Number of culms	.391 ± .026	.78± .017	2.66± .024	29.51± .697
*Light seed, mg. (214) [1]		4.01± .131	18.02± .185	22.28± .762
Weight of kernels or yield, cg.	.368 ± .040	47.75±1.557	154.44±2.202	30.92±1.100
*Heavy seed, mg. (233) [1]		4.67± .146	35.31± .206	13.23± .421
Weight of kernels or yield, cg.	.187 ± .043	55.29±1.728	194.05±2.444	28.49± .960
*Weight of individual kernels which produced only plump kernels, mg. (106) [1]		9.69± .449	27.96± .634	34.63±1.786
Average weight of plump kernels, mg.	-.018 ± .063	1.67± .077	25.57± .109	6.54± .303
* Cut seed, mg. (164) [1]		2.30± .086	17.16± .121	13.42± .509
Weight of kernels or yield, cg.	-.108 ± .052	43.15±1.607	142.07±2.273	30.37±1.231

* Subjective. [1] Number of plants studied.

THE BIOMETRICAL CONSTANTS DETERMINED.

Variations -

Using coefficient of variability as an index of the characters studied, weights of individual seed planted was the most variable (34.7±.842) while height of tallest culm was the least variable (5.67±.124). All gradations between these two extremes were found. Total length of spike (31.49±.751) was more than three times as variable as the average length (9.33±.203) which is to be expected, perhaps, in view of the fact that the average number of culms was 2.56±.024. It is interesting to note that the length of tallest culm was found to fluctuate less than the average length of culms. In other words one can foretell with greater precision the behavior of the tallest culm than the average height of all the culms. Total length of culms (31.26±.745), total weight of plant (32.11±.769), weight of kernels harvested (32.99±.793), weight of straw (32.37±.775), number of kernels per plant (31.82±.760) and number of culms (29.51±.697), all varied about equally. As would be expected, the average weight of plump kernels varied less than the average weight of kernels from the whole number of plants. Among the latter, shriveled kernels which deviated considerably farther from the mean than plump kernels, gave a wider variation than was found in the former, thus increasing the coefficient of variability. The individual weight of light seed (22.28±.752) varied almost twice as much as the individual weight of heavy seed (13.23±.421) if their respective coefficients of variability are used as the basis of comparison. This is largely due to the difference in means and not in standard deviation as is apparent from table 3. Number of culms with a coefficient of variability of 29.51±.697 varied from 1 to 5 culms inclusive per plant while number of kernels with a coefficient of 31.82±.750 varied from 10 to 135 kernels per plant.

Owing to the fact that the same unit of measure was not employed in all the data collected, the means and standard deviations are not strictly comparable. A few comparisons, however, among those in which the same unit was used may be of interest. The mean of average weight of plump kernels (25.57±.109 mgs.) was greater by about one milligram than the mean of average weight of the kernels (24.71±.066 mg.) where all the plants were considered. The respective means of the individual weights of the seed which produced the above two classes also differed by about one milligram; that which produced the former being 27.96±.634 mg. and the latter 26.96±.288 mgs. The mean length of tallest culms per plant (91.57±.160 cm.) was higher than would be expected from the mean of total length of culms (227.51±2.192 cm.) and number of culms, thus indicating that the culms produced in addition to the first two or three were considerably reduced in length. This was found to be the case. The mean yield of all the plants grown from normal seed was 172.99±1.759 milligrams while the light and heavy seed each yielded means of 154.44±2.202 and 194.05±2.444 milligrams, respectively.

Considering next standard deviations, total weight of plant (153.08±3.353 mg.) varies considerably more than either weight of straw (97.81±2.131 mg.) or yield (57.08±1.243 mg.). As with the coefficients of variability the standard deviations showed height of tallest culm (5.19±.113 cm.) to be less variable than the average length of culms (6.54±.142 cm.). This would seem to indicate that for some purposes height of tallest culm because of its low variability is more adapted to study than average height of culms or total length of culms. The standard deviation, as a measure of variability of the light individual seed, (4.01±.131 mg.) was found to be slightly less than that of heavy individual seed (6.07±.146 mg.) which is the reverse of the relation indicated by their respective coefficients of variability. However, this apparent discrepancy is easily understood when the means are considered, as has already been pointed out; the mean of light seed being of course smaller than the mean of heavy seed. A comparison of number of culms and number of kernels reveal much the same condition; the former with a standard deviation of .78±.017 has a coefficient of variability of 29.51±.697 while the latter's standard deviation is 22.0±.600 and its coefficient of variability 31.80±.780. Here are striking illustrations of the frequently misleading character of any one index of variation considered alone.

Correlations -

The correlations of the main part of the experiment ranged all the way from practically no correlation (.013 ±.031) to a medium high one (.459±.024). When the weight of individual seed was considered subjective and the following characters relative, total length of spikes, total length of culms, total weight of plant, total weight of kernels or yield, weight of straw, number of kernels and number of culms, the correlations .418 ±.026, .410 ±.026, .399 ±.026, .433 ±.025, .350 ±.027, .459 ±.024, and .391 ±.026 respectively were obtained. In other words for a pure line of Marquis, the heavier the seed selected the greater the resultant total length of spikes, total length of culms, total weight of plant, yield, weight of straw, number of kernels and number of culms. These relatively high positive relations may have been partly due to climatic conditions and the soil. Since these correlations are all derived with respect to weight of individual seed planted, one would expect to find a decided positive correlation between any two of the relatives; as for example number of kernels and yield. The correlation coefficient between weight of individual seed and average length of spikes was found to be only a little over one-third of that between the same subjective and total length of spike relative. This indicated that of the two, the average length of spikes produced is less dependent upon size of seed. When the average height of culms was considered relative a small positive correlation (.175 ±.030) was secured as compared with the relative characters, total length of culms (.410±.026), and height of tallest culm (.292±.028). Here again, as was previously pointed out under variation, the tallest culm seems to present a more stable and trustworthy character for study than does the average length of all the culms. Practically no correlation was obtained between weight of seed and average weight of kernels produced (.013±.031), a condition which is to be expected in a pure line. From the above facts the conclusion follows, that for some years and on soils of ordinary fertility found in this locality, weight of individual kernels of Marquis wheat planted, as described above, has a decided influence on resultant yield.

Tables IV to XIV present the data from which these conclusions are derived.

	2-5	5-8	8-11	11-14	14-17	17-20	20-23	23-26	26-29	29-32	32-35	35-38	38-41	41-44	
11-13		2	5	5	10	2	2	3							29
13-15		2	2	2	17	1	4	3	1						32
15-17		2		3	10	4	3	9	1						32
17-19		2		2	9	2	10	6				1			32
19-21				1	5	2	10	7							25
21-23		2	1	2	7	2	4	10	3		1				32
23-25		1	1		8	1	5	11	5						32
25-27		1	2	2	6	1	5	12	3						32
27-29		2	2		4	2	5	12	2		3				32
29-31			1		6	4	2	10	2	1					26
31-33	1	1	2			1	3	7	1	2	1				19
33-35			1		4	2	2	5	4	4	3	2		1	28
35-37				1	3	2	5	13	1	3	4				32
37-39		1	1		1	3	3	16	3	1	3				32
39-41		1			4		6	11	4	4			2		32
41-43		3					5	11	5	4	3	1			32
	1	20	18	18	94	29	74	146	35	19	18	4	2	1	479

Table IV. Weight of seed in milligrams, subjective
Total length of spikes in centimeters, relative.
Coefficient of correlation = .412 ± .025

	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	
11-13					4	3	2	10	6	4						29
13-15						2	15	3	8	4						32
15-17			1	1	1	3	5	10	5	5	1					32
17-19						3	7	11	7	3	1					32
19-21						3	6	7	7		1	1				25
21-23				1	1	2	6	6	12	1	2	1				32
23-25							7	7	8	7	2	1				32
25-27					1	2	4	5	10	8	1			1		32
27-29				1		3	3	4	13	6	2					32
29-31						1	2	6	10	6	1					26
31-33	1						4	5	5	4						19
33-35							7	5	9	5	2					28
35-37						1	2	12	12	5						32
37-39			1			2	1	7	14	5	2					32
39-41						1	8	5	13	3	2					32
41-43				1		1	6	6	11	4	3					32
	1		2	4	7	27	85	109	150	70	20	3		1		479

Table V. Weight of seed in milligrams, subjective
Average length of spikes in millimeters, relative.
Coefficient of correlation = .158 ±.030

	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	
11-13					1	3	6	10	8	1				29
13-15					1	1	5	14	9	2				32
15-17						1	2	11	14	2	2			32
17-19							1	12	14	5				32
19-21							2	12	8	2	1			25
21-23				1		1	3	7	14	6				32
23-25							1	7	16	7	1			32
25-27						2	1	2	14	10	3			32
27-29					2		1	7	13	9				32
29-31								4	14	6	2			26
31-33	1							3	7	8				19
33-35								4	13	7	3	1		28
35-37								4	13	14	1			32
37-39					1		1	3	11	13	2	1		32
39-41						1	1	10	12	8				32
41-43					1	1	2	5	14	9				32
	1			1	6	10	26	115	194	109	15	2		479

Table VI. Weight of seed in milligrams, subjective
Average height of tallest culm in centimeters, relative
Coefficient of correlation = .292 $\pm$.028

	48-52	52-56	56-60	60-64	64-68	68-72	72-76	76-80	80-84	84-88	88-92	92-96	96-100	100-104	104-108	
11-13					1	1	2	7	8	4	4	2				29
13-15	1				1	1	2	7	7	8	5					32
15-17			1				3	7	6	8	3	3	1			32
17-19							2	3	6	14	5	2				32
19-21							1	5	7	7	3	2				25
21-23					1		2	2	6	13	6	1	1			32
23-25							1	2	7	9	6	7				32
25-27							2	2	6	8	7	5	1	1		32
27-29						1	1	4	5	8	10	3				32
29-31								1	6	7	6	5		1		26
31-33		1							3	7	5	1	2			19
33-35		1						2	7	7	3	7	1			28
35-37							1	3	4	7	13	4				32
37-39							1	2	5	11	10	2		1		32
39-41							1	6	7	10	7	1				32
41-43						1	1	4	7	9	7	3				32
	1	2	1		3	4	20	57	97	137	100	48	6	3		479

Table VII. Weight of seed in milligrams, subjective
Average length of culm in centimeters, relative
Coefficient of Correlation = .176 ±.030

	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600	Total
11-13	7	3	13	4	2							29
13-15	4	3	18	5	2							32
15-17	2	1	15	7	7							32
17-19	2		13	8	8	1						32
19-21			8	9	8							25
21-23	3	1	10	5	11	2						32
23-25	2		9	6	15							32
25-27	2	1	9	4	16							32
27-29	4		6	6	13	2	1					32
29-31	1		9	4	10	2						26
31-33	4		1	1	10	3						19
33-35			7	2	9	6	2	1	1			28
35-37			6	4	15	3	4					32
37-39	2		3	4	18	3	2					32
39-41	1		4	8	14	3		2				32
41-43	3			8	12	7	2					32
	37	9	131	85	170	32	11	3	1			479

Table VIII. Weight of seed in milligrams, subjective
Total length of culms in centimers, relative.
Coefficient of correlation = .410 ±.025

	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600	600-650	650-700	700-750	750-800	800-850	850-900	900-950	950-1000	1000-1050	
11-13				2	4	4	4	6	4	2	1		2									29
13-15				2	1	6	7	4	7		3	1		1								32
15-17			1	1	1	3	3	3	7	5	5	1	1	1								32
17-19					1	3	2	6	6	5	5	2	1			1						32
19-21					1		1	4	9	3	4	2	1									25
21-23			1	2	1	1	3	4	4	5	3	5		1	2							32
23-25				1			5	2	7	3	4	2	3	3	1	1						32
25-27			1		1	2	1	3	3	6	4	4	5	2								32
27-29		1	1		1		4	2	3	2	3	7	2	4	2							32
29-31					1		1	4	3	7	6		4									26
31-33	1			1		2			1	4	5	1	1	2	1							19
33-35							3	1	2	4	1	4	4	2	4			1	1		1	28
35-37						1	1	1	5	2	6	7	3	3		3						32
37-39		1			1		1	2	1	3	7	7	3	2	2	2						32
39-41			1			1	1	1	4	4	2	7	3	3	3			1		1		32
41-43		1		2				1	2	2	4	6	3	5	3	1	1	1				32
	1	3	5	11	13	23	37	44	68	57	63	56	36	29	18	8	1	3	1	1	1	479

Table IX. Weight of seed in milligrams, subjective
Total weight of plant in centigrams, relative.
Coefficient of correlation = .399 ±.025

	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	300-325	325-350	350-375	375-400	
11-13		2	2	8	6	7	1	1	2								29
13-15			2	5	9	6	5	3	1	1							32
15-17		1	1	2	4	6	10	5	2	1							32
17-19				4	2	8	8	5	3	1		1					32
19-21				1		6	10	4	4								25
21-23		1	2	2	5	5	4	6	4	1	2						32
23-25			1		4	6	5	6	3	5	1	1					32
25-27		1		2	3	2	9	3	8	4							32
27-29		2		1	3	5	3	2	10	4	2						32
29ø31				1		7	4	10	1	3							26
31-33	1		1	2			3	6	2	2	2						19
33-35					2	1	4	6	5	3	4		2		1		28
35-37				1	1	3	3	7	7	6	2	2					32
37-39				1	2	1	3	8	7	5	2	3					32
39-41			1	1	1	1	6	4	9	3	4		1	1			32
41-43		1	2			3	3	4	8	3	5	1	2				32
	1	8	12	31	42	67	81	80	76	42	24	8	5	1	1		479

Table X. Weight of seed in milligrams, subjective
Yield of plant in centigrams, relative.
Coefficient of correlation = .433 ±.025

	10-50	50-90	90-130	130-170	170-210	210-250	250-290	290-330	330-370	370-410	410-450	450-490	490-530	530-570	570-610	610-650	650-690	
11-13			2	4	6	4	8	2	1		2							29
13-15			2	1	9	5	6	6	1	1		1						32
15-17			2	1	5	4	6	7	4	2	1							32
17-19				2	2	7	7	5	7	1			1					32
19-21				1		3	10	5	4	2								25
21-23		1	1	2	3	5	4	5	6	2	1	2						32
23-25			1		4	3	6	5	4	3	4	1	1					32
25-27			1	1	3	2	5	5	4	9	2							32
27-29		2		1	3	2	5	2	3	7	4	3						32
29-31				1		5	3	7	6	2	2							26
31-33	1			2	1		1	5	4	2	2	1						19
33-35					1	3	1	5	4	5	2	5		1	1			28
35-37					1	3	2	7	9	3	4	1	2					32
37-39		1	1		1	1	3	3	11	4	3	2	2					32
39-41		1			2	1	4	5	4	6	4	3		1			1	32
41-43		1	2			1	2	3	6	6	6	2	2	1				32
	1	6	12	16	41	49	73	77	78	55	37	21	8	3	1		1	479

Table XI. Weight of seed in milligrams, subjective
Weight of straw in centigrams, relative.
Coefficient of correlation = .360 ±.027

	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	
11-13		4	7	5	8	2	1	2							29
13-15		3	4	8	9	3	3	2							32
15-17		2	1	6	8	5	7	3							32
17-19			3	3	9	4	11	1			1				32
19-21				2	5	9	7	2							25
21-23	1	1	2	4	4	3	9	5	2	1					32
23-25		1		5	5	4	7	7	3						32
25-27		1	1	5	4	4	8	8	1						32
27-29	1	2		3	3	5	4	8	3	2	1				32
29-31			1		7	4	8	5	1						26
31-33	1	1	2		1	2	6	3	1	1	1				19
33-35				2	2	4	3	6	4	3	2	1		1	28
35-37				2	2	3	7	10	3	3	1	1			32
37-39	1	1		1	2		14	7	3	2	1				32
39-41		1		2	1	2	8	7	9				2		32
41-43	1	2				3	7	7	6	3	2	1			32
	5	19	21	48	70	57	110	83	36	15	9	3	2	1	479

Table XII. Weight of seed in milligrams, subjective
Weight of kernels in milligrams, relative.
Coefficient of correlation = .459 ±.024

	1	2	3	4	5	
11-13	7	16	6			29
13-15	4	20	8			32
15-17	2	15	15			32
17-19	2	13	16	1		32
19-21		8	17			25
21-23	3	11	16	2		32
23-25	2	9	21			32
25-27	3	9	20			32
27-29	4	6	19	3		32
29-31	1	10	13	2		26
31-33	4	1	11	3		19
33-35		6	11	9	2	28
35-37		6	19	7		32
37-39	2	4	21	5		32
39-41	1	4	21	4	2	32
41-43	3		20	9		32
	38	138	254	45	4	479

Table XIII. Weight of seed in milligrams, subjective
Number of culms , relative.
Coefficient of correlation =.391 ±.026

LIGHT AND HEAVY SEED.

In order to make a nicer determination, if possible, of the relation between endosperm size in the seed and yield, a correlation table for each the heavy and light seed was constructed. This was done by simply taking out the frequency class for 25-26 milligram seeds and those above and below, each studied as a seperate group. The correlation which resulted between light seed and yield (.368 ±.040) was about twice that between heavy seed and yield (.187 ±.043). In other words there seems to be a certain amount of endosperm which is of optimum importance in determining yield. That is, size of endosperm is more important where medium or small sized seeds are used than where large sized ones are used.

The regression curves (Charts I and II) bring out the same facts in a different manner. More regression is obtained with the small seed.

In the regression curve (Chart III) of weight of seed relative to yield for all the plant, a peculiar fact may be observed. The curve is fairly smooth, showing a steady increase in yield with weight of seed from the lightest seed up to those weighing 24 milligrams, where a distinct jump occurs. The next five classes are almost equal as to average yield while the last five classes tend to separate into a group of nearly equal yielders. A big jump is also found between the 31-33 milligram class and the one immediately following.

Chart I.
Regression of Light Seed
Yield in centigrams, relative

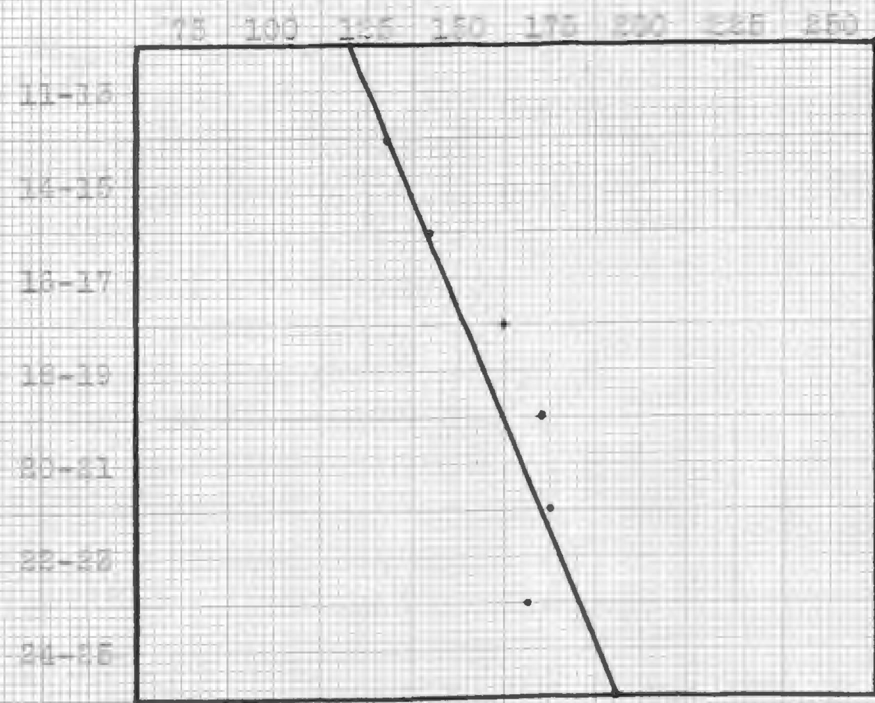
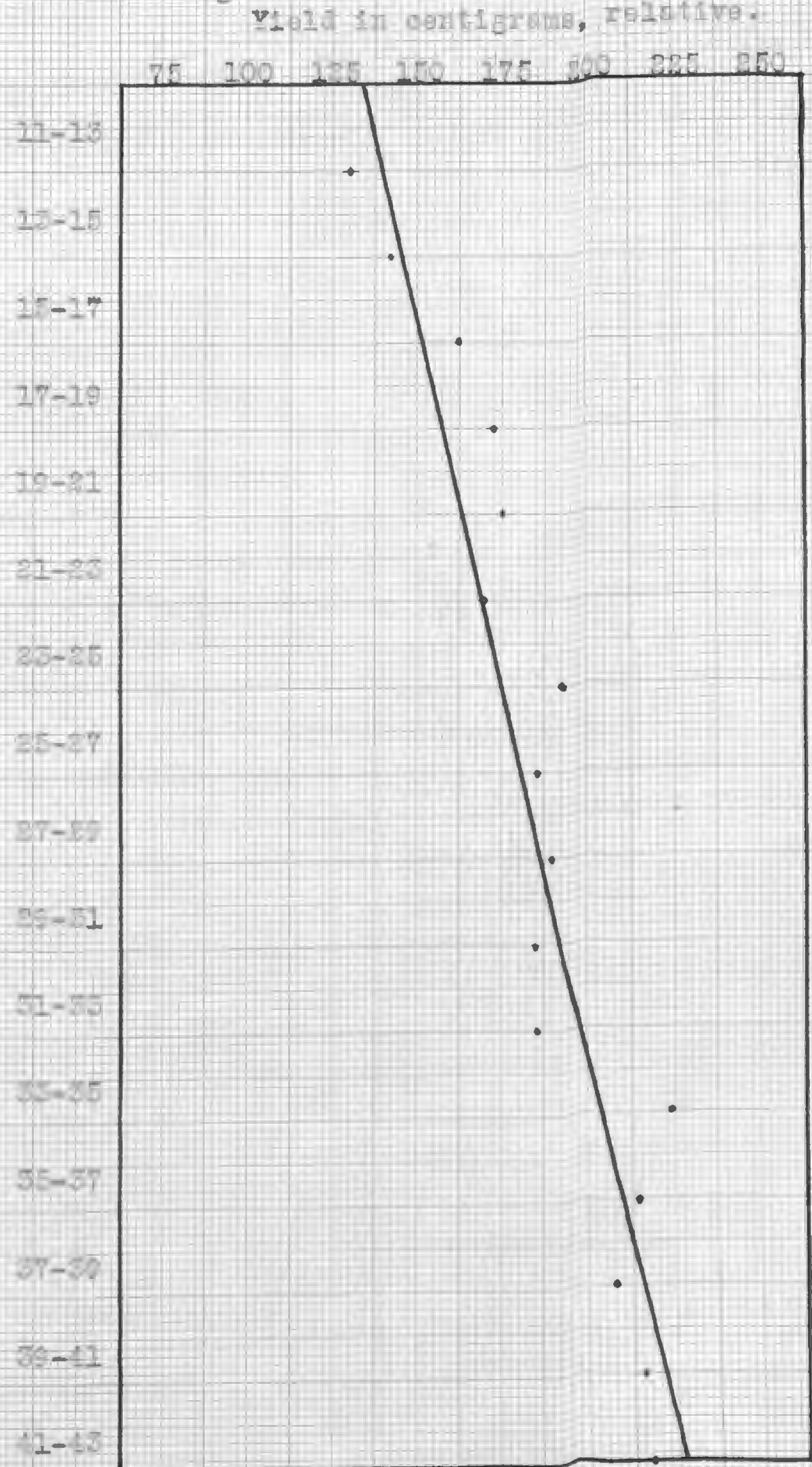


Chart II.
Regression of Heavy Seed
Yield in centigrams, relative

Chart III.

Regression of All Seeds.



	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	
11-13		2	2	8	6	7	1	1	2				29
13-15			2	5	9	6	5	3	1	1			32
15-17		1	1	2	4	6	10	5	2	1			32
17-19				4	2	8	8	5	3	1		1	32
19-21				1		6	10	4	4				25
21-23		1	2	2	5	5	4	6	4	1	2		32
23-25			1		4	6	5	6	3	5	1	1	32
		4	8	22	30	44	43	30	19	9	3	2	214

Table XIV. Weight of seed in milligrams, subjective
Yield in centigrams , relative.
Coefficient of correlation = .368 ±.040
Light Seed.

	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	300-325	325-350	350-375	
27-29		2		1	3	5	3	2	10	4	2					32
29-31				1		7	4	10	1	3						26
31-33	1		1	2			3	6	2	2	2					19
33-35					2	1	4	6	5	3	4		2		1	28
35-37				1	1	3	3	7	7	6	2	2				32
37-39				1	2	1	3	8	7	5	2	3				32
39-41			1	1	1	1	6	4	9	3	4		1	1		32
41-43		1	2			3	3	4	8	3	5	1	2			32
	1	3	4	7	9	21	29	47	49	29	21	6	5	1	1	233

Table XV. Weight of seed in milligrams, subjective
Yield in centigrams, relative.
Coefficient of correlation = .187 ±.043
Heavy Seed.

The following table is presented for the possible interest it may contain in connection with this paper. The figures show a consistent increase in yield with increased size of endosperm.

Table XVI.

A table showing the weight of seed planted, number of plants and average yield of each.

Weight of Seed Grams	Number of Plants	Average Yield per Plant, gms.	Average Yield of 2 classes
.012	14	1.0176	
.013	15	1.3206	1.1744
.014	16	1.3556	
.015	16	1.2325	1.1294
.016	15	1.2837	
.017	15	1.7012	1.4924
.018	16	1.6205	
.019	16	1.5787	1.5996
.020	13	1.6261	
.021	12	1.6241	1.6251
.022	15	1.5137	
.023	16	1.6243	1.5690
.024	16	1.8656	
.025	16	1.7156	1.7906
.026	15	1.8893	
.027	16	1.5781	1.7337
.028	16	1.9312	
.029	16	1.6143	1.7727
.030	16	1.7056	
.031	10	1.776	1.7236
.032	7	1.51	
.033	12	1.8591	1.7305
.034	12	2.2825	
.035	16	1.9912	2.1160
.036	16	1.9468	
.037	15	2.0825	2.0146
.038	16	2.0206	
.039	15	1.8743	1.9474
.040	15	2.1687	
.041	15	1.8818	2.0252
.042	16	2.0425	
.043	15	2.065	2.0537

CUT SEED.

In organizing and carrying out this cut seed investigation as has been described, it was hoped that more light might be thrown on the influence of endosperm on the following generation. The result was more or less of a disappointment. Perhaps, by removing portions of the endosperm, subsequent physiological disturbances were induced in spite of the fact every precaution was taken to prevent the same. Practically no correlation was found between weight of mutilated seed and resultant yield.

It may be of interest to point out that of the 198 seeds planted, 164 grew or a little over 82%. The vitality of the seed seems not to have been materially injured by the operation.

In as much as the endosperm serves primarily as a food supply consisting of starch proteids and fatty oils for the young plant until it becomes capable of independent nutrition, it would seem that by removing portions of this food supply the young plant would be hindered in its early growth and unless this handicap was overcome later, the yield would likely be reduced. Tables XVII and XVIII do not verify such an expectation. No consistent increase in yield with increased size of cut seed planted is shown.

In comparing the yields of the cut seed and normal seed (Table XVIII) it will be noticed that the plants from the former up to the 17 milligram class outyielded the plants from the latter. This again, as in the light and heavy seed, seems to indicate that size of endosperm is more important in smaller seeds than larger ones. A cut seed weighing 12 milligrams contains more available plant food for the young plant than a normal seed of the same weight, because the latter has a larger relative proportion of testa.

Table XIX presents the weights of the seed before various amounts of endosperm was removed. In general the heavier seeds yielded slightly more than the lighter ones.

The three following tables also point out the possibility of size of germ having some influence on the resultant yield.

As a whole, the data assembled from this phase of the investigation is incomplete and not sufficient to warrant drawing definite conclusions. Much more data is needed. To the writer, it seems, cut seed experiments of the future may be improved by selecting seeds of the same identical weights only, and then removing various portions of the endosperm. Then too, increasing the range in the amounts of endosperm cut off might be an improvement.

Table XVII.

A table comparing the yields of the cut seed with the yields of normal seed of the same weight.

Weight of Seed	12 mg.		13 mg.		14 mg.	
	C.S.	N.S.	C.S.	N.S.	C.S.	N.S.
No. of Plant	4	14	5	15	13	16
Av. Yld. per plant	1.4775	1.0178	1.41	1.3206	1.5425	1.3556

Weight of Seed	15 mg.		16 mg.		17 mg.	
	C.S.	N.S.	C.S.	N.S.	C.S.	N.S.
No. of Plant	21	16	25	16	22	16
Av. Yld. per plant	1.4661	1.2325	1.4812	1.2837	1.3604	1.7012

Weight of Seed	18 mg.		19 mg.		20 mg.	
	C.S.	N.S.	C.S.	N.S.	C.S.	N.S.
No. of Plant	24	16	21	16	21	13
Av. Yld. per plant	1.5429	1.6205	1.3004	1.5787	1.2676	1.6251

Weight of Seed	21 mg.		22 mg.	
	C.S.	N.S.	C.S.	N.S.
No. of Plant	5	12	4	16
Av. Yld. per plant	1.364	1.6241	1.505	1.5137

Table XVIII.

Arranged in consecutive order as to weight of seed planted the yields appear as follows:

Weight of Seed planted	C. S.	N. S.
12 milligrams	1.4775	1.0178
13 "	1.41	1.3206
14 "	1.5425	1.3556
15 "	1.4661	1.2325
16 "	1.4812	1.2837
17 "	1.3604	1.7012
18 "	1.5429	1.6205
19 "	1.3004	1.5787
20 "	1.2676	1.6251
21 "	1.364	1.6241
22 "	1.505	1.5137

Table XIX.

A table showing weight of kernels before part of endosperm was removed, number grown and average yield each produced.

Weight of Uncut Kernel	Number of Plants	Average Yield
.033	2	1.025
.034	3	1.61
.035	14	1.3457
.036	12	1.33
.037	18	1.4866
.038	15	1.3486
.039	22	1.3927
.040	21	1.4138
.041	18	1.6338
.042	15	1.296
.043	14	1.4471
.044	5	1.448
.045	3	1.4933

	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	300-325	325-350	350-375	
12			1		1			1	1							4
13				1		2	1	1								5
14			1	1	1	2	3	2	1	1						12
15			1	3	2	3	6	4	2							21
16		1		4	5	1	4	7	1	2						25
17			2	2	5	7	3	2	1							22
18					5	6	7	4	2							24
19			1	2	7	7	2	2								21
20		1	3	1	7	2	2	3	2							21
21				1	2		1	1								5
22						1	2		1							4
		2	9	15	35	31	31	27	11	3						164

Table XX. Weight of cut seed, in milligrams, subjective
Yield of plant in centimeters, relative.
Coefficient of correlation = −.108 ±.052

SUMMARY AND CONCLUSION.

1. A pure line of Marquis wheat was studied to determine the possible influence that size of endosperm may have on the succeeding generation.

2. Of the characters studied, height of tallest culm was least variable and weight of individual seed planted most variable. Between these extremes all gradations of variability were found. Standard deviation or coefficient of variability considered alone, as an index, may be misleading. This is well illustrated by comparing these constants for number of kernels produced with number of culms per plant.

3. The mean of the tallest culm was considerably greater than the mean of the average length of culms, this fact combined with the degree of variation found in each indicates that the tillers fluctuate more than the primary culms in height. Hence, the latter is a more stable criterion of comparison.

4. The weight of individual kernels planted was found to have a positive influence on yield, the total length of spikes, the total length of culms, the total weight of plant, the number of culms, the number of kernels, the weight of straw and to a slightly less degree on the height of tallest culm. The influence on the average length of spikes and the average length of culms was small. The comparatively high positive correlations may have been partly due to soil and climatic conditions.

5. The relative importance of endosperm, as far as, plant production is concerned, is greater in light seeds than in heavy

ones.

6. No relation was found between weight of seed planted and average weight of kernels produced or average weight of plump kernels produced. This lack of relation is indicative of a pure line.

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