STUDIES OF INHERITANCE
OF SHAPE IN BEANS

THESIS FOR DEGREE OF M. S.

WILLIAM KIA-SHEN SIE.

1917

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Plant-breeding

Farm crops

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ACKNOWLEDGMENT.

Upon the completion of his graduate work in Plant Breeding, the writer wishes to take this opportunity to express his sincere thanks to Professor F. A. Spragg, Expert in Plant Breeding, at the Michigan Agricultural College, for his patient teaching and for his criticism of this thesis.

CONTENTS.

INTRODUCTION.

As the knowledge of heredity is one of the principal developments of the agricultural plant breeding it is very important to investigate the influence of characteristics that are transmitted from generation to generation upon plant breeding practice. At the present time prominent investigators have and are doing considerable work upon the foundations of modern plant and animal breedings. Their investigations include quality, quantity, color, size, and last, but not least, shape. Ever since the breeders have given their attention to agricultural problems the inheritance of size and shape has been much neglected because the investigator had many easier problems at hand, and because his interests have only lately been called to these fields.

In the fall of 1914, Mr. P. K. Fu began an investigation of the inheritance of size and shape in beans. He found the problem too large for the season of 1915 and he was not able to cover the scope of my investigation. I am using his seed to lay the foundation for a study of the inheritance of shape in beans. Perhaps another may extend this investigation.

LITERATURE.

The references to Drs. Emerson, Belling, and Johannsen are copied from Mr. Fu's thesis. To this I have added a review of the literature on methods of studying shape, though none of it is upon beans.

Professor E. A. Emerson did much work on the inheritance of color in the seed coat of beans when he was connected with the Nebraska Experiment Station. In his work with bean crosses, he found that all the racial crosses of beans produced, show little variation in the first generation, but pronounced variation in the second and third generations. Under selection, they appeared fairly well fixed in the fourth and fifth generations. The characters of the two parents (atavistic tendencies) were usually reproduced among the offspring of the second or third generation though often the new tendencies were noticeable. Characters different from the parent forms were usually blends in the crosses or united unchanged in mosaics of small or large pattern.

In the study of size and shape in beans, he made numerous crosses between Fillbasket Wax having long flat seeds, Longfellow having long slender seeds, and Snowflake Navy having small round seeds. He then determined the mean, the coefficient of variability for each of their lengths, weights, breadths and thicknesses. He observed that in the first generation, the mean and the coefficient of variability were not materially greater than for parents, but in the second generation, individuals exhibited marked segregation of size and shape. From this, he concluded that "Shape may be definitely inherited. Observations of the second generation bean seeds where the parents differ in size but not in shape indicate that length and breadth are probably not inherited independently of each other. Large round beans crossed with small round ones do not give any long slender beans in the second generation, but only large medium and small round ones. On the other hand, when the parents differ in shape as well as in size, intermediate and parental shape as well as intermediate and parental dimensions occur in the second generation."

Mr. J. Belling, Assistant Botanist of the Florida Experiment Station in an attempt to secure a hybrid that would combine the thin unopening hull of the Velvet bean with the Lyon Beans' smooth pods which do not have the objectional irritating bristles, has also studied the standard deviation and coefficient of variability of the length, breadth, thickness and weight, also the correlation of length and breadth and thickness of the F_2 crosses between the Lyon and Velvet beans. He measured from 50 to 200 seeds of each of his 118 plants and found that they varied between 10.5 and 20.05 mm. in length, and from 8.3 to 13.55 mm. in breadth. In his study of the weights of these seeds, he found that they varied from .5 to 1.9 gm. He then concluded that, "The close agreement of the length and breadth of the hybrid seeds with those of the Lyon beans and of the thickness that of the Velvet may possibly be genetic or may be due to special conditions of growth." However, he did not investigate the size and shape of beans in general.

W. Johannsen worked with the weights of beans and found his pure line theory. He weighed the seeds of a single variety of beans and planted them separately. They arranged themselves in a normal curve round the weight of greatest frequency where the seeds from the individual plants were harvested separately. The crop from each individual again could be grouped according to their weights in normal curve round the most frequent weight characteristic of each individual. Thus, there was a rough correspondence between the modes for the individual plants and the weights of the individual seeds from which they sprang. The heavier strains on the whole come from the heavier seeds and the lighter from the lighter seeds. But when he selected the heavier and lighter seeds from a single strain and planted them separately, he found that the modal weights were approximately the same for the produce of both the heavier and the lighter seeds. This indicates that selection inside the strain raised from a single seed eos not alter the modal weight, i. e., the product of the two selections are the same genetically.

To sum up, it may be said that none of these investigators have told us what sizes are separately inherited, nor the number of inherited factors involved.

Johannsen has shown that there are such factors, because the progeny of homozygous beans belonging to slightly different sizes maintain separate means, and do not regress to the mean of all sizes of beans.

Emerson has shown that length and width are not inherited separately, but together as inheritance of sizes of the same shape. Variations in the inheritance of shape, he finds, occur only when the parents differ in shape.

Groth (N. J. Report 1911) has made a large number of tomato crosses, for example, "Currant upon Ponderosa" and "Plum upon Peach" and followed the offspring for several generations. His measurements of shape are the quotient of the measurements for length and width and are illustrated by the symbol L/W=C. In his summary we find the following: "In the F_2 the variation in size and shape are caused by the interaction of size and shape factors." "The dependence of the F_2 frequency distribution on that of F_1 is much greater than its dependence upon the frequency distributions of the parents." A close study of the pictures (in bulletin) of the parents and their F_2, somatically speaking, shows the segregation of the F_2 into the grandparental types, and their combinations of characteristics.

Professor Halsted (N. J. Report 1910) and his associates made crosses in peppers and secured one of considerable interest, namely: Black Nubian with Coral Gem. From this cross 42 plants were grown in F_2. Measurements of length and width of leaves and fruits were given in an accompanying table, but the authors did not enter into any statistical dessication of

this data. For this reason I have calculated the quotients between the length and width of each leaf and fruit, and obtained the average (mean) in each case. These determinations for shape are compared with the parents. The means for shape of the leaves and the fruits of F_1 were 2.143 and 3.250 respectively. In F_2 the leaves varied from 1.7 to 4.3. A study of the results shows that the F_2 segregation (and therefore variation) is considerably greater than the F_1, but an F_3 is needed to separate the segregating types from one another. In the report of 1913 the same authors secured similar results from many varieties of F_2 peppers.

East (Genetics, 1916, pp. 164-176) has recently presented some data on the length of Corolla in a cross between two varieties of tobacco (Nicotiana Longiflora Cav.). Upon a close study of the data it was found that the F_2 population was twice as variable as the F_1 and reached the extremes maintained by the grandparents.

Drs. Emerson and East (Nebr. Research Bulletin 42) made three crosses of distinct varieties of maize, and in their summary stated that "in every case the F_2 fraternities were more variable than the F_1 lots. In most cases the F_2's completely bridged the gap between the parents and in one case the F_2 range of variation was from practically the shortest ears of the short-eared parent to beyond the longest ears of the long-eared parent."

The results of the above experiments show that the F_2 is more variable than F_1 and usually includes the extreme of the grand-parental shape.

THE PROBLEM.

As can be seen from Mr. Fu's thesis, he concluded (page 28 of his thesis) that his data on the inheritance of shape is defective. In the original crosses, the kidneys were dominant over navies, and the extracted navies gave only navies, yet several exceptions were observed in later segregations, indicating no dominance. His material is being further investigated to get greater light along this line, and also to discover the factors involved in this inheritance.

SOURCES OF MATERIAL.

From among the bean accessions that have been gathered by the Michigan Experiment Station, Mr. Fu has listed eighteen original numbers and four natural crosses from which his material was drawn. The story of the origin of these crosses and their care up to fall of 1914 when he made the plant-selections entering into his work has already been fully told by him. He gathered all of the plants ripening satisfactorily in 1915, gave them plant numbers, threshed them individually and stored them in envelops in tin boxes away from the mice.

As each envelop contained the seeds from an individual plant, there were as many envelops for each plat or progeny as there were plants represented. In the search for heterzygous material in regard to shape, i. e., for plats of 1915 containing plants, some having navy seed, some intermediate and some kidney seed, the envelops were sorted into three piles, the one navy, another intermediate, and a third kidney. It is true that this is a

rough classification but served a purpose of observation and comparison. Those lots that fell only into one of these groups were not usable.

When the 1915 plats had thus been examined it was discovered that all of the plats showing satisfactory segregation had come from two of Mr. Fu's groups, namely, accession 61 (one of the 18 accessions) and the $\frac{\text{Navy}}{\text{Red Kidney}}$ cross (one of the four natural crosses.) This means that all of the other lines failed to furnish data in this investigation.

From among these lots, the plats showing the largest number of productive plants were chosen, and the highest producers of each lot were taken, because if we are to get reliable statistical constants for each lot, we must have a reasonably large number. However, certain envelops were discarded because of the presence of too much disease, and in the chosen lots the diseased individual beans were also discarded. Thus the most productive and the healthiest beans were chosen from among those lots that gave the most promising segregations.

METHOD OF MEASUREMENTS.

Taking a piece of cross-section paper divided into half inch squares and each square into tenths, the distances between the lines (1/20 inch) were taken as units of measurement. The length and width and the quotient or ratio between these measurements were obtained for each bean. This ratio represents the shape of the beans and is often indicated by the symbol L/W =S (or Length/Width=Shape.) The smaller the quotient,

the rounder the beans, and the greater the whotient, the longer the beans. Because the beans were small it was necessary to take a small unit of measure, in order to get a reasonably correct ratio between length and width. Thus after some consideration the one-twentieth inch was chosen as a convenient measure.

A question of how to measure naturally arose. The measurements were taken by means of the aboe mentioned cross-section paper, which was fixed upon a table. Besides this, there were two thin straight narrow sticks with smooth faces nailed (perpendicularly to one another) along the lines of the cross-section paper from which the measurements were counted; that is, one stick was placed close to a line of the cross-section paper longitudinally and another was placed in contact with the longitudinal stick close to a line of the cross-section paper transversely. Then a bean was measured by being placed in the wooden square in contact with the sticks, and upon the paper, the number of longitudinal lines being length, and a number of transversal lines being width. This method for measurement was used in all work.

It was usually found that the beans did not measure exact units. Fractions of more than half a division were considered a whole division, and if less than half a division were discarded. Judging the fractions and counting the lines needed careful observation.

The measurements of the beans were tabulated in three columns, i e., length, width and shape; however, the lengths and widths were recorded before the ratios between them were obtained.

STATISTICAL METHOD.

The beans were next classified according to their shapes, placed on sheets for the study of variation and calculations for statistical constants were executed for each envelop (that is, the seeds obtained from one plant). The calculations were for mean, standard deviation and coefficient of variability of shape.

PLANTING.

The seeds were planted during the first week of June, when the weather became quite warm. It was planted on a piece of sandy soil south of the orchard near the east line of the College farm and not far from the river. The lay of the land was as flat as could be found. The land was well worked. Under these conditions the plants had nearly an equal opportunity to develop.

About 200 plants had been carefully chosen from the 1915 material. Each plant had a selection number as well as a plat number recorded on a stake which was set up at the beginning of each row. The system was that in regular use by the Michigan Experiment Station and consisted of the following items: the register number, the selection number and the accession number. These were written in the above order on a card which was paraffined and tacked to a stake.

We feared to use a drill because the lots of beans were small and varied so greatly in size as not to insure equally distant planting. The desire was that the seed may be so planted that each plant may have the same amount of space. The land was marked off, that the rows may be straight and equal distance, and that the recently mellowed soil may be grooved. The seeds were dropped in these grooves, setting up the stake first at the beginning of the lot of beans and leaving gap of two or three feet before planting another lot of beans.

The envelops had the same number as the stakes. The stakes were always set up before the seeds were planted, by taking care to check up these numbers before each planting. I made sure that no lots of beans were misplaced. The individual plats were planted in the same order as the selection number given. The plats from 60100 to 614200 were progenies belonging to work planned by Prof. F. A. Spragg. The plats from 614300 to 630000 were those belonging to my thesis.

TABLE A.

Data on Shape of Seed Planted.

(Only productive plats are listed.)

Plat 1916	Plant 1915	Accession	Statistical Data N.	M.	C.	No. of plants Obtained in summer	Harvested in fall
614700	54021	$\frac{n}{2}$	131	1.432±.008	9.49±.39	76	20
615300	53205	"	40	1.508±.012	7.86±.59	32	8
615700	53211	"	162	1.676±.005	6.14±.23	119	22
617300	514214	61	29	1.119±.009	6.66±.59	23	16
619400	514516	61	24	1.106±.009	6.05±.59	22	13
619900	514618	61	18	1.601±.019	7.71±.86	13	7
620000	52630	$\frac{n}{2}$	85	1.436±.009	9.04±.47	72	12
620400	52605	"	65	1.395±.001	9.74±.57	51	15
621800	53817	"	51	1.351±.001	8.98±.59	41	15
624300	54322	"	151	1.151±.003	4.25±.16	95	71
627800	513002	"	67	1.428±.006	5.81±.34	41	14
629200	513109	"	58	1.215±.007	7.20±.45	26	16
629300	513114	"	45	1.241±.009	7.98±.56	30	17
629400	513102	"	169	1.390±.004	6.30±.23	111	31
629500	513105	"	67	1.351±.008	7.97±.46	32	13
629600	513120	"	71	1.271±.008	8.31±.47	37	28

A week or so after the seeds were planted the weather became suddenly cool and then it rained most of the remainder of the month. The germination was checked and also the growth. Approzimately 25 percent of the seeds thus failed to produce thrifty plants. This includes some sickly plants that were pulled out to prevent the spread of diseases.

During the growing season the plants were given personal care, being hoed and cultivated a number of times. When the plants were about six inches high the number of thrifty plants belonging to each plat were counted and recorded. The difference between this number and the number of the seeds that were planted showed how many failed in germination or became sickly. The remainder of the plants grew vigorously and were attractive looking, although they had passed through an unfavorable period.

In the first part of the growing season the field was soaked with water all the time and the sun seldom paid them a visit. This favored disease, but the sicklyones were pulled out, as mentioned above, in order to check the spread of disease.

Following the wet and cool June came a hot and dry July. The temperature climbed to 102.2 degrees daily during the blossoming period. Besides the heat, it was very dry, not giving two inches rainfall in the whole latter part of the season. Notes were taken in regard to the color of the flowers during the blossoming period, and recorded in the bean register. During the very hot days the flowers dropped off; the leaves turned yellow; a few undersized pods formed without beans; and the growth of some plants was stunted. However, this was the experience in nearly all the fields in Michigan and some other states, producing scarcity and the highest price in history.

HARVESTING.

Harvesting began September 20th. The plants were collected as soon as they were ripe. The foregoing description discourages hope for a good harvest. The harvesting of a few beans here and there was more trouble than harvesting plants full of beans. In some plats the plants yielded no beans at all. In other plats some plants gave one or two pods, thus being easily missed in collection.

Beginning with the first row the plats were examined in order. Plants with ripe pods were pulled, leaving those with green pods, and discarding sterile plants to save trouble with them later.

After pulling, the ripe plants belonging to each plat were tied in a bundle and labeled, indicating the plat number. The bundles were hung upon wires in the seed room in the order of the plat numbers. When dry, more notes were taken. Most of the green plants were frozen, and shriveled in the field, as it was too late to mature.

In the laboratory each plant was given a selection number beginning with one for each plat in accordance with the station's system, and the following notes were taken: the height of plant, the condition of disease, the number of pods, the length of pods, and the number of seeds. These were registered in the bean selection book. The seeds produced on each plant were threshed by hands, counted, and put in an envelop, writing selection number on the envelop to indicate the year planted, the plat number and the selection within the plat. The envelopes were arranged in the order of their numbers in tin boxes

to protect them from the mice. Thus when the work was done, all could be easily turned to.

In threshing it was found that some of the seeds were not naturally ripened. Such deformed or undersized seeds were discarded, and not counted. The seeds having mature shape were the only ones that were saved. It was necessary to eliminate the shriveled seeds in order to get accurate results, as deformed seeds would only deceive us in the study of inheritance of shape.

The plats were now studied systematically and grouped according to whether they had 10 to 24 seeds; 25 to 49 seeds; or 50 seeds and more. The plants producing fewer seeds were discarded. Most of the groups were at a disadvantage because of the limited number in their populations, but a few plants in each of the 15 plats produced quite well, and two plats were nearly normal in production.

TABLE B.

__Distribution of Individual Plants.__

(Based on mean of shape)

	No. of plants harvested with seed	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
614700	20					4	12	4	
615300	8				1	3	3	1	
615700	22					2	9	8	3
617300	16		3	2	6	2	3		
619400	13	3	4	4	2				
619900	7		1			2	3	1	
620000	12			8	3	1			
620400	15				2	2	6	3	2
621800	15			1	1	6	5	1	1
624300	71	5	9	11	15	18	6	2	5
627800	14			1	2	4	4	2	1
629200	16	3	5	5	3				
629300	17	2	3	5	5		2		
629400	31	1	2	5	12	3	5	2	1
629500	17	2	2	2	4	1	2		
629600	28		4	14	4	2	4		

There were 158 plats at planting time. Only sixteen of these produced enough seeds to give reliable results. These seeds were measured just as their mothers were, taking the length and width and then finding the ratio $\frac{L}{W}$ or shape. This determination is the measure of shape.

Table B gives the distribution of shape for the plants of each of the sixteen productive plats. The plants are classified according to the mean of shape, the shape being determined for each seed. Considerable variation may be noted among the plats, some having a much greater variability than others.

TABLE C.

	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
619400	3	4	4	2				
629200	3	5	5	3				
629300	2	3	5	5				

TABLE D.

	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
617300		3	2	6	2	3		
620000			8	3	1			
629500	2	2	2	4	1	2		
629600		4	14	4	2	4		

TABLE E.

	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
614700					4	12	4	
615300				1	3	3	1	
615700					2	9	8	3
619900		1			2	3	1	
620400				2	2	6	3	2
621800			1	1	6	5	1	1
627800			1	2	4	4	2	1

TABLE F.

624300	5	9	11	15	18	6	2	5
629400	1	2	5	12	3	5	2	1

Tables C, D, E, and F give different groups showing similar variabilities and indicate that each group has nearly a constant center of variation. A comparison of these groups shows that there is fairly definite segregation. Some groups have a limited range of variation, while others are extremely variable, probably due to a heterozygous condition.

As the two plats 624300 and 629400 (shown in Table F) are the most variable and also the most productive of the whole series, they are studied much more in detail The seeds that planted plat 624300 (as can be seen in Table A) was the least variable and almost the roundest beans that were listed; and the seeds that planted plat 629400 was about average in size and variability. Yet the offspring of these plats vary from very round (rounder than the ordinary navy) to excellent kidney types. It appears that the individual plant has a controlling influence on the shape of its seeds, the seed on a plant being reasonably constant.

TABLE G.

624300

Division 1.

Sel. No.	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
62	30	0	32								
63	20	0	38								
66	34	0	37								

Division 2.

3				5	1						
13			3	3	4						
20				5							
28			7	0	1						
46			11	0	1						
55			51	1	38						

Division 3.

4				1	6	2	2	1			
6				1	1	0	2				
10				2	1	1					
11				3	3	4	3				
12				3	1	1	7				
14				4	3	2	3				
15					1	3	2	1			
16					4	0	3	1			
17				6	6	3	5				
21				2	23	5	4	3			
23				7	13	5	10				

Division 4.

Selec. No.	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
24				1	24	0	17	3			
32				14	21	2	3				
61					1	14	0	23			
Division 5.											
59						29	0	26	1		
67				1	0	18	1	24	4		
Division 6.											
42									6	0	2
47								2	2	0	12
Division 7.											
37	3	0	30	0	5						
43	6	0	44	0	3						
44	3	0	20	0	2	1					
49	5	0	64	0	11						
51	3	0	22	0	1						
53	4	0	40	0	12	1					
57	27	0	32	0	1						
69	21	0	41	0	1						
70	39	0	40	0	1						

Division 8.

Selec. No.	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
7			2	14	8	1	5	1			
8			5	16	28	7	8				
9				6	1	2	0	1			
18			2	1	10	2	5				
22			2	3	15	4	6	2			
33			1	18	29	1	44				
35			6	11	38	7	37				
36			2	17	34	5	36				
38			5	14	47	2	23	4			
40			1	8	53	0	35				
45		1	3	24	19	3	4				
52			3	29	16	6	6				
54		1	27	56	6	3	1				
56		1	20	58	1	3	1				
64			26	9	21	0	1				
65		1	10	69	3	5	1	1			
71		2	26	54	5	4	1				
2			1	3	7	3	3	2			
60		1	16	45	2	0	4				

Division 9.

Selec. No.	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
5				1	7	2	7	0	1		
26					3	0	2	0	2		
58				2	1	21	2	22	2		
59						29	0	26	1		

Division 10.

19						3	1	18	15	0	8
29						3	0	4	8	0	4
39						7	1	27	18	0	13
68						12	2	25	6	0	1

Division 11.

25			1	5	8	4	1	0	1		
31			23	0	69	0	23	0	6		
34			3	7	57	0	12	0	2		
27				5	9	5	3	0	3		
48			6	30	37	7	22	0	1		
50			6	18	36	2	29	1	3		

Division 12.

41				3	4	10	19	38	29	0	28

TABLE H.

629400

Division 1.

Selec. No.	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
17	8	0	4								
19	2	1	8	1							
20	1	1	3	1							

Division 2.

2			2	7	1						
14			1	6	0	1					
18				4	1	2					
21			1	3							
24		3	4	16	2	14					
29				2	0	1					
31			1	6	0	5					
13				2	0	2	1				

Division 3.

5								3	1		
23							1	3			
25						2	0	3	1		
12						1	0	3			

Division 4

Selec. No.	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
1			1	5	0	1	1				
6				3	0	3	1				
7						2	0	4			
8			6	5	5	2	2	1			
9			2	2	0	0	1				
10				2	0	4	0	1			
11				2	0	0	1	1			
16			3	11	0	2	1	1			
22				5	0	1	0	1			
26			1	5	0	1	1				
27			1	1	0	2	1				
Division 5.											
28		1	2	7	0	6	2	1	1		
30		1	6	6	0	2	0	1			
Division 6.											
3				2	0	1	1	0	1	0	1
4				1	0	0	1	2	1	0	3
15						3	0	6	6	0	1

Tables G and H give the distribution of shape as determined for the individual seeds for each plant. Table G gives the data for plat 624300 and Table H for plat 629400. At the left of these tables will be found the selection numbers within the plats. The selection numbers are not in their numerical order, but are grouped so as to bring together the data for the plants having similar variability. These groups again indicate segregation of shape and variability. Some of the groups have narrow ranges of variation while others have a wide range of variation. The mothers have dominated the shape in the past generation. This should be studied another year to follow the segregation of the next generation; see how powerful the mother plants are in dominating shape, and find out how far it is possible to fix types. In other words, is there a certain basal probably environmental variability that is always present?

SUMMARY.

All plats show variability and some also show segregation, but variability does not definitely prove segregation.

There appears to be a dominance of shape held by theparent.

Certain shapes seem to be quite generally used as centers of variation, indicating segregation in certain populations, These are 1.2, 1.4, and 1.6. Perhaps there are other centers.

Plats 624300 and 629400 show a range from 1.1 to 1.8. These plats are extremely heterozygous, and are studied more fully in detail. Both of these plats come from the cross $\frac{\text{Navy}}{\text{Red Kidney}}$.

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