THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given James Peel Shelton 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
May 17th 1921

H.K. Hayes
Chairman

M. J. Dorsey.

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THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by James Peel Shelton 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.

H.K. Hayes.
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M.J. Dorsey.

E.M. Freeman

May 17th 19~~18~~21

CORRELATION STUDIES IN WHEAT

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

James P. Shelton

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TABLE OF CONTENTS

Page

Acknowledgements 1

Introduction 2

Review of Literature 6

Materials and Methods 10

Comparative Variability of Various Quantitative Characters of Pure Lines of Wheat 12

Comparative Variability of the Spikes of Single Plants of Pure Lines of Wheat as Measured by Quantitative Characters . . 27

The Effect of Weight of Seed Planted Upon Quantitative Characters in the Resultant Plants 39

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INTRODUCTION

The agricultural and horticultural literature of the past few decades contains many experiments and statements as to the relative value of small and large seeds, as measured by the plants to which they give rise. The agronomic value of large seed in ensuring to the germinating seedlings a large supply of food material, and thus a good start in life, has been a subject of great interest and much discussion. Similar interest has been evinced in the question by plant physiologists, who use the same end results as their criterion of value, but are perhaps more interested in the mechanism which connects cause and effect, than in the end results as such.

The question of the effect of weight of seed upon the resultant plant is bound up with a more general one. Quite apart from the genetic factors which the embryo carries forward from the parental generation to shape the development of the new plant, what are the effects upon that new plant of seed and seedling conditions considered as part of the environmental non-genetic factors of development? These predetermining influences as they have been called by Kidd and West (7) include degree of maturity, age, weight and chemical constitution of the seed; changes in the seed as a response to factors affecting it during the dormant period; and an addition, conditions of environment during the period of germination before the young seedling has become an independent individual, for example temperature and moisture content of the soil. Physiologists claim that these influences, acting upon the plant during its most impressionable stage of life, often cause their results to appear during later stages of development of the plant without reference to conditions then existing. Such effects, which can be traced to the environmental conditions that have operated in the past stages of the plant's life, are to be distinguished from those which are due to the operation of hereditary factors, which they often tend to mask and distort.

Seed and seedling conditions, therefore, while environmental in their nature, have a possible application to, or bearing upon genetic investigations quite apart from the agronomic importance with which they have been credited. Are they sufficiently effective to be taken into consideration in planning genetic studies and in analysing genetic data? Or on the other hand may they legitimately be ignored by the geneticist?

F. L. Engledow (5) of Cambridge University, England, working with a cross between Polish and Kubanka wheats in respect to spike characters such as glume length, found that the parental forms extracted from the F_2 and the F_3 generations differed markedly in mean glume length from comparable populations of the pure parental types grown the same year under the same conditions. The F_2 plants with long glumes were obviously Polish in all spike characters, and had glumes of the same characteristic texture, shape and relative length as the parental Polish; similarly the F_2 plants with short glumes were undoubtedly similar to the parental Kubanka. Nevertheless, the mean glume length of the F_2 Polish type was reduced by 24.8% of the comparable parental value. While the F_2 Kubanka type showed an increase in mean glume length when compared with the parent, the difference was much smaller than for Polish and not significant in relation to the probable error; so that it cannot be considered to indicate a definite change. Engledow called the change exhibited by the segregated Polish type by the convenient name of "shift", which term will be employed here.

In the selfing of F_2 heterozygotes when plants of the parental Polish type were again evolved, there was no evidence of super-added shift. Likewise, there was no evidence of a tendency to the restoration of parental values of mean glume length. The "shifted" Polish F_2 forms bred true in the next generation. The author states specifically that the shift was quite definite, and could not be explained by errors of sampling, seasonal variation, or any such cause. For kernel length analogous results were obtained, but the long Polish kernel type of the F_2 generation showed a reduction in mean kernel length of only 12.5% of the parental value. The amount of shift was so great that the statement is made, that, while the parental Polish type reappeared in the F_2 generation so far as general qualitative characters were concerned, it failed to do so in regard to the quantitative character of glume length. Similar shift of mean glume length in crosses with Polish wheat as one parent has been noted by Caporn [(4) page 259] and Backhouse [(2) page 130 Fig. 1a].

In discussing his experimental results Engledow mentions the possibility of gametic impurity or contamination as an explanation of shift, but does not enlarge upon it. The stability of the gene is still an open question, but the balance of evidence is undoubtedly in favour of stability. The behaviour of glume length in a cross involving Polish wheat is representative of much of the evidence advanced in support of gametic impurity. There is another explanation of shift not advanced by the author. In addition to the major pair of factors which undoubtedly seems to differentiate Polish and Kubanka wheats in regard to glume length, there are probably several or many modifying factors concerned in the development of the glume length. Shift may then be due to the segregation of these minor factors for glume length. On this hypothesis shifted Polish glumes would be due to the segregation of plants with fewer minor factors than were contained in the original Polish parent. In the segregated Polish type of the F_2 generation some plants should have a glume length equal to, while other plants should have a glume length less than the parental form. Some of the F_2 segregates should breed true for shifted glume length. Corresponding results would be obtained for Kubanka. This possible explanation of shift could be investigated by growing on the parental forms segregated from the F_2 generation as a series of families each derived from a single F_2 plant.

Engledow, however, brings forward theoretical deductions from the double fertilization hypothesis of the origin of the endosperm in cereals to show the possibility of four types of endosperm occuring among the kernels borne by the heterozygous F_1 plants of the Polish x Kubanka cross. These four theoretical types of endosperm should show differentiation on the basis of weight of kernel, in addition to other characters of a chemical and physiological nature. There would be four types of kernel in regard to weight if only one pair of factors controlled weight of endosperm. If more than a single pair of factors were involved the number of classes for weight amongst the kernels borne on F_1 plants would be correspondingly greater.

It is at once apparent that Engledow is considering the possibility that the abnormal genetic results may be explained by the predetermining influence of seed characters upon the expression of certain genetic factors in the mature plant. A method of attacking the particular problem of the Polish glume length was to determine if weight of seed planted had any appreciable effect upon mean glume length within a known pure line. The extreme variation in the effect of predetermining influences upon the growth and yield of the plant as detailed by Kidd and West (7) showed that the matter was still an open one. Apart from the immediate bearing on "shift" an investigation of the effect of weight of seed planted upon such a definite measurable character as glume length would be of considerable value in itself. A review of literature showed that the effect of seed weight had hitherto been measured in characters such as height and vigor of plants, yield, etc., which are probably far more complicated in their genetic constitution than is glume length - even if the latter is modified by several pairs of minor factors.

In 1920 I was a student at the Plant Breeding Institute of Cambridge University. At Engledow's request I undertook the investigation of the effect of weight of seed planted upon glume length, in the same pure lines of Polish and Kubanka wheats that he had used as parental material for the crosses that revealed the "shift" phenomenon. The results of that investigation are presented here. Several side issues that arose during the progress of the study are presented and discussed under the heading of "comparative variability of various quantitative characters" and "comparative variability of the spikes of single plants of a pure line" before the main question of the effect of seed weight is considered.

Review of Literature

It is not proposed to review separately any of those numerous experiments that have been reported, dealing with the effect of weight of seed planted upon the resultant plants, which deal with small numbers of plants and which have not been analysed statistically. Many investigators have drawn profound deductions from results obtained by contrasting plants from a few large and a few small seeds, measuring the differences in vigor and development by eye judgment.

In many cases where large numbers of plants have been studied and results showing considerable effect, due to weight of seed planted, have been obtained, the interpretation of the results in the light of the pure line theory shows that the effects have been due to the isolation of two or more pure lines, which differ in kernel size and weight as well as in other characters. In many such experiments the seed was derived from commercial samples, so that mixtures of several pure lines at least were certain.

The effect of weight of seed planted has been judged from the development of the seedlings in the majority of experiments. The balance of evidence in such cases is undoubtedly in favor of the heavier seeds, as producing larger and more vigorous seedlings. This evidence is also subject to severe criticism on the basis of the pure line theory. Moreover, judgment was given in favor of the heavier seeds after such short periods of seedling growth as five days in some cases. Such evidence is surely unreliable from the agronomic point of view. Where plants were allowed to become more nearly mature, or to complete their growth, many investigators have remarked that differences between plants from light and heavy seeds, though marked at first, gradually disappeared, till at harvest comparatively small differences were obtained if any at all.

Kidd and West (7) have admirably summarized much of the literature dealing with the type of experiment discussed above. They have reviewed it from the point of view of the laboratory physiologist interested in the effects of the so called predetermining influences on the development of the plant. They note the almost exclusive attention that has been concentrated, hitherto, upon the question of germination, in the enormous mass of literature dealing with the seed. In only a relatively small number of cases have observations been made upon the subsequent development of the plant. They are of the opinion that the balance of evidence is in favor of the conclusion that larger seeds give rise to more vigorous plants and a better yield. They do not, however, criticise the evidence in the light of the pure line theory; the small number of plants involved in many tests; nor the significance of results in relation to the probable error of the experiments, which in every case reviewed has been ignored by the investigators. Experiments involving the removal of part or all of the cotyledons or endosperm of seeds prior to or during germination have confirmed the general belief in the benefits to be derived from the use of heavy seeds. In their own discussion the authors point out that the selection of vigorous seedlings is a common paractice among horticulturists. They say: "It is recognized that some sort of correlation exists between the vigor of the seedling and that of the adult plant and some recent scientific work has quantitatively established this fact. But the proper deductions have not been made. The vigor of the seedling may be due either to hereditary causes or to environmental factors which have operated previously to, or during germination. The critical question is, therefore - can we propound a law to the effect that increased vigor of seedling development due to environmental conditions as distinct from hereditary causes is correlated with increased vigor of growth throughout the life of the plant and with increased yield independently of the subsequent environmental conditions?" Evidently the authors think that, where increased growth beyond the seeding stage is correlated with heavy weight of seed planted, such increased growth may be due to genetic factors, rather than to the direct influence of the heavy seed. In some cases indeed the increased weight of the seed may be due to the operation in the formation of the endosperm, of the same genetic factors for growth which later on influence the size and vigor of the plant. Under such conditions the value attached to heavy seed would be much diminished, except in so far as heavy seed is an indication of the presence of growth factors.

Love and Leighty (8) working with a pure line of oats found that biometrical constants - that is to say, means, standard deviations, coefficients of variability and correlation coefficients, - vary more or less with environmental conditions, such as degree of crowding of the plants and differences in the weather conditions. They found that for different years and consequently different weather conditions but under the same cultural conditions, correlations could be divided, but with only fair accuracy, into two classes: (1) those which vary by considerable amount from year to year, and which they called fluctuating correlations; and (2) those which are fairly constant from year to year and which they called stable correlations.

Hutchinson (6) in a statistical study of oat plants grown from individually weighed seeds planted at definite distances apart, found fairly high positive correlations between weight of seed planted and each of the following characters; yield of kernels; total weight of plant; number of kernels harvested; height before second leaf; height at 4, 6, and 10 weeks, at heading, and at harvest. No correlation was found between weight of seed planted and average weight of seed harvested. This extensive experiment undoubtedly proves that the influence of weight of seed planted is somewhat effective in the mature plant so far as general growth characters are concerned. The number of characters in which correlation was found give it added weight.

Arny and Garber (1) worked with Marquis wheat for four years. They investigated the amount of correlation between weight of seed planted and fourteen separate plant characters, mostly functions of total production per plant. The determinations were made on a total of 2048 plants; 300 in 1914; 571 in 1915; 698 in 1916; and 479 in 1917. Each plant was derived from an individually weighed seed, planted separately, and always identifiable in respect to the plant it produced. The seed in the first three years was taken from bulk selections and no statement is made as to whether the original supply, received from Canada, was a pure line. The seed for the fourth year was derived from a pedigree line established by selecting an individual plant from the experimental plants in 1914. Coefficients of correlation ranging from .356 ± .040 to .712 ± .015 were found between weight of seed planted and height of plants at six weeks. The latter was the highest degree of correlation found in any instance. All the calculated coefficients of correlation between weight of seed planted and various characters of the mature plant were below .5. The main feature of the results is the variation from year to year with respect to the same character. With eight characters of the mature plant the coefficient for 1916 and 1917 were on the average about equal with regard to each character; the coefficients for 1914 are on the average about one-half as great as the corresponding values for 1916 and 1917; while the coefficients for 1915 show still further reduction to about one-half the value for 1914. This yearly fluctuation is well illustrated in the values for the correlation between weight of seed planted and total length of spikes per plant - the only correlation at all comparable to those discussed in this thesis. The coefficient for this correlation were .259 ± .036 in 1914; .018 ± .028 in 1915; .442 ± .020 in 1916; and .417 ± .025 in 1917. The authors considered that there is a distinct tendency toward correlation between weight of seed sown and the characters of the resultant plants; that the correlation, however, under average field conditions is not high in any instance; and is subject to the influence of environmental conditions to so marked an extent that with some characters the relation may be obliterated entirely; and with other characters, including yield, may be so slight that no relation can be detected under the ordinary conditions of a field experiment.

Materials and Methods

The plants used in this investigation were grown at University Farm, Cambridge, England in 1920. The immediate parental generation had been grown at the same place on the same soil in 1919. Pure lines of Polish wheat (*T. polonicum*) and Kubanka wheat (*T. durum*) were obtained from F. L. Engledow of Cambridge University. They were part of the parental material used in investigations on the inheritance of glume length and grain length, reported by him (5). In turn he had received them from Professor R. H. Biffen of Cambridge University by whom they had been found to satisfy over some 16 years all the requirements of pure lines; indeed they were the same pure lines that had been used in the original investigations on Mendelian inheritance in wheat by Biffen (3).

The material was grown in the Plant Breeding nursery at Cambridge on a red gravel clay soil, which had received uniform hand cultivation over a number of years, and which was apparently uniform over the small area involved. The plants from which the seed for the experiment was derived were grown at Cambridge in 1919 from seed harvested in 1914 and kept in the spike throughout the following period. After harvest in 1919 the seed to be used for sowing in 1920 was kept in the spike until it was to be weighed. Each ear was then rubbed out separately, care being taken to recover all of the grain. Before rubbing out, however, each spike was measured for glume length and rachis length, so that these measurements and the ratio of glume length to rachis length are known for one spike of all parental plants. Every kernel from one spike of forty plants of each variety was weighed to the nearest milligram, the forty plants being a random sample of the parental generation. After weighing, each kernel was placed in a small envelope, labeled and kept separate. At planting a record was kept of the position of every weighed kernel, so that the resulting plants could be identified in respect to the seed from which they grew. When the seedlings were six inches high they were checked over and failures were noted on the planting plan.

The seed was sown in rows 46 inches long and 4 inches apart. Seed was planted separately in holes dibbled two inches apart in the rows to a uniform depth of 1½ inches and all seeds were planted the same way up with respect to the embryo. Planting was carried out on two successive days, the 3rd and the 4th of March. As the main object was to test the effect of weight of seed planted on subsequent growth of the plants every possible precaution was taken to ensure even germination and to inhibit as far as possible the effect of seed characters other than weight. Rain fell the day following planting, and germination was quick and regular. Growth conditions were fairly favorable throughout the seasons; the plants were healthy, rust incidence in each pure line being comparatively light and regular. At harvest the plants of each pure line were uniform in appearance.

At harvest the plants were identified as the weighed seed from which each was derived; each plant was kept separate; and each spike of a plant was harvested separately and numbered in order of size and development. After harvest every spike was measured to obtain the maximum glume length and the rachis length. From these figures the ratio of glume length to rachis length was calculated for each spike.

All measurements of plants of both generations were made in a standard manner as follows. The glumes of the median group of four to eight spikelets on a spike are all approximately of the same length and represent the maximum glume length of the spike. With the same pure lines Engledow (5) had previously found that fifty per cent of the single measurements deviated from the means of the sets of eight to which they belonged by no more than ± 0.4 mm. As the accuracy of measurement was only ± .5 mm. he consequently considered one glume measurement per spike to be sufficiently accurate. For this experiment the average of the length of the four median glumes (both glumes from the median spikelets on each side of the spike) has been considered as characteristic of the spike. If the number of spikelets on a side were an even number (say 2 n) then the n^{th} spikelet from the tip of the spike was selected to be measured for glume length. Each glume while still attached to the spike was measured to the nearest millimeter by means of direct reading calipers. The measurement was from the point of attachment at the base to the tip which in both Polish and Kubanka is always very definite. The average of the four measurements on each spike was calculated to the nearest millimeter. It is this average that is referred to whenever glume length is mentioned herein. The spikelets were then carefully stripped from the rachis of the spike and the length of the rachis was measured to the nearest millimeter. Measurements were taken from the point of attachment of the terminal spikelet to the basal node of the rachis regardless of the presence or absence of fertile spikelets. The ratio of glume length to rachis length was calculated to the nearest one thousandth for every spike.

Comparative Variability of Various Quantitative Characters of Pure Lines of Wheat.

Owing to the attention which has been given to the concept of pure lines and their importance in plant breeding, genetics and general biological experiments, the question of comparative variability of characters within a pure line is one that merits some discussion.

In any random sample of wheat spikes, even within a pure line, there is a wide range between the lower and upper extremes for both rachis length and glume length. This is especially apparent with a long spiked, long glumed variety such as Polish. It is a matter of common observation that the length of glume tends to vary with the length of the rachis in a very definite manner. Thus it seemed reasonable to assume that the ratio of the glume length to the rachis length would show a much more restricted range of variability, as expressed by the coefficient of variability, than either the glume length or rachis length considered in respect to the same population. If this were so, then the ratio of glume length to rachis length would be a much better character to use as a criterion of such a population in respect to spike type than either glume length or rachis length.

In the experiment herein described where the effect of certain seed factors upon resultant spike type is being investigated, it is evident that such effect would be more easily apparent, (though perhaps no more real) in a character of the ear which is subject to a narrow range of normal fluctuation within a pure line, than in one with a wider range of normal fluctuation, where deviations from the mean due to seed factors would be more often masked by normal deviations. Again in the experiments described by Engledow (5) where the inheritance of glume length in a Polish x Kubanka cross was being investigation, the ratio of glume to rachis length would have been a better and easier criterion upon which to sort the segregating F_2 generation, than either the glume length or rachis length. The narrower range of variability in the case of the ratio should have inhibited a great amount of the overlapping of the types which was found when they were sorted on a basis of glume length.

As there seemed some value attached to the use of the ratio the exact correlation between the glume length and rachis length was determined in a number of cases to confirm the generally observed relation. The correlations for six populations are given in Tables I to VIII, and are brought together for comparison in Table IX.

Table IX. Coefficients of correlation between glume length and rachis length of the same spike for various populations of Polish and Kubanka wheat.

Variety	Population	Coefficient of correlation
Polish	One spike from each of 150 plants grown in 1914	.295 ± .0503
Polish	One spike from each of 316 plants grown in 1920 which produced only one spike	.918 ± .0060
Polish	Larger spike from each of 110 plants grown in 1920 which produced only two spikes	.768 ± .0264
Polish	Largest spike from each of 38 plants grown in 1920 which produced only three spikes.	.852 ± .0300
Kubanka	One spike from each of 150 plants grown in 1914	.469 ± .0430
Kubanka	The spike from each of 205 plants grown in 1920 which produced only one spike	.751 ± .0205
Kubanka	Larger spike from each of 107 plants grown in 1920 which produced only two spikes.	.717 ± .0317
Kubanka	Largest spike from each of 55 plants grown in 1920 which produced only three spikes.	.494 ± .0688

The coefficients in Table IX are all very highly significant in relation to their respective probable errors. In all the six populations considered the coefficients indicate a relatively high correlation between the glume length and rachis length of the same spike thus confirming the general observation. A correlation of $r = .918 \pm .006$ which was obtained for a population of 316 Polish plants, is almost as high as could be obtained in any biological experiment.

Table I. Correlation between glume length and rachis length in plants of Polish wheat grown in 1919.

Rachis length. Class interval 7 m.m.

Glume length. Class interval 2 m.m.

	56	63	70	77	84	91	98	105	112	119	126	133	140	Totals
21.5		1												1
23.5	1	3			1									5
25.5		2	1	7	1	1								12
27.5		1	4	8	3	3	2	3	1					25
29.5				3	2	9	2	3	1	1				21
31.5				3		11	9	7	4	2				36
33.5						3	3	14	9		1	1		31
35.5						2	2	3	3	2	2	1	1	16
37.5							1			1	1			3
Totals	1	7	5	21	7	29	19	30	18	6	4	2	1	150

Glume length.
Mean 30.7 ± .19 m.m.
Standard deviation 3.40 ± .132 m.m.

Rachis length.
Mean 95.6 ± .90 m.m.
Standard deviation 16.42 ± .639 m.m.

r = . 295 ± .0503

Table II. Correlation between glume length and rachis length in plants of Polish wheat which produced only a single spike.

Rachis length. Class interval 7 mm.

Glume Length. Class Interval 2 mm.	21	28	35	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	Totals
9.5	1			1															2
11.5				1															1
13.5				2	1														3
15.5				2	1	1													4
17.5			1	2	1														4
19.5			1	3	4	5	2												15
21.5					1	4	4	14	2	1									26
23.5				1			2	11	13	6	3		1						37
25.5							1	4	7	13	19	8	3						55
27.5								1	3	5	14	11	16	3					53
29.5											2	11	23	13	7	1			57
31.5													3	11	15	6	4		39
33.5												1		2		6	5	3	17
35.5																1		2	3
Totals	1	0	2	12	8	10	9	30	25	25	38	31	46	29	22	14	9	5	316

Glume length.
Mean 26.5 ± .17 mm.
Standard deviation 4.54 ± .122 mm.

Rachis length.
Mean 92.1 ± .90 mm.
Standard deviation 23.73 ± .637 mm.

$r = .918 \pm .0060$

Table III. Correlation between glume length and rachis length in plants of Polish wheat which produced only two spikes.

Rachis length. Class interval 7 mm.

Glume Length. Class interval 2 mm.	56	63	70	77	84	91	98	105	112	119	126	133	140	147	Total
21.5			1												1
23.5	1														1
25.5				1	4				1						6
27.5					1	2	2		4	3	1				13
29.5						1	1	3	5	8	3	3			24
31.5						1	1		6	11	16	6	2		43
33.5										2	4	5	4	1	16
35.5												4	2		6
Totals	1	0	1	1	5	4	4	3	16	24	24	18	8	1	110

Glume length.
Mean 30.6 ± .17 mm.
Standard deviation 2.62 ± .119 mm.

Rachis length.
Mean 118.4 ± 1.05 mm.
Standard deviation 16.38 ± .745 mm.

$r = .768 \pm .0264$

Table IV. Correlation between glume length and rachis length in plants of Polish wheat which produced only three spikes.

Rachis length. Class interval 7 mm.

Glume length. Class interval 2 mm.	77	84	91	98	105	112	119	126	133	140	147	154	161	Totals
21.5	1													1
23.5			1											1
25.5						1								1
27.5					1		2		1					4
29.5					1			3	3					7
31.5						1	1	2	2	3	1			10
33.5								2	2	2	2			8
35.5										1	1		1	3
37.5												1	2	3
Totals	1	0	1	0	2	2	3	7	8	6	4	1	3	38

Glume length.

Mean 31.3 ± .39 mm.

Standard deviation 3.55 ± .275 mm.

Rachis length.

Mean 130.8 ± 1.94 mm.

Standard deviation 17.75 ± 1.373 mm.

$r = .852 \pm .0300$

Table V. Correlation between glume length and rachis length in plants of Kubanka wheat grown in 1919.

Rachis length. Class interval 7 mm.

Glume length. Class interval 1 mm.	28	35	42	49	56	63	70	77	Totals
9	1		1						2
10		1	5	8	6	3			23
11			4	12	12	15	5		48
12				2	13	18	23	4	60
13						5	8	4	17
Totals	1	1	10	22	31	41	36	8	150

Glume length.

Mean 11.4 ± .05 mm.

Standard deviation .93 ± .036 mm.

Rachis length.

Mean 60.1 ± .54 mm.

Standard deviation 9.77 ± .380 mm.

$r = .469 \pm .0430$

Table VI. Correlation between glume length and rachis length in plants of Kubanka wheat which produced only one spike.

Rachis length. Class interval 7 mm.

Glume length. Class interval 1 mm.

	28	35	42	49	56	63	70	77	84	91	Totals
8	1		1								2
9	2	4	7	4	3						20
10		4	8	22	13	1	1				49
11		1		7	19	29	9				65
12		1	1	4	3	17	21	7	2		56
13						1	6	5		1	13
Totals	3	10	17	37	38	48	37	12	2	1	205

Glume length.
Mean 10.9 ± .05 mm.
Standard deviation 1.11 ± .037 mm.

Rachis length.
Mean 58.0 ± .56 mm.
Standard deviation 11.85 ± .395 mm.

$r = .751 \pm .0205$

Table VII. Correlation between glume length and rachis length in plants of Kubanka wheat which produced only two spikes.

Rachis length. Class interval 7 mm.

Glume length Class interval 1 mm.	28	35	42	49	56	63	70	77	84	91	Totals
9	1	1		1	1						4
10			2	4	1	1					8
11			1	2	2	9	11	2	1		28
12				1	1	5	21	15	6		49
13						2	2	9	3	1	17
14									1		1
Totals	1	1	3	8	5	17	34	26	11	1	107

Glume length.

Mean 11.6 ± .06 mm.

Standard deviation .99 ± .045 mm.

Rachis length.

Mean 68.5 ± .75 mm.

Standard deviation 11.56 ± .533 mm.

r = .717 ± .0317

Table VIII. Correlation between glume length and rachis length for plants of Kubanka wheat which produced only three spikes.

Rachis length. Class interval 7 mm.

Glume length Class interval 1 mm.	49	56	63	70	77	84	91	98	Totals
10			1						1
11	1		2	3	2				8
12			5	6	7	6			24
13				3	3	7	4	1	18
14			1		1	2			4
Totals	1	0	9	12	13	15	4	1	55

Glume length.
Mean 12.3 ± .08 mm.
Standard deviation .87 ± .056 mm.

Rachis length.
Mean 76.0 ± .87 mm.
Standard deviation 9.57 ± .615 mm.

$r = .494 \pm .0688$

The most striking thing about the results is the much lower value of the coefficient for the plants grown in 1914 than for those grown in 1920. This might be due to seasonal variation. Perhaps the more likely explanation is that the low values are due to the different constitution of the population. In 1914 one spike from each of 150 plants was chosen for each variety regardless of the number of spikes that a plant had produced, and without any effort to obtain from each plant the first matured or the largest spike. These results point to the fact stressed later on, that each spike of a plant does not give the same expression to the genetic factors underlying its development, and that in a comparison of the spike characters of a plant, not only must the plants be comparable, but that each spike must be selected on a basis that will allow comparison. In considering the correlations (see Table IX) the results obtained in 1920 will be the only ones discussed.

Polish wheat with its greater range of variability shows consistently higher values for the correlation between rachis and glume length than does Kubanka. It is in Polish wheat, with the greater variability, that one would look for the greater usefulness of the ratio. The value of the coefficient for the Kubanka population of 55 plants , $r = .494 \pm .0688$, is somewhat lower than in the other cases; but as it is not nearly as significant in relation to its probable error as are the coefficients in the other cases, it is safe to conclude that this single slight exception to the general rule is due to the small number of plants involved in the correlation. The results presented in Table IX support the idea, derived from general considerations, that the ratio of glume length to rachis length would show less variability and therefore be a better criterion of a pure line than either of the individual units involved in the ratio.

Preliminary studies having pointed to the probable value of the ratio as a substitute for either the glume length or the rachis length, the ratio was calculated for each spike in four separate populations of both Polish and Kubanka wheat. Each set of four are samples of the same pure line, but each includes samples grown in 1914, 1919 and 1920. The usual mathematical constants for the three characters studied are given in Table X for the samples of Polish wheat and in Table XI for those of Kubanka wheat.

Table X. Some mathematical constants for glume length, rachis length and ratio of glume length to rachis length in four separate populations of a pure line of Polish wheat.

Population	Plant Character	Mean	Standard Deviation	Coefficients of Variability %
One spike from each of 150 plants grown in 1914.	Glume length	30.7 ± .19 mm.	3.38 ± .131 mm.	11.01 ± .434
	Rachis length	95.7 ± .91 mm.	16.54 ± .644 mm.	17.28 ± .693
	Ratio	0.326 ± .0020	0.0369 ± .00144	11.32 ± .446
One spike from each of 60 plants grown in 1919	Glume length	29.1 ± .32 mm.	3.68 ± .227 mm.	12.65 ± .791
	Rachis length	84.4 ± 1.47 mm.	16.85 ± 1.037 mm.	19.96 ± 1.277
	Ratio	0.352 ± .0036	0.0410 ± .00252	11.65 ± .727
One spike from each of 316 plants grown in 1920 which produced only 1 spike	Glume length	26.5 ± .17 mm.	4.54 ± .122 mm.	17.13 ± .473
	Rachis length	92.1 ± .90 mm.	23.73 ± .637 mm.	25.77 ± .736
	Ratio	0.2980 ± .00175	0.04609 ± .00124	15.47 ± .425
One spike from each of 110 plants grown in 1920 which produced only 2 spikes	Glume length	30.6 ± .17 mm.	2.62 ± .119 mm.	8.56 ± .389
	Rachis length	118.4 ± 1.05 mm.	16.38 ± .745 mm.	13.83 ± .641
	Ratio	0.2618 ± .00182	0.02835 ± .00129	10.83 ± .498

Considerable fluctuation is shown in the values of the mean and the standard deviation for each of the three characters, but as these represent seasonal changes they are of no significance here. Interest centres in the comparative value for the coefficient of variability in each of the three characters. Four determinations for this coefficient in regard to each character are available in each variety.

Considering Polish wheat (Table X) the coefficient of variability for rachis length is consistently higher than the coefficient for either glume length of ratio; generally the difference is equal to from 50% to 75% of the value of the coefficient in the latter two characters. Comparing the coefficients in the case of glume length and ratio, no significant difference is noted; in two cases the difference is slightly in favor of the glume length; in the other two cases it is slightly in favor of the ratio.

Table XI. Some mathematical constants for glume length, rachis length and ratio of glume length to rachis length in four separate populations of a pure line of Kubanka wheat.

Population	Plant Character	Mean	Standard Deviation	Coefficients of Variability %
One spike from each of 150 plants grown in 1914	Glume length	11.5 ± .05 mm.	0.92 ± .036 mm.	8.00 ± .312
	Rachis length	59.3 ± .52 mm.	9.43 ± .367 mm.	15.90 ± .635
	Ratio	0.196 ± .0014	0.0259 ± .00101	13.21 ± .523
One spike from each of 60 plants grown in 1919	Glume length	12.1 ± .09 mm.	0.99 ± .060 mm.	8.18 ± .504
	Rachis length	57.5 ± .79 mm.	9.02 ± .555 mm.	15.69 ± .990
	Ratio	.215 ± .0027	.0308 ± .00190	14.32 ± .900
One spike from each of 205 plants grown in 1920 which produced only 1 spike	Glume length	10.9 ± .05 mm.	1.11 ± .037 mm.	10.18 ± .343
	Rachis length	58.0 ± .56 mm.	11.85 ± .395 mm.	20.43 ± .708
	Ratio	0.1961 ± .00169	0.03585 ± .00119	18.29 ± .629
One spike from each of 107 plants grown in 1920 which produced only 2 spikes	Glume length	11.7 ± .06 mm.	0.99 ± .045 mm.	8.46 ± .390
	Rachis length	68.5 ± .75 mm.	11.56 ± .533 mm.	16.88 ± .800
	Ratio	0.1745 ± .00143	0.02196 ± .00101	12.58 ± .589

Table XI indicates somewhat similar results for Kubanka wheat as were obtained for Polish. In all cases the rachis length shows the highest coefficient of variability; in general the difference between it and that for glume length is much greater than in the case of Polish wheat ranging up to 100% of the value for glume length. While the coefficient of variability for the rachis length is always greater than that for the ratio the difference is much less than for Polish wheat, and indeed the difference appears significant in only one case. In all four samples glume length shows a coefficient ranging from one-third to two-thirds the value of the coefficient for the ratio.

Definite studies therefore have not confirmed the preliminary indication that the ratio of glume length to rachis length would be a better criterion of a pure line than either glume length or rachis length. In Kubanka wheat it is definitely of far less value than the glume length. In Polish wheat it has more or less the same value as the glume length when small variability is taken as a measure of value and the coefficient of variability is used as the criterion of variability due to normal fluctuations. The glume length is the least variable of the three characters studied, and the most reliable criterion of the pure line, so far as spike type is concerned.

Reverting to the discussion of Engledow's study of the F_2 generation of the Polish Kubanka hybrid it is apparent that the use of the ratio does not afford a means of overcoming the difficulties caused by the overlapping of the Kubanka and intermediate and the intermediate and Polish classes when sorted on a glume length basis. Indeed, the overlapping would be emphasized and increased by the use of the ratio, because the mean values for the parental types lie closer together on a unit scale for ratio value, than they do on a unit scale for glume length. The average value of the mean glume length for Polish wheat (see Table X) is 29.2 mm. and for Kubanka wheat in Table XI is 11.6 mm. The corresponding values for the ratio are Polish .309 and Kubanka .195. With approximately the same coefficient of variability for glume length as for ratio, there would be greater overlapping in the latter than in the former case due to the relatively shorter distance separating the means on the unit or class interval scale for the respective calculations and measurements.

Apparently the only means of unmasking the effects of overlapping is to grow on the complete F_2 generation or at least such part as will include all the overlapping plants, and to reclassify the F_2 plants by the performance of their F_3 progeny. The use of the ratio has not justified itself in the particular instance. Whether similar negative results will be obtained in other instances where theoretical considerations can be argued in favor of the use of a ratio as opposed to absolute measurements remains a matter for investigation. Such results will depend upon the legitimacy of the ratio used in respect to the absolute measurement, and on the relative degree of separation of mean values of opposing ratios and opposing absolute measurements.

Comparative Variability of the Spikes of Single Plants of Pure Lines of Wheat as measured by Quantitative Characters.

In genetic experiments involving spike characters in the cereals it is a usual practice to select one spike, generally the largest or the first to be matured, as giving the full or typical expression of the various genetic factors concerned in the formation of the spike. It is an open question as to the validity of this practice, more especially in regard to pure line investigations. In other words, to what extent will the genetic classification of a plant be varied according as it is judged by the same character expression in its several spikes? Obviously each spike of a plant is the result of the interaction of the same factor complex; the result of the expression of the same individual factors; because each spike is only a part of the one soma. But the spikes of a plant do not all arise and develop simultaneously under identical conditions. They develop and mature at intervals under different climatic or ecological conditions, at different periods in the development and maturity of the plant, and with different food supplies. Unquestionably, therefore, different spikes of an individual plant will show different expressions of the same genetic factors. It is on these expressions as a basis that the plant is classified genetically, generally on one arbitrarily chosen set of expressions; so that the question of variability of expression is very pertinent.

At harvest in 1920 each plant of both varieties was harvested separately and every spike of a plant was harvested. Plants were sorted into groups according to the number of spikes which they had. Data was taken for all the spikes harvested. Thus, material was available for computing correlations between the different spikes of a plant in respect to glume length, rachis length and ratio of glume length to rachis length. The tables for these correlations in respect to spikes of plants which produced only two spikes are given in Tables XII, XIII, XIV, for Polish wheat, in Tables XV, XVI, XVII for Kubanka wheat. In respect to the first and third spikes of plants of Polish wheat which produced only three spikes, the correlations are given in Tables XVIII, XIX, XX, while data for similar plants of Kubanka wheat are not available. For comparative purposes the various coefficients of correlations are tabulated in Table XXI for two spike plants and in Table XXII for three spike plants.

Table XXI. Coefficients of correlation for various characters of Polish and Kubanka wheat in plants which produced only two spikes.

Variety	Character	Coefficient of Correlation
Polish	Glume length	.501 ± .0482
	Rachis length	.665 ± .0359
	Ratio	.512 ± .0474
Kubanka	Glume length	.599 ± .0418
	Rachis length	.659 ± .0369
	Ratio	.699 ± .0334

Table XXII. Coefficients of correlation for various characters of Polish wheat in plants which produced only three spikes

Variety	Character	Coefficient of Correlation
Polish	Glume length	.429 ± .0893
	Rachis length	.439 ± .0883
	Ratio	.428 ± .0894

In Table XXI the coefficients of correlation in every case are of much the same order and all very significant in relation to their respective probable errors. There is a tendency for the rachis lengths of the two spikes to

Table XII. Correlation between glume length of first spike and glume length of second spike in plants of Polish wheat which produced only two spikes.

Second spike. Class interval 2 mm.

First spike. Class interval 2 mm.

	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	Totals
21.5					1								1
23.5				1									1
25.5	1		1		1		2	1					6
27.5					2	2	5	3		1			13
29.5			1	1	3	4	10	4	1				24
31.5					2	6	11	18	6				43
33.5				1	1	2	4	2	1	4		1	16
35.5									3	1	2		6
Totals	1	0	2	3	10	14	32	28	11	6	2	1	110

Glume length, first spike.
Mean 30.6 ± .17 mm.
Standard deviation 2.62 ± .119 mm.

Glume length, second spike.
Mean 25.9 ± .22 mm.
Standard deviation 3.45 ± .157 mm.

$r = .501 \pm .0482$

Table XIII. Correlation between rachis length of first spike and rachis length of second spike in plants of Polish wheat with two spikes.

Second spike. Class interval 7 mm.

First spike. Class interval 7 mm.

	56	63	70	77	84	91	98	105	112	119	126	133	140	Totals
56	1													1
63														0
70	1													1
77		1												1
84	2	1		2										5
91				3				1						4
98		1		2			1							4
105		1				2								3
112	1	2	1	3	2	3	4							16
119				3	5	5	5	4		1		1		24
126		2	1	1	3	5	4	4	3	1				24
133			1	1	1	1	2	3	5	3	1			18
140									2	1	2	2	1	8
147											1			1
Totals	5	8	3	15	11	16	16	12	10	6	4	3	1	110

Rachis length, first spike.
Mean 118.4 ± 1.05 mm.
Standard deviation 16.38 ± .745 mm.

Rachis length, second spike.
Mean 93.0 ± 1.25 mm.
Standard deviation 19.44 ± .884 mm.

$r = .665 \pm .0359$

Table XIV. Correlation between ratio of glume length to rachis length of first spike and ratio of glume length to rachis length of second spike in plants of Polish wheat which produced only two spikes.

Second spike. Class interval .015

First spike. Class interval .015

	.215	.230	.245	.260	.275	.290	.305	.320	.335	.350	.365	.380	.395	.410	.425	.440	.455	Totals
.215		1		1														2
.230		1	7	2	1													11
.245	1	1	5	10	10	3	2		2			1						35
.260	1		8	3	8	4	1		3		3	1						32
.275					2	2	2	1	3		1	1			1			13
.290						1		1	1		1							4
.305				1			2	3									1	7
.320						1												1
.335					1						2							3
.350									1									1
.365																		0
.380																		0
.395										1								1
Totals	2	3	20	17	22	11	7	5	10	1	7	3	0	0	1	0	1	110

Ratio, first spike.
Mean .2618 ± .00182
Standard deviation .02835 ± .00129

Ratio, second spike.
Mean .2881 ± .00288
Standard deviation .04486 ± .00204

$r = .512 \pm .0474$

Table XV. Correlation between glume length of first spike and glume length of second spike in plants of Kubanka wheat which produced only two spikes.

Second spike. Class interval 1 mm.

First spike. Class interval 1 mm.	8	9	10	11	12	13	Totals
9	1	2	1				4
10		1	6	1			8
11	1	1	15	10	1		28
12		1	7	23	15	3	49
13			1	9	5	2	17
14					1		1
Totals	2	5	30	43	22	5	107

Glume length, first spike.
Mean 11.7 ± .06 mm.
Standard deviation .99 ± .045 mm.

Glume length, second spike.
Mean 10.9 ± .07 mm.
Standard deviation 1.01 ± .047 mm.

$r = .599 \pm .0418$

Table XVI. Correlation between rachis length of first spike and rachis length of second spike in plants of Kubanka wheat which produced only two spikes.

Second spike. Class interval 7 mm.

First spike. Class interval 7 mm.	28	35	42	49	56	63	70	77	84	Totals
28		1								1
35		1								1
42		1	2							3
49		2	6							8
56		1	2	1	1					5
63		1	5	1	8	1	1			17
70	1		1	5	17	8	1	1		34
77			4	3	4	7	6	1	1	26
84				1	1	3	3	2	1	11
91							1			1
Totals	1	7	20	11	31	19	12	4	2	107

Rachis length, first spike.
Mean 68.5 ± .75 mm.
Standard deviation 11.56 ± .533 mm.

Rachis length, second spike.
Mean 55.2 ± .77 mm.
Standard deviation 11.79 ± .544 mm.

r - .659 ± .0369

Table XVII. Correlation between ratio of glume length to rachis length of first spike and ratio of glume length to rachis length of second spike in plants of Kubanka wheat which produced only two spikes.

Second spike. Class interval .015

First spike. Class interval .015	.140	.155	.170	.185	.200	.215	.230	.245	.260	.275	.290	.305	.320	.335	Totals
.140		1	2	3											6
.155	2	1	13	6	4	3	1		1	1					32
.170		2	5	14	8	4	1			1	1		1		37
.185				2	4	1	3	3	1	1					15
.200			1		1	1	1		3						7
.215								1		1	1				3
.230										1				1	2
.245									1		1	1			3
.260															0
.275							1								1
.290								1							1
Totals	2	4	21	25	17	9	7	5	6	5	3	1	1	1	107

Ratio, first spike.
Mean .1745 ± .00143
Standard deviation .02196 ± .00101

Ratio, second spike.
Mean .2059 ± .00261
Standard deviation .04011 ± .00185

r = .699 ± .0334

Table XVIII. Correlation between glume length of first spike and glume length of third spike in plants of Polish wheat which produced only three spikes.

Third Spike. Class interval 2 mm.

First spike. Class interval 2 mm.

	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	Totals
21.5						1						1
23.5					1							1
25.5					1							1
27.5				1	1	1	1					4
29.5	1				2	3	1					7
31.5					2		4	3	1			10
33.5	1					2	1	1	1	1	1	8
35.5					1					2		3
37.5								3				3
Totals	2	0	0	1	8	7	7	7	2	3	1	38

Glume length, first spike.
Mean 31.3 ± .39 mm.
Standard deviation 3.55 ± .275 mm.

Glume length, third spike.
Mean 26.8 ± .47 mm.
Standard deviation 4.26 ± .330 mm.

r = .429 ± .0893

Table XIX. Correlation between rachis length of first spike and rachis length of third spike in plants of Polish wheat which produced only three spikes.

Third spike. Class interval 7 mm.

First spike. Class interval 7 mm.	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147	154	Totals
77				1													1
84																	0
91				1													1
98																	0
105	1							1									2
112					1	1											2
119							3										3
126					1		1	1	3			1					7
133							3	3		2							8
140		1	1							1	1	2					6
147									1	1				1		1	4
154						1											1
161					1				1	1							3
Totals	1	1	1	2	3	2	7	5	5	5	1	3	0	1	0	1	38

Rachis length, first spike.
Mean 130.8 ± 1.94 mm.
Standard deviation 17.75 ± .1.373 mm.

Rachis length, third spike.
Mean 97.6 ± 2.38 mm.
Standard deviation 21.72 ± 1.680 mm.

r = .439 ± .0883

Table XX. Correlation between ratio of glume length to rachis length of first spike and ratio of glume length to rachis length of third spike in plants of Polish wheat which produced only three spikes.

Third spike. Class interval .015

First spike. Class interval .015	.230	.245	.260	.275	.290	.305	.320	.335	.350	.365	.380	.395	.410	.425	Totals
.215	1		1			1									3
.230	1	7	3	1	2	1								1	16
.245		3	1	2	1	1	1		1						10
.260			2		1		1								4
.275					1	1		1							3
.290											1				1
.305							1								1
Totals	2	10	7	3	5	4	3	1	1	0	1	0	0	1	38

Ratio, first spike.
Mean .2430 ± .02188
Standard deviation .02012 ± .01547

Ratio, third spike.
Mean .2809 ± .04589
Standard deviation .04194 ± .00324

r = .428 ± .0894

show a higher correlation than the glume length, but only in Polish wheat has the difference any significance in relation to its probable error. In Table XXII the correlations between the first and third spike are consistently lower than those shown in Table XXI for two spike plants. This is to be expected, as there is naturally more differences between the first and third spikes than between the first and second spikes, owing to greater disparity in time of development and ripening.

These correlations ranging from .4 to .7 are not high enough to give any basis for a practice of indiscriminate selection of one spike as representative of a plant in regard to a particular character. The correlations are undoubtedly lowered by the deliberate inclusion of all plants which produced only two or three spikes in their respective classes, provided all the spikes were fully formed, ripe, and grain bearing at the time of harvest. No plants were eliminated from their proper class because the smaller spikes (second or third) were so small in comparison to the first that they would never be selected under normal circumstances as representative of the plant on which they grew. Nevertheless, the actual correlation tables show that while the average value for glume length and rachis length are considerably lower for second and third spikes than for corresponding first spikes, as would be expected, yet the actual distribution in respect to the average is substantially the same for all comparable populations. In no case is there an abnormal number of poorly developed second or third spikes causing lack of smoothness at the lower extreme of the frequency curve.

From the high correlation between glume length and rachis length of the same spike indicated in Table IX it would be expected that when the second or third spike of a plant showed a marked decrease in rachis length compared to the first spike there would be a proportionate decrease in the glume length. In such a case the ratio of glume length to rachis length would be approximateshow a higher correlation than the glume length, but only in Polish wheat has the difference any significance in relation to its probable error. In Table XXII the correlations between the first and third spike are consistently lower than those shown in Table XXI for two spike plants. This is to be expected, as there is naturally more differences between the first and third spikes than between the first and second spikes, owing to greater disparity in time of development and ripening.

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Table XXI abd XXII show, however, that contrary to expectation there is approximately the same amount of correlation between different spikes of a plant in respect to the ratios as there is in respect to the actual glume lengths and rachis lengths. Again it can only be said that the actual amount of correlation between glume length and rachis length while high,is not sufficiently so to give the practical value to the use of the ratio that can be adduced theoretically.

Therefore, studies of the correlation between the different spikes of a plant in respect to three quantitative studies indicate that when one spike is taken as typical of a plant, all plants should be treated alike, and either the largest spike or that first ripened should be selected in every case where there is any appreciable difference between the spikes of any plant. Indiscriminate selection of a spike as typical of a plant must cause errors in the investigation of quantitative characters, that will vary in degree with the amount of difference between the various spikes of a plant.

The Effect of Weight of Seed Planted upon Quantitative Characters in the Resultant Plants.

The effect of weight of seed planted upon the glume length, rachis length and ratio of glume length to rachis length of the resultant plants was determined by direct correlation. For this purpose the plants of both Polish and Kubanka wheat grown in 1920 were grouped according to the number of spikes on the plant. In each variety the group made up of plants with a single spike was used for the correlation studies in order to make the plants within the population more comparable, by excluding any effect on other plant characters that might be due to the production of more than one spike per plant. For these single spike plants the correlations between weight of seed planted on the one hand and glume length, rachis length and ratio on the other hand are shown in Tables XXIII, XXIV, and XXV respectively for Polish wheat and in Tables XXVI, XXVII and XXVIII respectively for Kubanka wheat. The coefficients of correlation are tabulated for comparison in Table XXIX.

Table XXIX. Coefficients of correlation between weight of seed planted and various characters of the resultant plants of Polish and Kubanka wheat which produced only one spike.

Variety	Population	Character compared with weight of seed planted	Coefficient of correlation
Polish	316 plants which produced only a single spike	Glume length	.065 ± .0378
		Rachis length	.043 ± .0379
		Ratio	.000 ± .0379
Kubanka	205 plants which produced only a single spike	Glume length	.262 ± .0439
		Rachis length	.157 ± .0460
		Ratio	.003 ± .0471

For Polish wheat there is no relation at all between the weight of seed planted and any of the three spike characters of the resultant plants that were investigated. For Kubanka wheat there is likewise no correlation so far as the ratio is concerned. In regard to glume length a correlation of .262 ±.0439 is significant in regard to its probable error. The chances are 19230 to 1 that the correlation between weight of seed planted and glume length is significant. The correlation for rachis length, .157 ± .046 is also significant in regard to its probable error, for there are 45 chances to 1 that the correlation between weight of seed planted and rachis length is significant. Nevertheless, these

Table XXIII. Correlation between weight of seed planted and glume length of resultant plants of Polish wheat which produced only a single spike.

Glume length. Class interval 2 mm.

Weight of seed planted. Class interval 3 mg.	9.5	11.5	13.5	15.5	17.5	19.5	21.5	23.5	25.5	27.5	29.5	31.5	33.5	35.5	Totals
21								1							1
24											1				1
27									2						2
30											1				1
33					2			2	3	1	1	2			11
36							2	1	2	1	3				9
39			1			1	1		2	2	6		1		14
42							2	4	2	1	8	2	2		21
45			1			1	3	3	2	4	3		1	1	19
48				1	1	3	6	4	2	8	2	3	1		31
51		1						2	4	6	5	1	1		20
54				1		1	2	2	2	3	4	3	1		19
57	1					1	3	7	6	4	3	1	1	2	29
60			1					2	2	3	2	6	1		17
63	1			1	1	1	1	2	7	5	8	6	3		36
66				1		2	1	2	9	2	2	8	2		29
69						2	1	3	3	5	4	1			19
72						1	2	2	3	6	4	3	2		23
75						2	2		2	1		2			9
78									2	1		1			4
81													1		1
Totals	2	1	3	4	4	15	26	37	55	53	57	39	17	3	316

Weight of seed planted.
Mean 55.5 ± .46 mg.
Standard deviation 12.17 ± .327 mg.

Glume length.
Mean 26.5 ± .17 mm.
Standard deviation 4.54 ± .122 mm.

r = .065 ± .0378

Table XXIV. Correlation between weight of seed planted and rachis length of resultant plants of Polish wheat which produced only a single spike.

Rachis length. Class interval 7 mm.

Weight of seed planted. Class interval 3 mg.

	21	28	35	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	Totals
21										1									1
24													1						1
27											1		1						2
30															1				1
33				1	1			2	1	1	2	1	1	1					11
36					1		1		1	1	1			3		1			9
39				1	1			1		2		2	6			1			14
42							1	2	1	2	2	2	5	2	2		1	1	21
45				1	1			2	1	2	5		3	1	1	1		1	19
48				3	1	2	2	5	2	5	1	1	3	3	1	2			31
51				1			1	1	1	1	4	4	4	1		1	1		20
54				2				4	1			3	2	3	1	1	2		19
57				1		1	1	7	3	2	4	3	3		1	1	1	1	29
60					1				2	1	3	1	2	1	4	1		1	17
63	1		1			1	1	2	3		5	7	4	5	4	1	1		36
66					1	2		3	3	3	1	3	4	3	3	2	1		29
69				2		1		1	6		1	1	3	2	1		1		19
72			1		1		1			2	7		4	2	2	2		1	23
75						3	1			1		2		1	1				9
78										1	1	1		1					4
81																	1		1
Totals	1	0	.2	12	8	10	9	30	25	25	38	31	46	29	22	14	9	5	316

Weight of seed planted.
Mean 55.5 ± .46 mg.
Standard deviation 12.17 ± .327 mg.

Rachis length.
Mean 92.1 ± .90 mm.
Standard deviation 23.73 ± .637 mm.

r =.043 ± .0379

Table XXV. Correlation between weight of seed planted and ratio of glume length to rachis length of resultant plants of Polish wheat which produced only a single spike.

Ratio. Class interval .015

Weight of seed planted. Class interval 5 mg.	.230	.245	.260	.275	.290	.305	.320	.335	.350	.365	.380	.395	.410	.425	.440	.455	.470	.485	.500	.515	.530	.545	Totals
21					1																		1
24						1																	1
27		1		1																			2
30			1																				1
33				1	4	1	2	2					1										11
36	1	1	1	2		1		1	1		1												9
39				5	4	4						1											14
42		3	3	4	3	6	1			1													21
45		2	5	3	3	1	2	1	1		1												19
48		2	1	6	5	3	2	5	1	1	1	2	1			1							31
51		1	4	5	5	1	1	1	1		1												20
54	1	2	3	5	1	2	2				2						1						19
57		3	3	4	3	9	4	1	1			1											29
60		1	4	5	3	2	2																17
63		4	5	6	9	4	2	3		1						1		1					36
66		1	5	9	2	4	3	1	1	1	2												29
69	1	3	2	1	1	2	2	2	2	1						1						1	19
72	1	1	6	3	4	3	2		1				1							1			23
75			1	2	1	1	1			2	1												9
78		1	1			2																	4
81		1																					1
Totals	4	27	45	62	49	47	26	17	9	7	9	4	3	0	0	3	1	1	0	1	0	1	316

Weight of seed planted.

Mean 55.5 ± .46 mg.

Standard deviation 12.17 ± .327 mg.

Ratio.

Mean .2980 ± .00175

Standard deviation .04609 ± .00124

$r = .000 \pm .0379$

Table XXVI. Correlation between weight of seed planted and glume length of resultant plants of Kubanka wheat which produced only a single spike.

Glume length. Class interval 1 mm.

Weight of seed planted. Class interval 3 mg.	8	9	10	11	12	13	Totals
12			1				1
15	1		1		1		3
18			2				2
21			3	2	1		6
24		1	4	4	1		10
27		3	6	2	7		18
30		4	4	6	7		21
33	1	2	3	7	4		17
36		1	4	5	2	3	15
39		3	4	9	5	2	23
42		1	5	5	2	2	15
45		4	1	7	8	1	21
48				4	3		7
51			6	6	2		14
54			4	4	3	1	12
57			1	3	3	2	9
60					4		4
63					2		2
66						1	1
69				1	1		2
72		1				1	2
Totals	2	20	49	65	56	13	205

Weight of seed planted.
Mean 39.4 ± .56 mg.
Standard deviation 11.95 ± .398 mg.

Glume length.
Mean 10.9 ± .05 mm.
Standard deviation 1.11 ± .037 mm.

r = .262 ± .0439

Table XXVII. Correlation between weight of seed planted and rachis length of resultant plants of Kubanka wheat which produced only a single spike.

Rachis length. Class interval 7 mm.

Weight of seed planted. Class interval 3 mg.

	28	35	42	49	56	63	70	77	84	91	Totals
12				1							1
15			1		1		1				3
18				2							2
21			1	1	2	2					6
24				5	1	2	2				10
27	1		4	4	1	3	4	1			18
30		1	2	3	7	5	3				21
33	1	3	2		2	5	2	2			17
36			2	3	2	4	3	1			15
39			3	3	2	8	6		1		23
42				4	4	3	2	2			15
45	1	1	1	2	3	7	5		1		21
48		1			2	3	1				7
51		1		3	7	1	1	1			14
54		2		2	2	2	2	2			12
57				2	2	2	2	1			9
60			1	2			1				4
63							1	1			2
66										1	1
69						1	1				2
72		1						1			2
Totals	3	10	17	37	38	48	37	12	2	1	205

Weight of seed planted.
Mean 39.4 ± .56 mg.
Standard deviation 11.95 ± .398 mg.

Rachis length.
Mean 58.0 ± .56 mm.
Standard deviation 11.85 ± .395 mm.

r = .157 ± .0460

Table XXVIII. Correlation between weight of seed planted and ratio of glume length to rachis length of resultant plants of Kubanka wheat which produced only a single spike.

Weight of seed planted. Class interval 3 mg.	.110	.125	.140	.155	.170	.185	.200	.215	.230	.245	.260	.275	.290	.305	.320	.335	.350	Totals
	Ratio. Class interval .015																	
12									1									1
15					1	1	1											3
18							2											2
21					1	2	2		1									6
24				1	3		3	3										10
27				1	5	2	2	4	1	2							1	18
30				1	5	4	7	1		1	1	1						21
33				3	5	3			2		1	1	1			1		17
36					4	5	1	3	2									15
39				2	5	8	4	3	1									23
42				2	2	8	1		2									15
45				3	3	7	4	2				1		1				21
48					3	2		1							1			7
51				1	2	3	6	1					1					14
54	1			1	4	2	1		1				2					12
57				1	1	2	2	1	2									9
60						1				1	1		1					4
63				1	1													2
66				1														1
69					2													2
72				1									1					2
Totals	1	0	0	19	47	50	36	19	13	4	3	3	6	1	1	1	1	205

Weight of seed planted.
Mean 39.4 ± .56 mg.
Standard deviation 11.95 ± .398 mg.

Ratio.
Mean .1961 ± .00169
Standard deviation .03585 ± .001194
r = .003 ± .0471

correlations are not sufficiently high to be of great importance. They perhaps represent one of those small seasonal fluctuations in the effect of weight of seed planted which are in some respects the most outstanding feature of all studies of the effect of seed characters upon the resulting crop.

Weight of seed planted has then no appreciable influence in Polish and Kubanka wheat on the final degree of development to which the resulting plants reach so far as can be measured with glume length and rachis length as the criteria. The hypothesis advanced by Engledow (5) explaining the shift in glume length in F_2 parental types in crosses involving these identical pure lines as due to the weight of seed planted is not supported in any way by this experiment. In Polish wheat which showed a greater shift than Kubanka there is less evidence of the effect of weight of seed planted than there is in the latter variety, indeed there is strong evidence that weight of seed planted has no effect on glume length.

Furthermore, the results go to show that so called predetermining influences operating through the germinating seedlings do not impress themselves on the mature plant to such a degree as to appreciably mask or distort the effects of genetic factors. In individual plants such effects of predeterming influences can undoubtedly be found under certain conditions. All experiments, however, that have been conducted with a sufficiently large population to allow statistical analyses of the results have furnished evidence contrary to the belief in the constant importance of these influences.

Summary

1. Pure lines of Polish wheat (*T. polonicum*) and Kubanka wheat (*T. durum*) were obtained, and all the kernels from one spike of forty plants from each variety were weighed and planted separately. The progeny of each seed was measured for maximum glume length and rachis length of each spike. The ratio of glume length to rachis length was calculated for every such spike.

2. Studies of the comparative variability in Polish and Kubanka wheats of glume length, rachis length and ratio of glume length to rachis length showed that glume length is the least variable of these three spike characters. The coefficient of variability was used as the measure of comparative variability.

3. Coefficients of correlation were calculated between the spikes of plants which produced only two and only three spikes. The spikes were compared, and the calculations made for glume length, rachis length and ratio of glume length to rachis length. Coefficients ranging from .4 to .7 were obtained. These are not high enough to give a basis for the indiscriminate selection of any one of the spikes produced by a plant as typical of the plant in respect to these quantitative characters. In cases where one spike is taken as typical of a plant, all plants should be treated alike, and either the largest spike or that first ripened should be selected from each.

4. The effect of weight of seed planted upon the glume length, rachis length, and ratio of glume length to rachis length of the resultant plants was determined by direct correlation. No effect was observed for Polish wheat. In Kubanka wheat coefficients of .262 ± .0439 and .157 ± .0460 were obtained for glume length and rachis length respectively. These correlations are not sufficiently high to be of great importance.

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