AN EXPERIMENTAL STUDY OF HYBRID VIGOR OR HETEROSIS IN RATS[1]

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INTRODUCTION

A review of the literature of both plant and animal hybridization shows that increased vigor of growth and reproduction usually accompanies hybridization although it is by no means a universal phenomenon. The term hybridization is here used as it is commonly employed by students of genetics rather than in the restricted sense sometimes ascribed to it in systematics. It applies to any cross between individuals of different genetic constitution, whether or not they belong to different Linnean species, or merely to different varieties, breeds or families of the same species.

HYPOTHESES ADVANCED AS AN EXPLANATION OF HYBRID VIGOR

The fact that the early plant and animal hybridizers did not know of any mechanism of heredity accounts for their failure to attempt to give any explanation as to the cause of hybrid vigor. Animal breeders, however,

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did make use of both inbreeding and crossbreeding in the early development of many breeds of farm animals. They realized that while close-breeding tended to standardize type, such a system of breeding often concentrated undesirable characters, such as loss of vigor and size, low fertility and susceptibility to disease. Their antidote for these bad conditions was the use of an unrelated sire, and as a rule more vigorous and productive offspring were the result of such an outcross.

DARWIN (1877) could not see why the bad qualities of inbred plants and animals could be caused by a concentration of such qualities, because he knew of many cases of inbred plants and animals of different strains or coming from different herds but possessing the same or similar undesirable qualities, which when crossed, gave vigorous progeny. Cases of this kind proved to him the great advantage of crossing even though the individuals crossed were weak or carried undesirable qualities. He attributed the hybrid vigor to the bringing together of diverse sexual elements from compatible but somewhat unrelated types, and not to the mere act of crossing. His closing arguments on the value of cross-fertilization are based on the fact that there must be a difference in the sexual elements before hybrid vigor is possible. DARWIN believed that the environment of individual plants or animals was directly associated with the change in, or the differentiation of the sexual elements. He seems to have been the first to offer an explanation of hybrid vigor.

DAVENPORT (1908) spoke of the influence of dominant and recessive factors in a pair of Mendelian allelomorphs. He believed the dominant factor to be the progressive one while the recessive was retrogressive and often lacked in vigor. From this point on, two general hypotheses of hybrid vigor have been advanced.

In brief, one of these hypotheses is based upon the degree of heterozygosity brought about by crossbreeding, that is, the more nearly crossbreeding brings about a 100 percent heterozygous condition of all allelomorphic pairs of genes the more vigorous the hybrid will be. This conception of hybrid vigor led to the acceptance of "heterosis" (G. H. SHULL) as a logical word to express the increased growth or vigor possessed by many hybrid animals and plants. The second of these hypotheses is based upon the number of dominant genes which are brought together in hybrids and the greater the number of dominants, it is supposed, the more clearly will hybrid vigor be manifested. A modification of the second hypothesis regards certain dominant genes as contributing more largely than others to the vigor of the offspring, or even as having a predominant influence on vigor so that they can be regarded as specific "growth genes."

Three investigators seem to have been interested in the dominant hypothesis as an explanation of hybrid vigor at about the same time. BRUCE (1910) points out that the total number of dominant factors is greater in a hybrid population than in either parent population and that there is consequently a correlation between hybrid vigor and the number of dominant factors. He did not state why a greater number of dominant factors produced an increase in vigor. KEEBLE and PELLEW (1910) believed that the dominance of characters contributed by both parents might explain the increased vigor of hybrids. They crossed two varieties of peas (*Pisum sativum*) which differed in height and the F_1 hybrids were taller than either parent. The dominance of characters in the hybrids was offered as a possible explanation. I am not able to state whether the first suggestion of the dominant hypothesis should be credited to BRUCE or KEEBLE and PELLEW, but G. H. SHULL (1911) gives the credit to BRUCE.

In discussing "The Genotypes of Maize" SHULL mentions two possible explanations of hybrid or crossbred vigor. The first, and the one which SHULL favored, gave heterozygosis credit for the increased vigor and size of the F_1 generation. In many corn crosses which gave greater vigor to the F_1 hybrids he believed that a correlation existed between the degree of vigor and the number of heterozygous characters. To quote, "I do not believe that this correlation is perfect, of course, but approximate, as it is readily conceivable that even though the general principle should be correct, heterozygosis in some elements may be without effect upon vigor, or even depressing." The second hypothesis mentioned by SHULL, for which he gives A. B. BRUCE credit, is based on the assumption that the degree of vigor depends upon the number of dominant elements present rather than the number of heterozygous elements. The following quotation explains SHULL'S reaction to the two hypotheses: "Mr. A. B. BRUCE proposes a slightly different hypothesis in which the degree of vigor is assumed to depend upon the number of dominant elements present, rather than the number of heterozygous elements. While all of my data thus far are in perfect accord with my own hypothesis, and I know of no instance in which self-fertilization of a corn plant of maximum vigor has not resulted in a less vigorous progeny, it is quite possible that I have still insufficient data from which to distinguish the results expected under these two hypotheses. However, for the purpose of the present discussion, it is not necessary to decide which of these two hypotheses (if either) is correct. Both of them are based upon the view that the germ-cells produced by any plant whose vigor has been increased by crossing are not uniform, some possessing positive elements or genes not possessed by others."

EAST and HAYES (1912) give support to the heterozygosis hypothesis in reporting their results secured in tobacco crosses. These investigators make a clear distinction between dominance and the effects of heterozygosis. The following quotation is of value in order to understand fully their support of the hypothesis of heterozygosis: "The term vigor has hitherto been used with the general meaning which the biologist readily understands. We will now endeavor to show in what plant characters this vigor finds expression. It is not an easy task because of the possibility of confusing the phenomena of Mendelian dominance with the physiological effects due to heterozygosis. The confusion is due to superficial resemblance only. Dominance is the expressed potency of a character in a cross and affects the character as a whole. A morphological character, like the pods of individual maize seeds, or the products of some physiological reaction like the red color of the seed pericarp in maize, may be perfect dominance, that is, it may be developed completely when obtained from only one parent. Size characters, on the other hand, usually lack dominance or at least show incomplete dominance. The vigor of the first hybrid generation theoretically has nothing to do with these facts. This is easily demonstrated if one remembers that the increased vigor manifested as height in the F_1 generation can not be obtained as a pure homozygous segregate, which would be possible if due to dominance. Furthermore, the universality with which vigor of heterozygosis is expressed as height shows the distinction between the two phenomena. If the greater height were the expression of the meeting of two factors ($T_1t_2 \times t_1T_2$) both of which were necessary to produce the character, one could not account for the frequency of the occurrence. Nevertheless, in practice the confusion exists, and while we have considerable confidence in the conclusions drawn from our experiments we have no intention of expressing them dogmatically."

A. F. SHULL (1912) and CASTLE (1916) agree that heterosis cannot be explained satisfactorily on the basis of dominant factors. SHULL, although not taking a definite stand for either hypothesis, does state that heterozygosis is more likely to account for hybrid vigor than the presence of certain dominant genes. To quote SHULL: "The former view (heterozygosis) admits of a plausible foundation in cell physiology, and the essence of it may be extended to cases of decrease of vigor in which there is no change in genotypic constitution and which are, therefore, without the pale of either theory." CASTLE takes somewhat the same view as SHULL as will be noted in the following quotation: "Crossbreeding has, then, the same advantages over close-breeding that fertilization has over

parthenogenesis. It brings together differentiated gametes, which, reacting on each other, produce greater metabolic activity. Whether or not the uniting gametes differ by Mendelian unit-characters is probably of no consequence. That they differ chemically is doubtless the essential thing in producing hybrid vigor. Heterozygosis is mentioned merely as an evidence of such chemical difference."

EMERSON and EAST (1913) offer an objection to the hypothesis of dominance because F_2 generations do not show an unsymmetrical distribution in respect to characters in which heterosis was shown in the F_1.

This objection was based upon their study of the inheritance of quantitative characters in maize.

JONES (1917) revived the dominance hypothesis by introducing linked factors as an explanation as to why it was very difficult to get homozygous segregates possessing the vigor so often manifest in F_1 hybrids. The knowledge that genetic linkage often occurs does in a measure answer one of the chief objections to the dominance hypothesis. This principle of linkage also answers the objection raised by EMERSON and EAST as to why F_2 generations do not show an unsymmetrical distribution in respect to many known characters. A chief difficulty of the hypothesis is the necessary supposition that genes favoring growth are so specific in nature and so few in number that their being borne on homologous chromosomes and at adjacent loci in different races of the same species could regularly result in repulsion in gametogenesis in F_1 individuals, so that hybrid vigor regularly disappears in F_2. JONES (1918) discussing "a Mendelian interpretation of heterosis" makes the following statements:

"Whether or not dominance of factors is wholly adequate to account for all of the immediate effects of exogamy remains to be seen. The former view that dominance was not concerned at all has been maintained so insistently that I have taken the extremely opposite view in order to show that dominance at least can be held responsible for a large part of the increased development shown by hybrids. The treatment of the subject in this light has been dogmatic. That cross-fertilization may produce some effect which can never be attained in self-fertilization or asexual reproduction is still possible.

"The difference between the two hypotheses is not as great as might seem at first sight. The older hypothesis is general in its application and does not commit itself to the interpretation of specific effects. The view presented here is specific in its application and may be shown to be inadequate for the interpretation of all phases of the problem of increased development following cross-fertilization.

"The greatest progress in our knowledge of inbreeding and crossbreeding was made when their effects were linked with Mendelian phenomena. This was the big step forward. The two ways of interpreting these results here differ only in minor features and it is not putting the matter fairly to hold them up as rival hypotheses, one to be chosen from the other. Placing the effects of inbreeding and crossbreeding entirely on a Mendelian basis is merely an outgrowth of the older view as knowledge of the methods of inheritance increased."

EAST and JONES (1919) agree that the dominance hypothesis explains heterosis, and state that the recent developments in our knowledge of hereditary factors, especially linkage conditions, remove the major objections to such a hypothesis. In other words, EAST has abandoned the heterozygosis hypothesis in favor of the dominance hypothesis. Hayes has also been converted to the latter hypothesis as indicated in the text on "Breeding Crop Plants" by HAYES and GARBER (1927).

WRIGHT (1922) makes the following statements in connection with results of inbreeding and crossbreeding of guinea pigs:

"Analysis of the various crosses indicates that the results are all the direct or indirect consequence of the Mendelian mechanism of heredity. The fundamental effect of inbreeding is the automatic increase in homozygosis in all respects. An average decline in vigor is the consequence of the observed fact that recessive factors, more extensively brought into expression by an increase in homozygosis, are more likely to be deleterious than are their dominant allelomorphs. The differentiation among the families is due to the chance fixation of different combinations of the factors present in the original heterozygous stock. Crossing results in improvement because each family in general supplies some dominant factors lacking in the others. Dominance or even imperfect dominance in each unit character is built up into a pronounced improvement over each parent stock in the complex characters actually observed.

"A certain portion of the increase in vigor of the first cross between inbred families is maintained on resuming random-mating. One half of this increase is maintained in stocks founded on two inbred lines, two-thirds in the case of three lines, three-fourths in the case of four lines, four-fifths in the case of five lines, and so on." The above quotations leave no doubt where WRIGHT stands on the two hypotheses.

DISCUSSION OF THE HYPOTHESES OF HYBRID VIGOR

The essential difference between the explanations which have been offered for hybrid vigor seems to be this: On the heterosis interpretation

hybrid vigor does not result either from dominant or from recessive genes as such, but from a union of unlike elements dominant with recessive, *dissimilarity* in content of genes between the uniting gametes producing, it is supposed, a more vigorously developing zygote.

The original suggestion that a greater content of *dominant* genes made for greater vigor seems to have been a logical outgrowth of the presence-absence concept, in which recessives were conceived as simple absence of the dominants. Naturally if a dominant contributed anything to the total vigor of the organism, the recessive would contribute less, so that, other things being equal, the most vigorous zygote would be the one containing the most dominants.

In the revival of the dominant theory by JONES, the presence-absence idea is dropped, and the conception brought forward of special (dominant) genes making for vigor in the organism. If a combination of all such genes could be secured in a homozygous state the maximum of vigor would be realized, according to JONES, and a heterozygous state of one or more such genes would add nothing to the vigor of the organism. In a recent paper (1926) he cites the KING inbred rats as an example of a presumably, completely homozygous organism possessing a maximum of vigor. Experimental observations to be presently discussed show, however, that still further vigor of development can be imparted to the KING inbred race by an outcross with a race no larger than itself.

In every such case JONES is forced to assume that the race with which a cross was made did after all contain one or more genes making for vigor which were not present in the inbred race. He might then simply say that he was mistaken in his previous estimate of the KING race. It left something yet to be desired in the way of vigor. The question is whether there has ever existed, or can be produced, an organism which would not derive additional vigor from an outcross. This is the gist of the heterosis interpretation, for or against which experimental evidence is desired.

EXPERIMENTAL STUDY OF HYBRID VIGOR

Location of Work and Animals Used

Experimental work was started at the Bussey Institution, HARVARD UNIVERSITY, Forest Hills, Boston Massachusetts in the fall of 1924. After one year's work at the Bussey Institution all necessary experimental animals were moved to the WEST VIRGINIA AGRICULTURAL EXPERIMENT STATION, Morgantown, West Virginia, where active breeding was continued until the late summer of 1927.

Three strains of rats (*Rattus Norvegicus*) were used and for convenience in keeping records they were designated as strains S_1, S_2, S_3. Such symbols are used exclusively in charts, tables, and in all discussions referring to the different strains. These strains were stock rats maintained at the Bussey Institution laboratory previous to their use in my work.

The S_1 strain may be described as pink-eyed yellow rats of the known genetic composition *CCppRRHHAA*. This stock had been rather closely bred for several generations although sib (brother and sister) matings had not been regularly followed. Ten rats of this strain, 8 females and 2 males, were selected from two litters for my work. These two litters were from sib matings, having the same sire and their dams being litter mates to each other and to the male. This strain proved to be vigorous and prolific throughout the experiment.

The rats of the S_2 strain are red-eyed hooded cream with the known genetic composition *CCPPrrhhaa*. This strain had been more closely inbred than the S_1 strain, having been closely inbred for several generations. The matings were known to have been sib matings for three generations. This strain was known not to be very prolific and it was necessary to select my initial animals, nine in number, from three litters. Two females and one male were selected from each litter. This strain was a handicap to the progress of the work due to small litters and also due to the failure of a number of females to produce more than one litter. I am unable to explain the fact that many females of this strain produce one litter and fail to conceive thereafter.

The rats of the S_3 strain are known as KING inbred albinos. This strain was secured from the WISTAR INSTITUTE of Philadelphia through the kindness of Doctor HELEN DEAN KING, a short time before this experiment was started. The known genetic composition of this strain is *ccPPRRhhaa*. The foundation rats of this strain consisted of six females and one male from a litter of twelve. This litter represented the fifty-first generation of brother by sister matings according to the records of Doctor KING and the Bussey Institution. This strain proved prolific and vigorous throughout the experiment.

Basis of Study

This study of hybrid vigor is based solely upon growth as measured by weight. A careful growth record was made of all stock strains (S_1, S_2, and S_3) and of the F_1 and F_2 progeny of crosses, $S_1 \times S_2$ and $S_1 \times S_3$. The F_2 progeny of the $S_1 \times S_3$ cross were all tested for their genetic consti-

tution by back-crossing to the stock strains, thus giving a known genetic basis for studying animals of the F_2 generation.

Methods of Handling Experimental Animals

1. Rats were kept in the standard $14'' \times 17''$ wire cages which were used for all rat work at the Bussey Institution.
2. All rats were fed and cared for in as like a manner as possible.
3. With few exceptions, five rats were retained in a cage from the time they were weaned at 30 days of age until they were 90 days of age.
4. Cages and other equipment (water bottles and feed dishes) were thoroughly cleaned each week to guard against disease and digestive disturbances.
5. All rats were ear marked and careful growth weights to the nearest 5 grams were recorded for 30, 50, 70, 90 and 150 days of age.
6. A Hanson Brothers' spring scale, graduated to one gram and weighing a maximum of 500 grams, was used for weighing the rats.
7. All stock rats (S_1, S_2, and S_3) were produced by brother-sister matings during the experiment.
8. In all cases total litters were recorded and the only rats born in litters contained in this work, not accounted for, died before their growth records were complete, or failed to breed. Apparent sterility in a few F_2 ($S_1 \times S_3$) rats eliminated them from studies involving their genetic constitution.
9. All statistical studies are based on the weights of rats at 90 days of age. Many females were mated following the 90 day weight period and the subsequent occurrence of gestation and lactation periods, change of cages, and the varying number of animals kept in one cage make it undesirable to use the weights of the 150 day period.

DATA AND STATISTICAL STUDIES

Average Weights

Males and females of each parent strain and of their F_1 and F_2 progenies were treated separately to get the average weight of each sex at 30, 50, 70, 90, and 150 days of age. Table 1 shows these average weights and the number of rats each group contains. This table does not contain all rats used in this study, as many stock rats were used for breeding purposes in connection with tests to determine the genetic constitution of F_2 ($S_1 \times S_3$) rats. For such test animals growth weights were not recorded. The S_2 strain of rats gave so much trouble, due to small litters and their failure

to breed, that the progeny of the cross between the S_1 and S_2 strains were not studied extensively. However, the data derived from this cross are of interest in connection with the data of the other cross ($S_1 \times S_3$). The data contained in table I are given graphically in figures 1–4.

TABLE 1

Average weight in grams of rats of various stocks and of their F_1 and F_2 progeny at ages 30–150 days.

STOCK	SEX	NO	30 DAYS	50 DAYS	70 DAYS	90 DAYS	150 DAYS
S_1	Males	100	43	86	132	168	234
S_1	Females	98	44	81	111	134	175
S_2	Males	52	30	58	100	130	189
S_2	Females	59	28	54	79	100	137
S_3	Males	62	46	99	158	199	268
S_3	Females	80	45	87	125	153	199
$F_1(S_1 \times S_2)$	Males	48	47	101	159	206	272
$F_1(S_1 \times S_2)$	Females	37	44	92	129	156	191
$F_2(S_1 \times S_2)$	Males	51	46	97	150	183	247
$F_2(S_1 \times S_2)$	Females	64	42	83	116	141	179
$F_1(S_1 \times S_3)$	Males	53	44	117	179	213	278
$F_1(S_1 \times S_3)$	Females	69	43	97	141	161	205
$F_2(S_1 \times S_3)$	Males	137	42	87	133	177	244
$F_2(S_1 \times S_3)$	Females	132	41	81	114	142	179

Growth Curves

By a glance at figures 1 and 3, one is convinced that heterosis is exhibited in F_1 animals of each cross made. Figures 2 and 4 show that this F_1 vigor is materially reduced in the F_2 generation of each cross. In the case of the S_1 by S_2 cross (figure 1) there is a large difference in size between the parent strains. The average weight of S_1 males is 234 grams and the average weight of S_2 males is 189 grams at 150 days of age, yet the F_1 males have an average weight greater than that of males of the heavier parent race (S_1), namely 272 grams at 150 days of age. The same relation exists in the case of the F_1 females compared with the parent stocks. Figure 2 shows that both the F_2 males and the F_2 females fail to develop as rapidly and are smaller at 150 days of age than the same sex of the F_1 generation. Even though a noticeable decrease in size is shown in the F_2 generation, both males and females are still heavier at 150 days of age than the males and females of the larger or S_1 parent strain. In

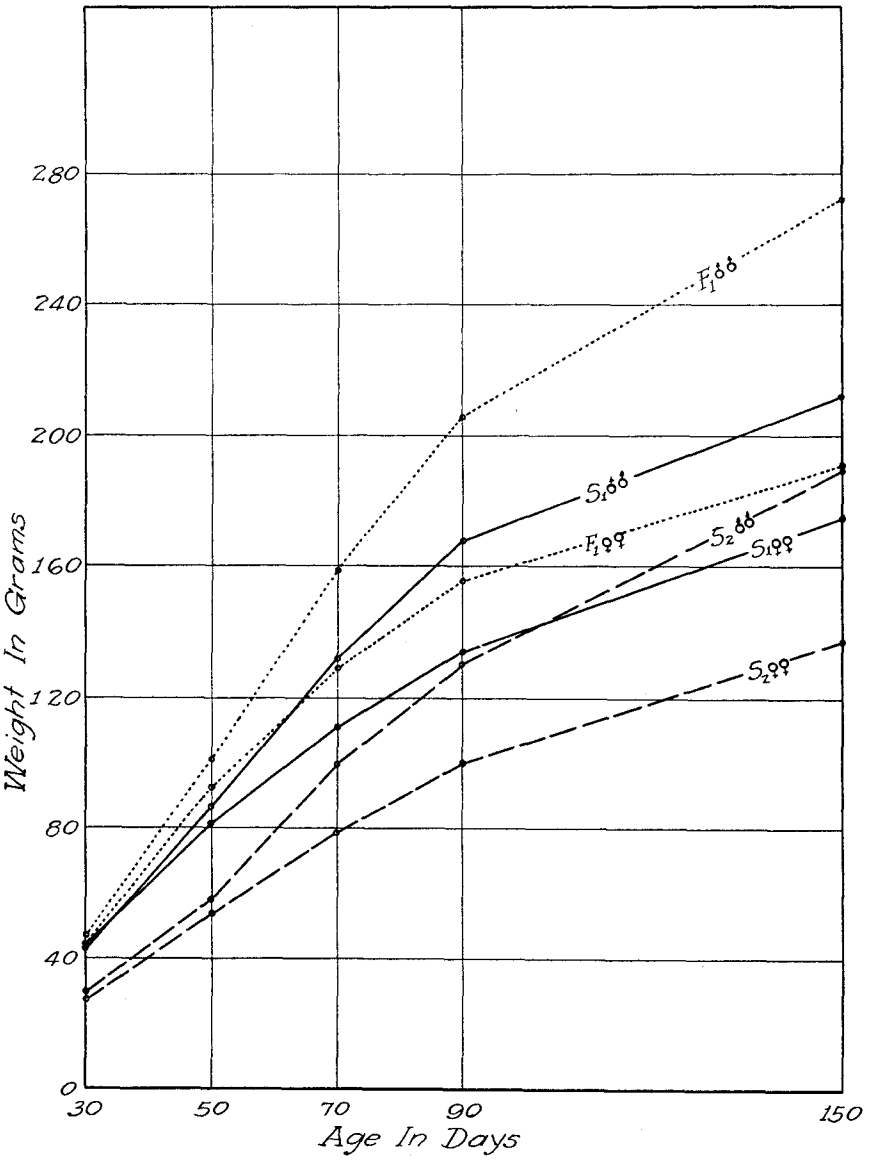

FIGURE 1.—Growth curves for S_1 and S_2 stock and their F_1 progeny.

this cross S_2 males were, in all cases, mated to S_1 females due to the low productiveness of the S_2 females.

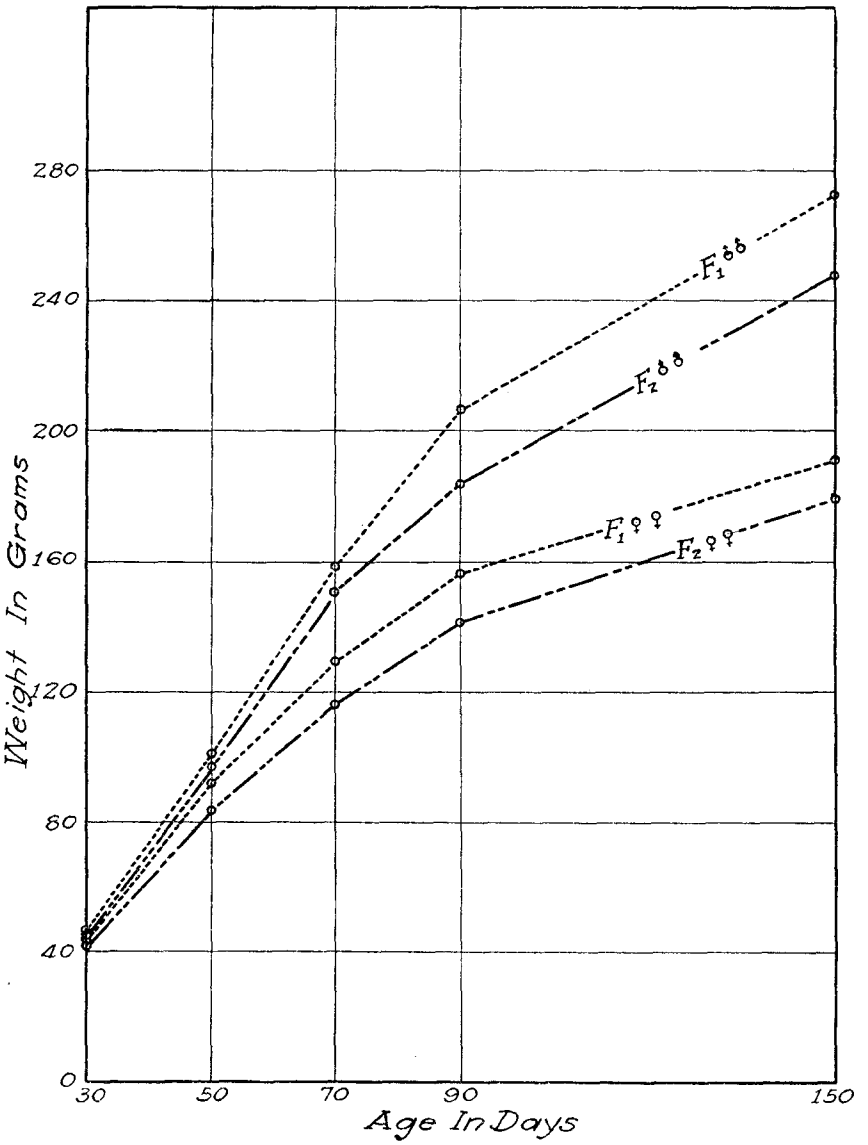

FIGURE 2.—Growth curves for F_1 and F_2 progeny of $S_1 \times S_2$ stocks.

The stock strains of the S_1 by S_3 cross, as shown in figure 3, are nearer the same size at 150 days of age than were the stock strains (S_1 and S_2)

of the previous cross. The results of the S_1 by S_3 cross are comparable to the results of the S_1 by S_2 cross, with one exception; the F_2 generation

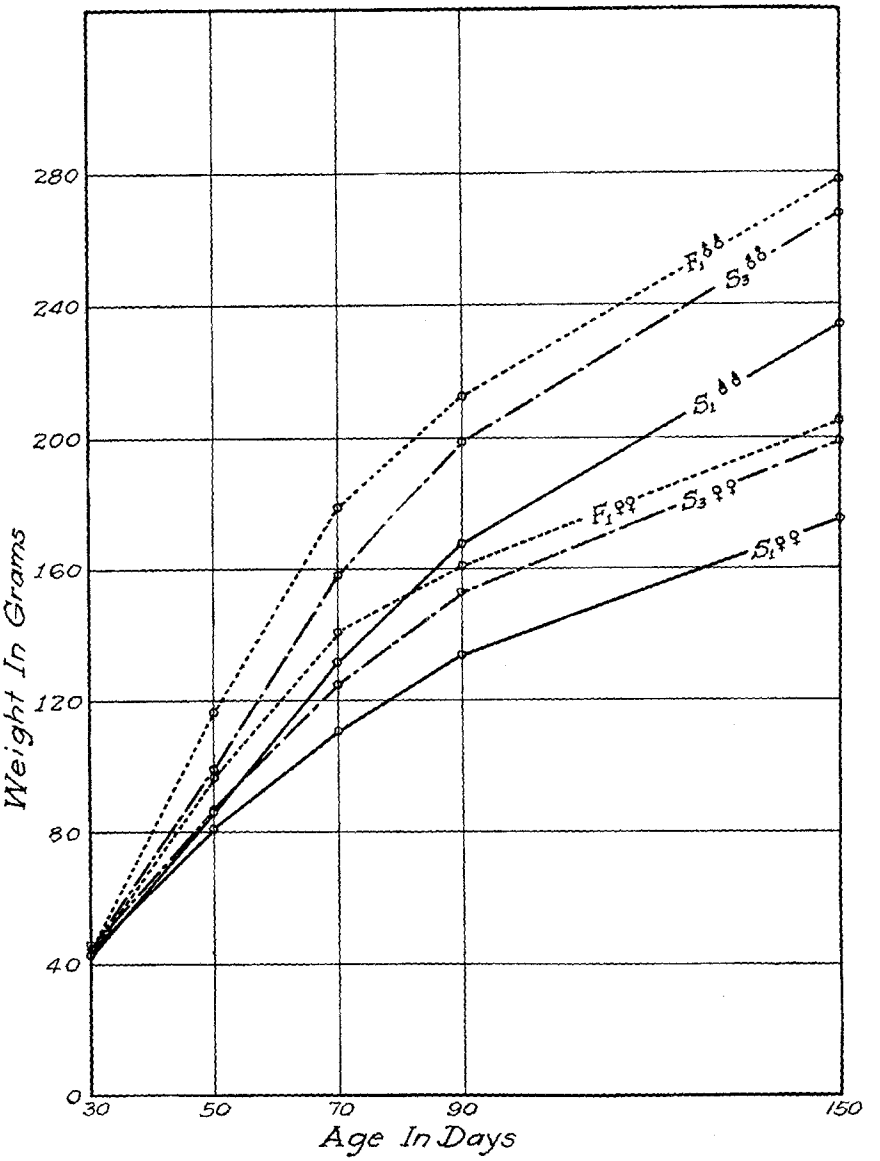

FIGURE 3.—Growth curves for S_1 and S_3 stock and their F_1 progeny.

(figure 4) drops in average weight to near the average weight of the smaller or S_1 parent strain at the same age. In this case the F_1 vigor apparently

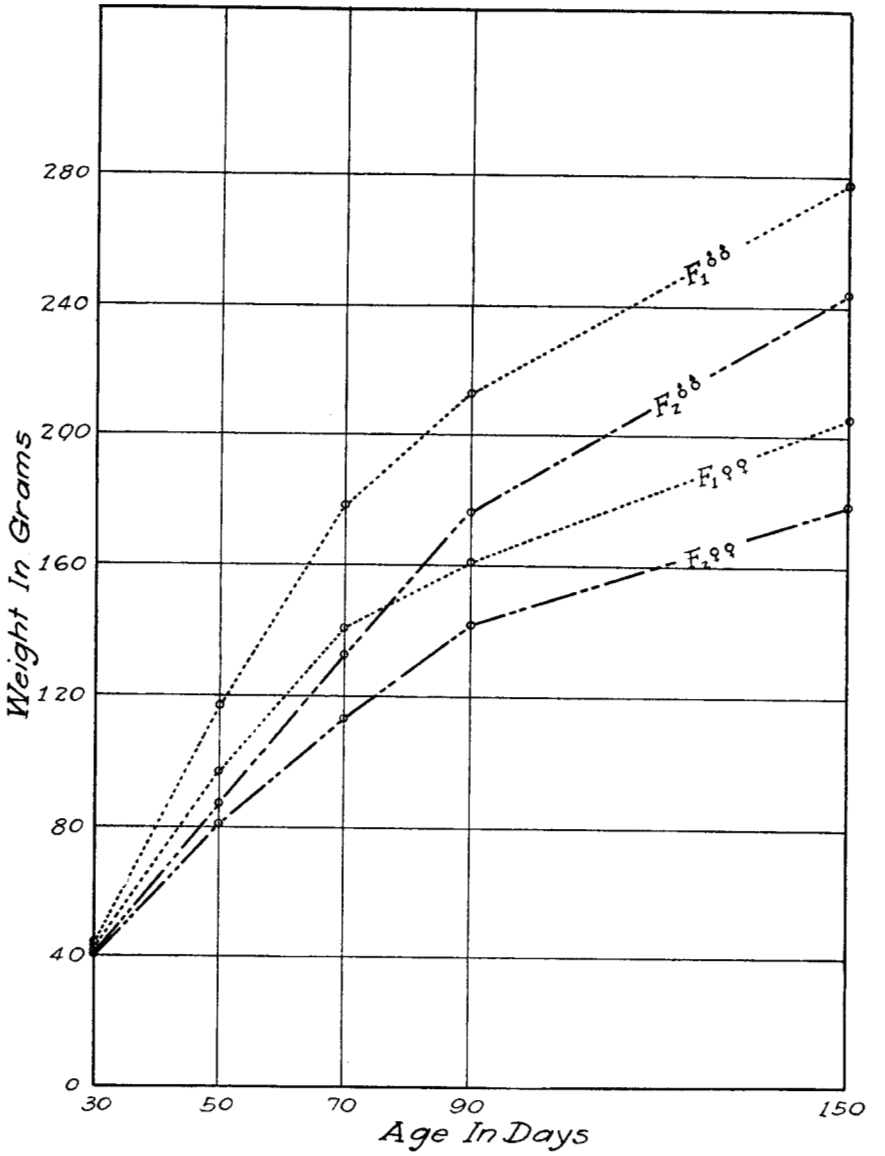

FIGURE 4.—Growth curves for F_1 and F_2 progeny of $S_1 \times S_3$ stock.

was being lost at a more rapid rate than in the former cross. The average loss in weight between the F_1 and F_2 generations, at 150 days of age, in the two crosses is as follows:

	$S_1 \times S_2$	$S_1 \times S_3$
Loss in weight of males	25 grams	34 grams
Loss in weight of females	12 grams	26 grams

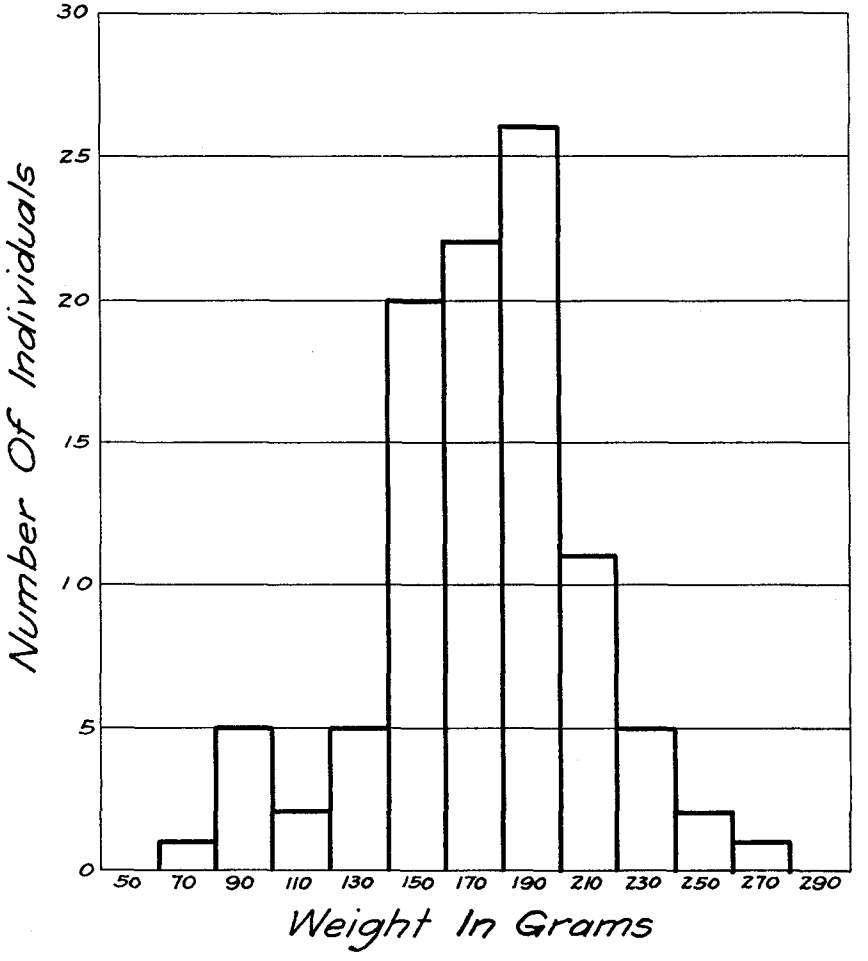

FIGURE 5.—Frequency polygon showing variation in weight of 100 S_1 males at 90 days of age.

Frequency Polygons

Frequency polygons (figures 5–12) show the variations in weight at ninety days of age of all male and all female rats in connection with the

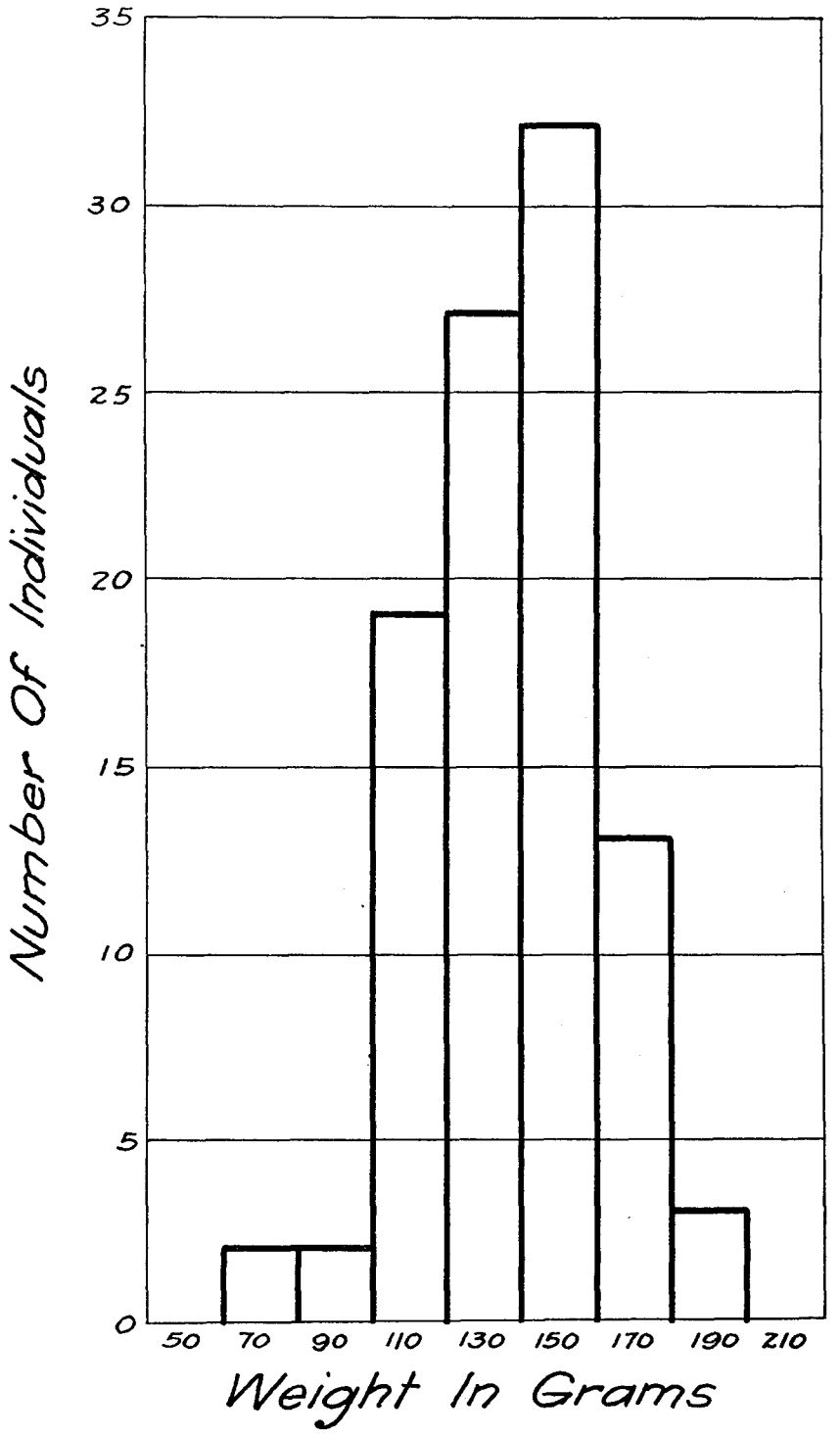

FIGURE 6.—Frequency polygon showing variation in weight of 86 S_1 females at 90 days of age.

$S_1 \times S_2$ cross. These graphs show that male rats are more variable than females in the S_1 and S_2 stock strains. The F_1 and the F_2 rats do not show any marked difference in the variablility of males and females. However, table 2 shows that the coefficient of variability for the F_1 females is slightly higher than for the F_1 males, and that the coefficients of variability of the F_2 males and females are almost identical. Figures 9 and 11 show slightly more variability among the F_2 males than among the F_1 males,

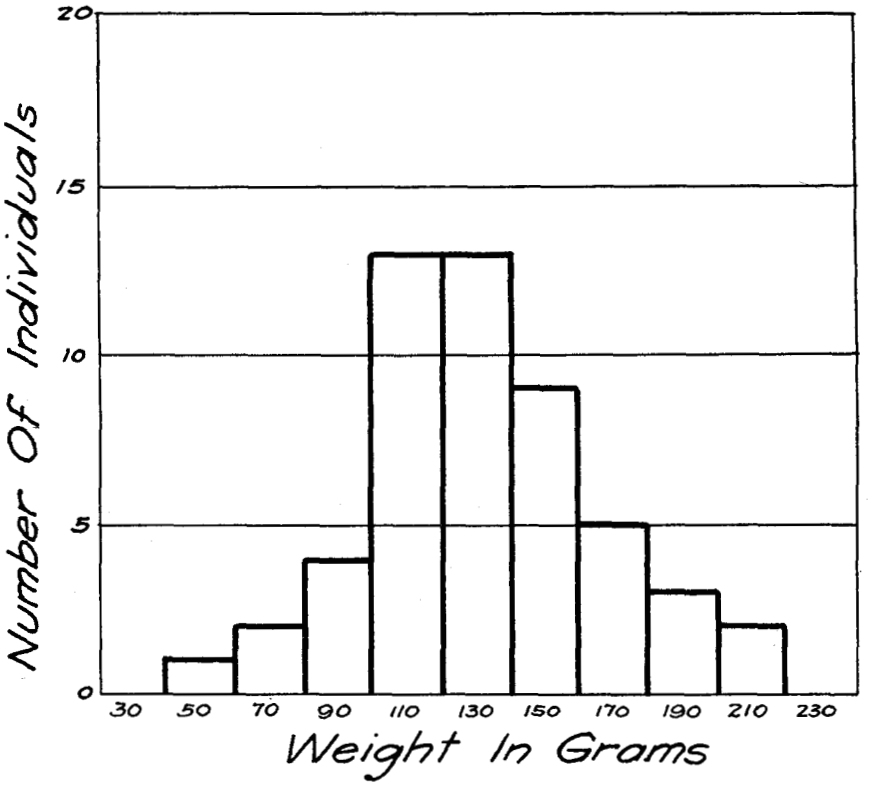

FIGURE 7.—Frequency polygon showing variation in weight of 52 S_2 males at 90 days of age.

but the F_2 males are less variable than the males of either parent strain (figures 5 and 7). Figures 10 and 12 do not indicate a greater variability among the F_2 females than among the F_1 females. In fact, these graphs indicate less variability among the F_2 females. Table 2 shows the coefficients of variability for the F_1 and F_2 females to be almost identical.

Frequency polygons (figures 5, 6, and 13–18) show the variations in weight of all male and all female rats in connection with the S_1 by S_3

cross, at 90 days of age. These graphs indicate that male rats are uniformly more variable than females of the same stock strain or the same progeny generation. This greater variability of the body weight of male rats was observed also by KING (1923). These graphs also indicate that

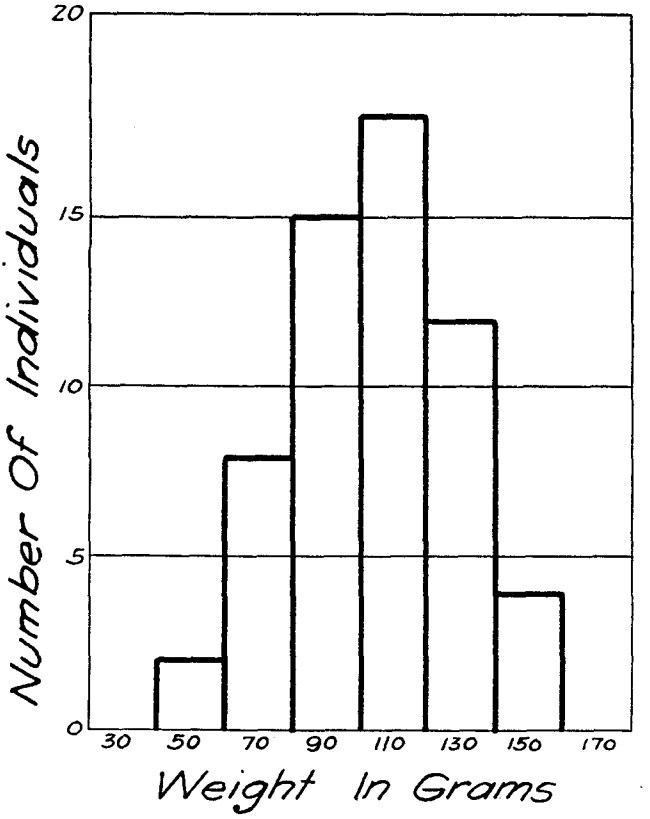

FIGURE 8.—Frequency polygon showing variation in weight of 59 S_2 females at 90 days of age.

both F_1 males and F_1 females are less variable than the corresponding sex of either parent strain. Figures 15 and 17 indicate a greater variability among F_2 males than among F_1 males, but this relation does not exist in the case of F_1 and F_2 females as shown in figures 16 and 18.

Statistical Study at Ninety Days of Age

Growth curves and frequency polygons are valuable graphical helps to visualize the comparative rate of growth and the comparative variations of the groups of rats studied, but they do not give a positive answer as to whether the difference in growth or the difference in variation is large

enough to be significant. Therefore a more reliable statistical study has been attempted as shown in tables 2, 3, and 4. The data contained in table 2 are based upon the weights of rats at ninety days of age. I have previously mentioned why I selected weights at this age for this study.

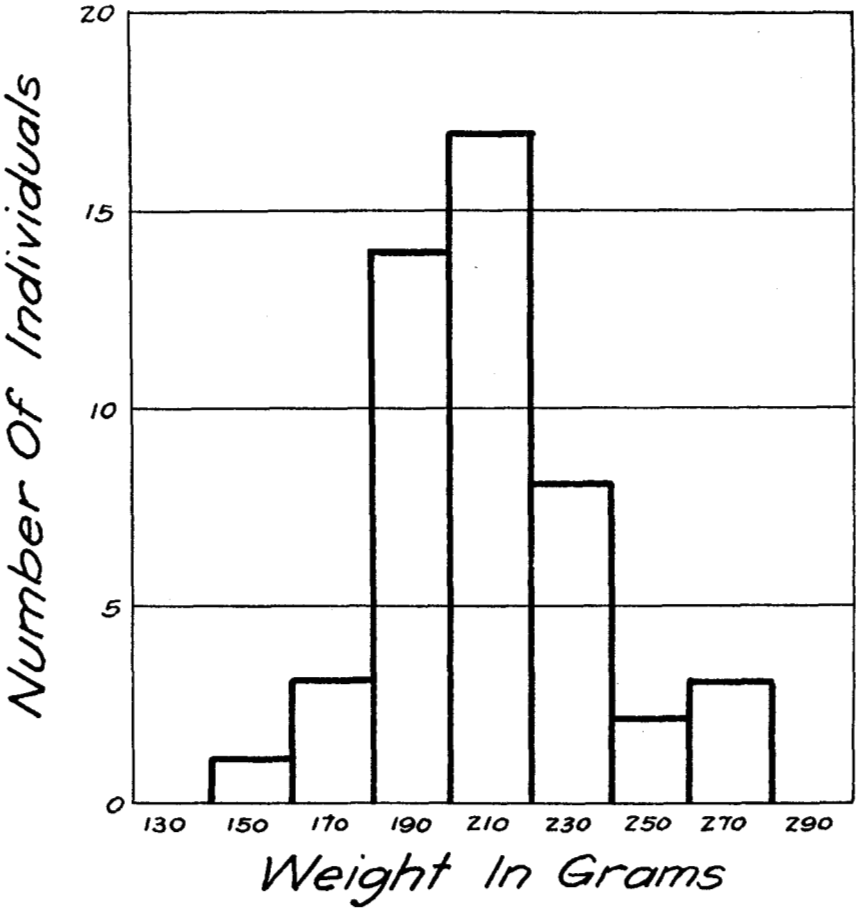

FIGURE 9.—Frequency polygon showing variation in weight of 48 F_1 ($S_1 \times S_2$) males at 90 days of age.

The data of table 2 were calculated on the same frequency as previously shown in frequency polygons.

Tables 3 and 4 are based on the data contained in table 2 and show in a comparative way whether the differences in mean weights and the differences in coefficients of variability are significant or not. In making these

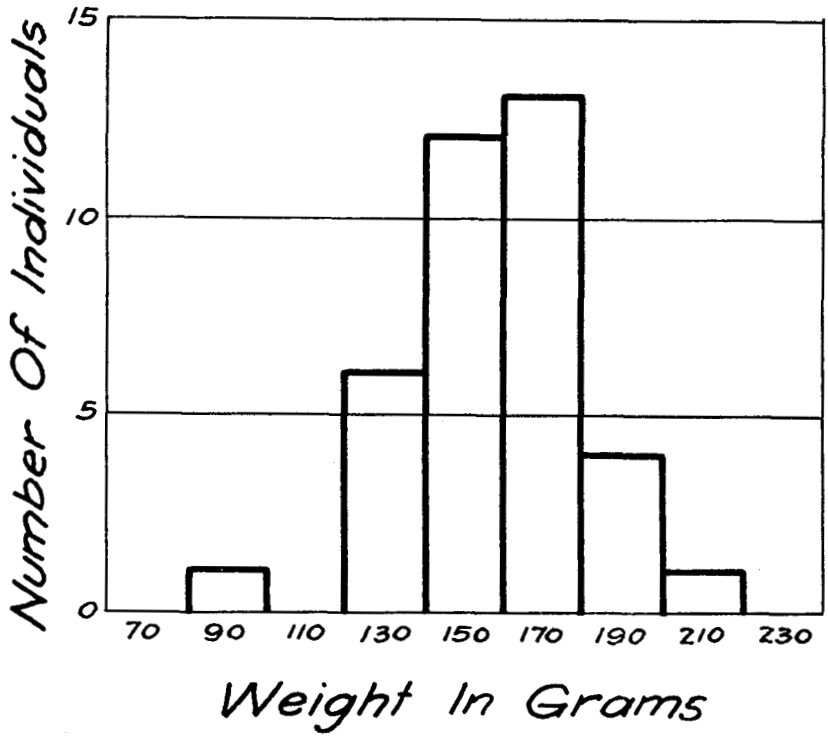

FIGURE 10.—Frequency polygon showing variation in weight of 37 F_1 ($S_1 \times S_2$) females at 90 days of age.

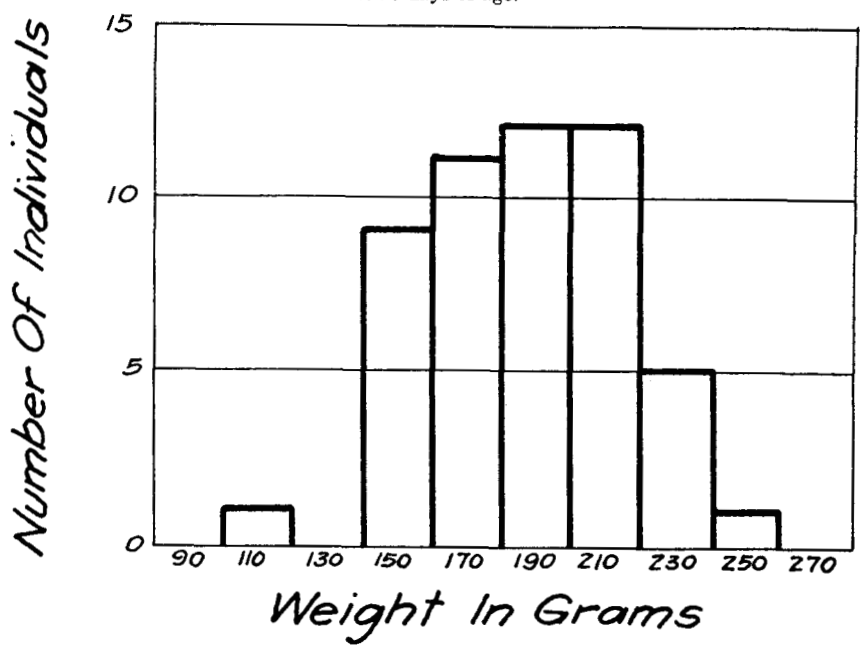

FIGURE 11.—Frequency polygon showing variation in weight of 51 F_2 ($S_1 \times S_2$) males at 90 days of age.

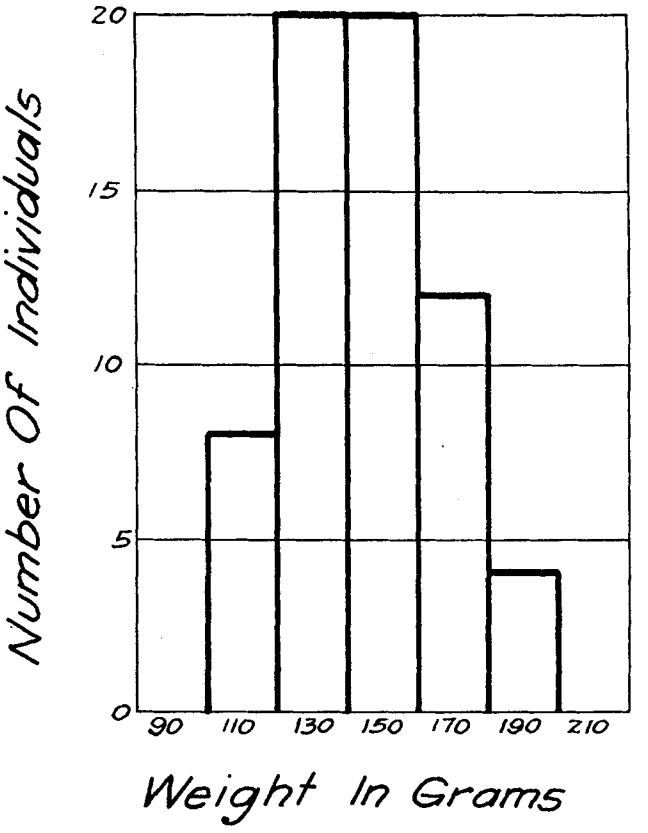

FIGURE 12.—Frequency polygon showing variation in weight of 64 F_2 ($S_1 \times S_2$) females at 90 days of age.

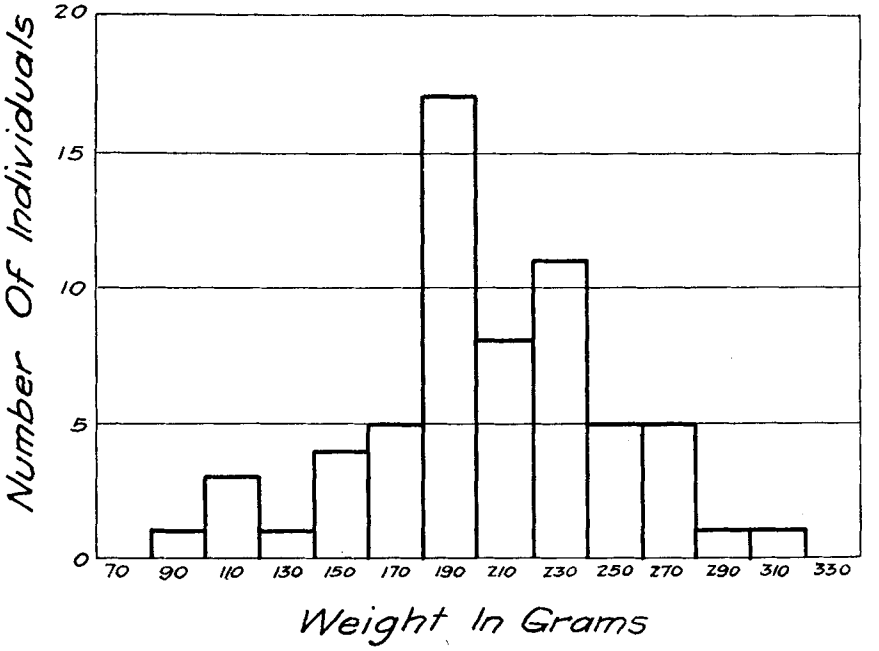

FIGURE 13.—Frequency polygon showing variation in Weight of 63 S_3 males at 90 days of age.

comparisons I used the following formula in calculating the probable error of the differences:

$$\text{Probable error of difference} = \sqrt{\Sigma(\text{p.e.})^2}$$

Table 3 contains the comparative data on the difference in mean weights and the difference in the coefficient of variability of groups of rats connected with the $S_1 \times S_2$ cross. These data show that both the S_1 males and the S_1 females are significantly larger than the same sex of the S_2 strain;

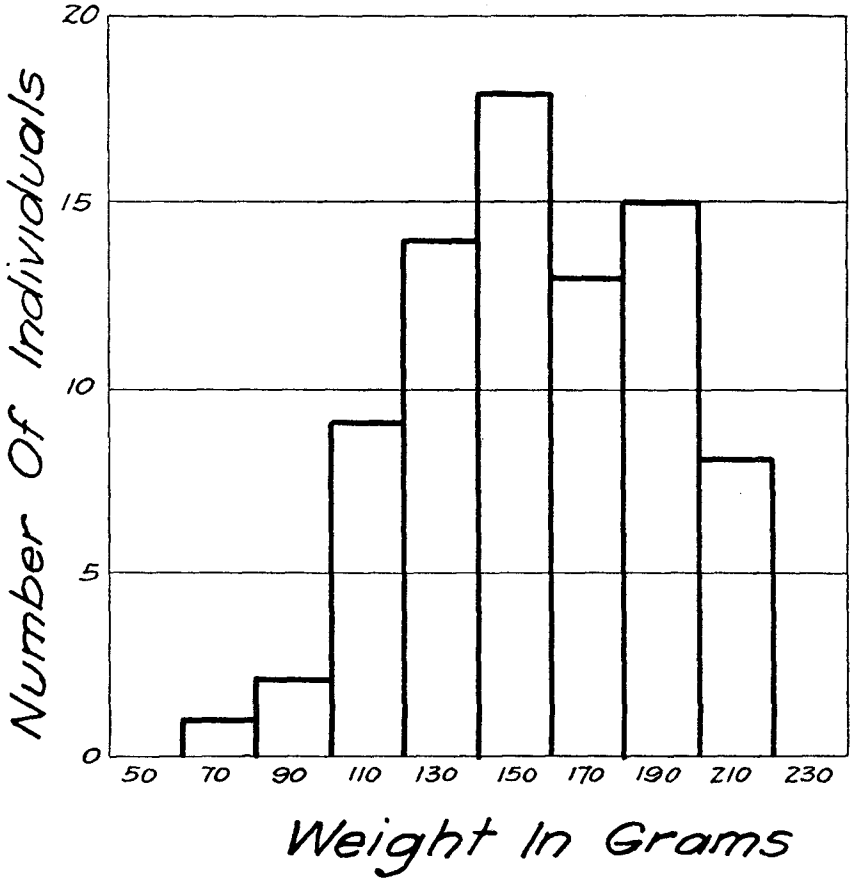

FIGURE 14.—Frequency polygon showing variation in weight of 80 S_3 females at 90 days of age.

that the S_2 females are significantly more variable than the S_1 females; and that while the S_1 males are more variable than the S_2 males, it is not a significant difference. In comparing the S_1 and S_2 strains with the F_1 generation we find both males and females of the F_1 generation signifi-

cantly larger and less variable than the corresponding sexes of the S_1 and S_2 strains. The F_1 rats of either sex are larger than the F_2 rats of the same sex, and while the F_2 rats are slightly more variable than the F_1's the difference is so slight that it is not significant. In comparing the size and variability of the F_2 generation with the parent strains, we find the F_2 rats to be significantly larger than the larger parent strain and less variable

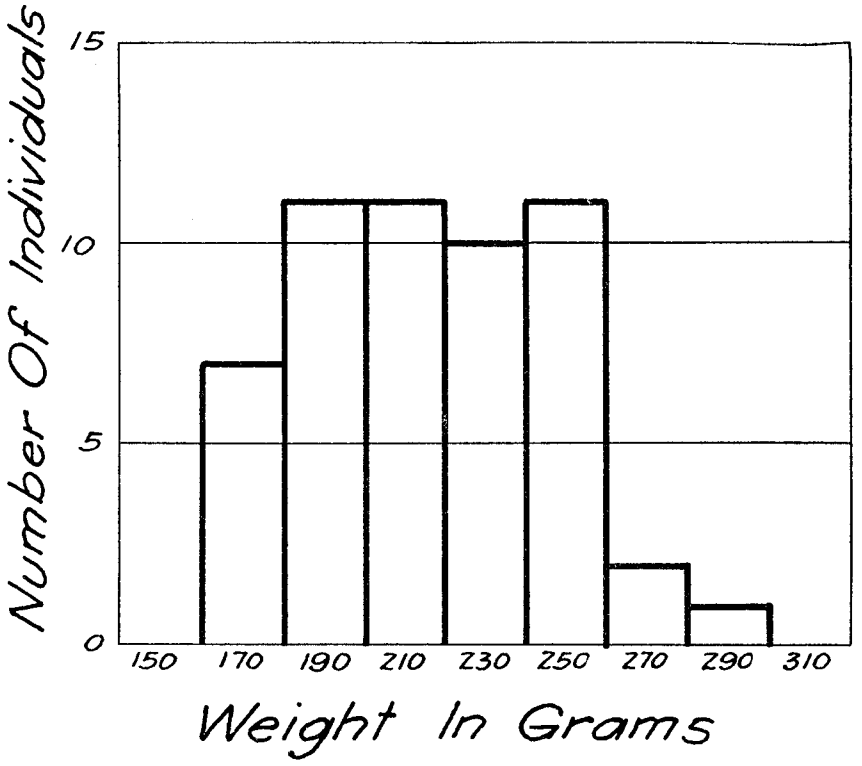

FIGURE 15.—Frequency polygon showing variation in weight of 53 F_1 ($S_1 \times S_3$) males at 90 days of age.

than either parent strain. This difference in variability, however, is not significant in the case of the S_1 and F_2 females.

Table 4 contains the comparative data on the difference in the mean weights and coefficients of variability of groups of rats connected with the S_1 by S_3 cross. These data show that both males and females of the S_3 strain are significantly larger than the males and females of the S_1 strain, and that there is not a large difference in the variability of the two

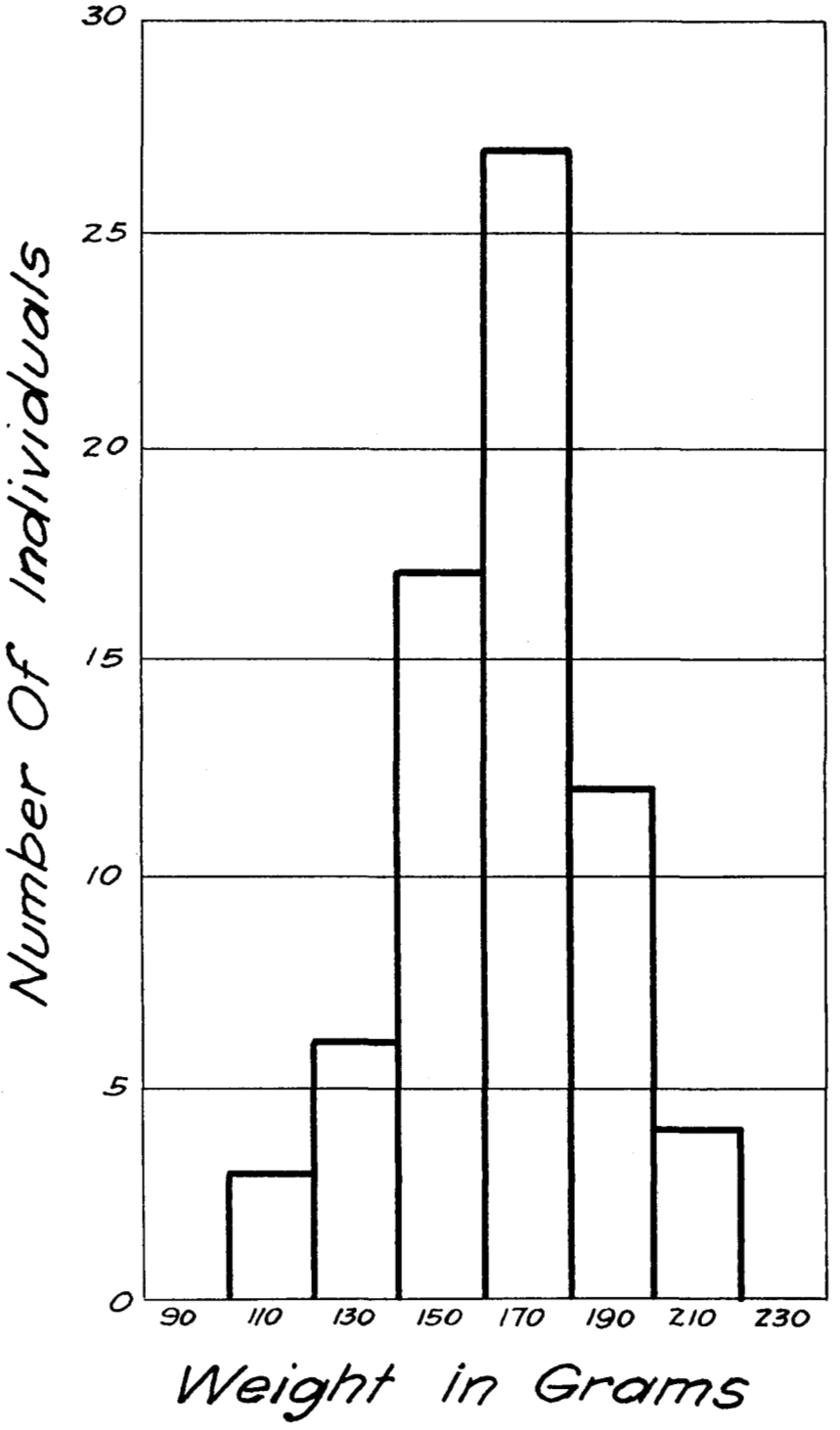

FIGURE 16.—Frequency polygon showing variation in weight of 69 $F_1(S_1 \times S_3)$ females at 90 days of age.

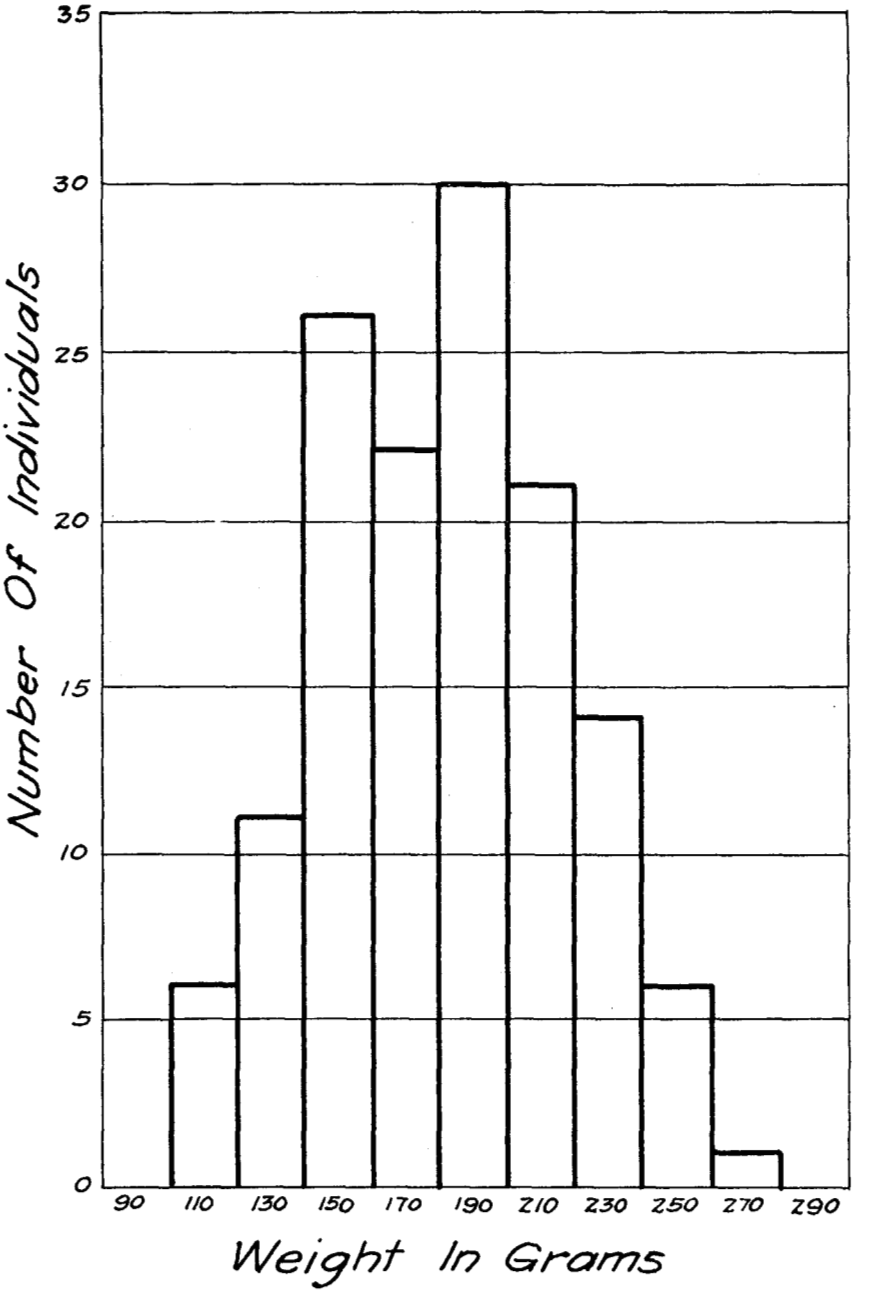

FIGURE 17.—Frequency polygon showing variation in weight of 137 F_2 ($S_1 \times S_3$) males at 90 days of age.

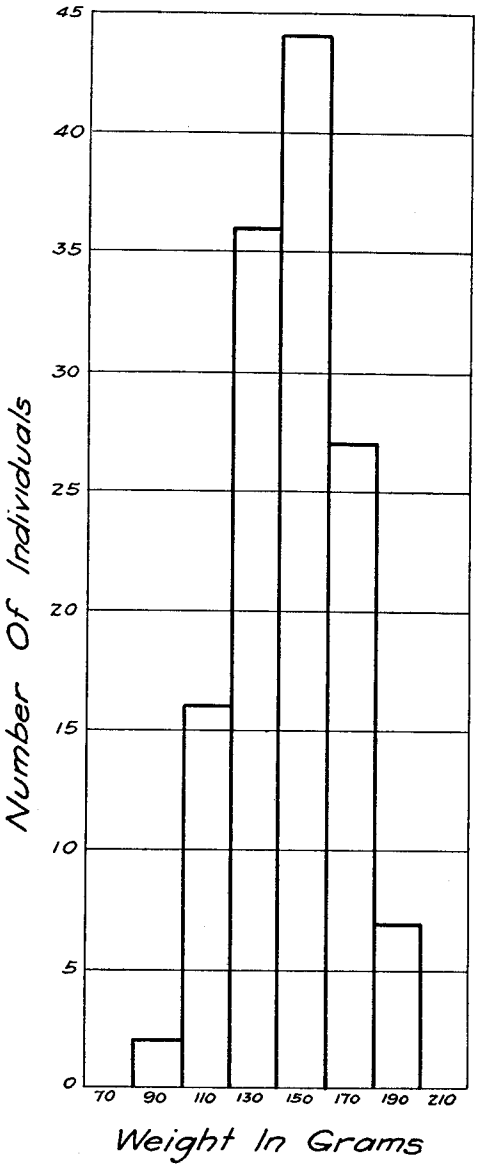

FIGURE 18.—Frequency polygon showing variation in weight of 132 $F_2(S_1 \times S_8)$ females at 90 days of age.

TABLE 2

Statistical study of weights of rats of strains S_1, S_2, and S_3, and of their F_1 and F_2 progeny at age 90 days.

STOCK	SEX	NO	*M*	*S*	C. OF V.
S_1	Males	100	173.0±3.17	47.02±2.24	27.17±1.29
S_1	Females	98	137.8±1.64	24.03±1.16	17.43±0.84
S_2	Males	52	131.9±3.18	34.01±2.24	25.78±1.70
S_2	Females	59	104.3±2.14	24.43±1.51	23.43±1.45
S_3	Males	62	203.9±3.98	44.80±2.70	21.95±1.33
S_3	Females	80	156.3±2.52	34.44±1.77	21.30±1.13
$F_1(S_1 \times S_2)$	Males	48	209.2±2.48	25.47±1.75	12.12±0.83
$F_1(S_1 \times S_2)$	Females	37	159.2±2.55	23.06±1.81	14.48±1.13
$F_1(S_1 \times S_3)$	Males	53	218.4±2.85	29.95±2.02	13.71±0.95
$F_1(S_1 \times S_3)$	Females	69	164.3±1.65	19.49±1.16	11.86±0.71
$F_2(S_1 \times S_2)$	Males	51	186.9±2.40	28.39±1.69	15.18±1.01
$F_2(S_1 \times S_2)$	Females	64	145.0±1.83	21.79±1.30	15.02±0.89
$F_2(S_1 \times S_3)$	Males	137	181.3±2.02	35.01±1.42	19.31±0.79
$F_2(S_1 \times S_3)$	Females	132	145.0±1.31	22.34±0.93	15.40±0.64

The mean weights are slightly larger in this table than the average weights at 90 days of age as shown in table 1. The value of frequencies was made slightly higher by uniformly throwing all weights which fell on group weight divisions into the higher groups.

strains of rats. In comparing the stock strains, S_1 and S_3, with their F_1 progeny we find that the F_1 rats are larger than either parent strain. However, the difference in size is not large enough in the case of the S_3 and F_1 females to indicate a positive difference in size. In comparing the F_1 and F_2 rats we find that the rats of the F_1 generation are larger and less variable than the F_2's. In comparing stock rats with the F_2 generation, the data show that the F_2 rats are intermediate in size between the two stock strains and less variable than either of the stock strains.

Known Genes not Linked with Growth Genes

Since there is a higher coefficient of variability with respect to weight among the F_2 rats than among the F_1 rats of the $S_1 \times S_3$ cross, it should be of interest to group the F_2 rats in a manner which might show whether there is any major growth gene linked with the known genes studied. It should be kept in mind that only three pairs of chromosomes are involved in this study.

TABLE 3

Comparison of means and coefficients of variability in S_1 and S_2 stocks and in their F_1 and F_2 progeny.

	DIFFERENCE IN MEAN WEIGHT	LARGER	DIFFERENCE IN C. OF V.	MORE VARIABLE
S_1 and S_2 Males	41.1±4.48	S_1	1.38±2.13	S_1 (N.S.)
S_1 and S_2 Females	33.5±2.69	S_1	6.00±1.66	S_2
S_1 and F_1 Males	36.2±4.02	F_1	15.05±1.53	S_1
S_1 and F_1 Females	21.4±3.02	F_1	15.27±1.81	S_1
S_2 and F_1 Males	77.3±4.03	F_1	13.67±1.89	S_2
S_2 and F_1 Females	54.9±3.32	F_1	8.95±1.83	S_2
F_1 and F_2 Males	22.3±3.45	F_1	3.06±1.30	F_2 (N.S.)
F_1 and F_2 Females	14.2±3.13	F_1	0.54±1.43	F_2 (N.S.)
S_1 and F_2 Males	13.9±3.97	F_2	11.99±1.63	S_1
S_1 and F_2 Females	7.2±2.45	F_2	2.41±1.22	S_1 (N.S.)
S_2 and F_2 Males	55.0±3.98	F_2	10.61±1.97	S_2
S_2 and F_2 Females	40.7±2.81	F_2	8.41±1.70	S_2

N. S. as used in tables 3 and 4 indicates "not significant."

TABLE 4

Comparison of means and coefficients of variability in S_1 and S_3 stocks and in their F_1 and F_2 progeny.

	DIFFERENCE IN MEAN WEIGHT	LARGER	DIFFERENCE IN C. OF V.	MORE VARIABLE
S_1 and S_3 Males	30.9±5.09	S_3	5.22±1.79	S_1
S_1 and S_3 Females	18.5±3.00	S_3	3.96±1.40	S_3 (N.S.)
S_1 and F_1 Males	45.4±4.25	F_1	13.46±1.60	S_1
S_1 and F_1 Females	26.5±2.32	F_1	5.57±1.09	S_1
S_3 and F_1 Males	14.5±4.98	F_1	8.24±1.62	S_3
S_3 and F_1 Females	8.0±3.00	F_1 (N.S.)	9.53±1.33	S_3
F_1 and F_2 Males	37.1±3.48	F_1	5.60±1.23	F_2
F_1 and F_2 Females	19.3±2.10	F_1	3.54±0.99	F_2
S_1 and F_2 Males	8.3±3.75	F_2 (N.S.)	7.86±1.50	S_1
S_1 and F_2 Females	7.2±2.09	F_2	2.03±1.04	S_1 (N.S.)
S_3 and F_2 Males	22.6±4.45	S_3	2.64±1.54	S_3 (N.S.)
S_3 and F_2 Females	11.3±2.83	S_3	5.99±1.32	S_3

In crossing the S_1 (*CCppRRHHAA*) and S_3 (*ccPPRRhhaa*) stock strains we obtain F_1 rats which are agouti in color and of the genetic constitution *CcHhAa*. In the F_2 generation we get all the possible combinations of these three allelomorphic pairs of genes; therefore, if there are major growth genes carried on the same chromosomes, they should be brought to light by the F_2 groupings made in table 5. The data of table 5 do not give any definite evidence that growth genes are linked with the known

TABLE 5

Statistical study of weights of F_2 animals, $S_1 \times S_3$ cross, at 90 days of age.

SEX	GENES	NUMBER OF RATS	*M*	*S. D.*	C. OF V.
Males	*CC*	45	185.1±3.11	31.02±2.20	16.97±1.20
"	*Cc*	60	181.3±3.24	37.29±2.29	15.05±0.92
"	*cc*	36	169.5±3.87	34.47±2.74	20.33±1.61
"	*HH*	51	168.5±3.05	32.38±2.16	19.21±1.28
"	*Hh*	62	190.7±3.27	38.24±2.32	20.05±1.21
"	*hh*	28	177.9±3.75	29.46±2.65	16.43±1.48
"	*AA*	43	186.7±3.65	35.55±2.58	19.03±1.38
"	*Aa*	64	177.8±2.86	34.01±2.02	19.12±1.14
"	*aa*	33	172.4±4.76	40.52±3.36	23.50±1.95
Females	*CC*	27	138.2±3.25	25.12±2.30	18.17±1.66
"	*Cc*	72	143.9±1.67	21.00±1.18	14.58±0.81
"	*cc*	34	147.6±2.24	19.39±1.58	13.12±1.06
"	*HH*	33	145.6±2.32	20.09±1.64	13.79±1.12
"	*Hh*	67	141.4±1.87	22.74±1.32	16.08±0.93
"	*hh*	33	145.1±2.65	22.58±1.87	15.15±1.29
"	*AA*	29	140.4±2.62	20.78±1.84	14.80±1.31
"	*Aa*	74	144.9±1.30	23.02±1.27	15.88±0.88
"	*aa*	30	142.7±2.62	21.60±1.88	15.13±1.31

The data of table 5 are based on the weights of seven more rats than the number used in previous tables. The data on the rats which were added at this point were not complete when previous tables were compiled.

genes. In the case of the F_2 males there is an indication that growth genes are carried on the same chromosome with the gene (*C*) for chromogen. Male rats homozygous for this gene are slightly larger than those in a heterozygous condition, and those in a heterozygous condition are larger than pure recessives (those homozygous for the gene *c* for albinism). This condition does not hold true for the females and therefore cannot be true for the males, unless there is a complementary action between growth

TABLE 6

F_2 Males ($S_1 \times S_3$) weighing 225 grams or more at 90 days of age.

NUMBER	PHENOTYPE	GENOTYPE	NUMBER IN LITTER	AGE IN DAYS				
				30	50	70	90	150
20c	agouti	*Cc Hh Aa*	5 (1)	65	135	220	275	340
40a	black	*Cc Hh aa*	10 (3)	50	100	175	255	320
55*a*	black hooded	*Cc hh aa*	6	55	100	170	255	330
21c	agouti	Failed to breed	5 (1)	65	145	210	250	330
1a	p. e. yellow	*Cc Hh AA*	8 (2)	65	110	175	245	330
10a	p. e. yellow	*CC Hh AA*	8	65	110	165	240	320
14c	p. e. yellow	*CC Hh Aa*	10	50	110	180	240	330
4a	albino	*cc HH Aa*	8 (2)	65	105	170	235	335
39a	agouti	*Cc Hh AA*	10 (3)	50	100	160	235	300
71a	albino	*cc Hh AA*	8 (5)	40	110	165	230	300
88b	albino	*cc Hh Aa*	8	50	120	180	230	270
92b	black	*Cc Hh aa*	9	50	135	185	230	280
27a	p. e. yellow	*Cc HH Aa*	8 (4)	65	120	175	225	280
28a	p. e. cream	*CC Hh aa*	8 (4)	65	115	170	225	245
73a	agouti	*Cc Hh Aa*	8 (5)	40	100	160	225	280
11c	agouti	*CC Hh AA*	10 (6)	40	105	175	225	290
12c	agouti	*CC HH AA*	10 (6)	50	125	180	225	300

F_2 Males ($S_1 \times S_3$) weighing 135 grams or less at 90 days of age.

80a	black	*Cc HH AA*	8 (1)	30	60	100	135	240
81a	p. e. yellow	*CC HH Aa*	8 (1)	30	60	100	130	195
82a	p. e. yellow	*CC HH AA*	8 (1)	30	55	100	130	230
90a	albino	*cc hh aa*	9	35	65	95	130	220
56b	albino	*cc hh aa*	8	30	55	85	130	205
50c	albino	*cc Hh Aa*	7	45	70	110	130	190
70c	agouti	*Cc HH Aa*	8 (2)	40	80	110	130	175
12b	albino	*cc Hh Aa*	8	35	50	80	125	200
86c	albino	*cc Hh Aa*	9	20	45	75	125	180
4b	agouti	*Cc Hh Aa*	10 (3)	35	50	90	120	180
27b	agouti	*Cc HH Aa*	11	25	45	70	120	200
71c	agouti	*CC HH Aa*	8 (2)	25	60	110	120	180
8b	p. e. yellow	*Cc Hh AA*	10 (3)	30	40	80	120	200
3b	agouti	*Cc Hh Aa*	10 (3)	30	50	85	115	190
62b	black	*Cc Hh aa*	9	20	55	70	115	175
10b	albino	*cc HH AA*	10 (3)	30	40	70	110	180
79a	albino	*cc Hh aa*	8 (1)	30	45	75	105	210
1b	agouti	*Cc HH Aa*	10 (3)	30	50	70	100	195
41b	albino	*cc HH aa*	7	20	40	65	100	190

TABLE 7

F_2 Females ($S_1 \times S_3$) weighing 170 grams or more at 90 days of age.

NUMBER	PHENOTYPE	GENOTYPE	NUMBER IN LITTER	AGE IN DAYS				
				30	50	70	90	150
58a	p. e. yellow	*CC HH Aa*	6 (1)	60	110	160	195	230
16a	agouti	*Cc Hh Aa*	8 (3)	60	105	155	190	190
72b	agouti	*Cc Hh Aa*	8	30	90	125	180	230
42a	albino	*cc Hh Aa*	10 (2)	45	85	140	180	210
8a	albino	*cc HH Aa*	8	55	100	155	180	220
83b	agouti hooded	*Cc hh Aa*	5	65	130	160	180	205
57a	albino	*cc hh aa*	6 (1)	50	105	150	175	215
43a	albino	*cc hh aa*	10 (2)	50	90	135	175	210
66a	agouti	*Cc Hh Aa*	10	45	95	140	170	200
8c	agouti hooded	*Cc hh Aa*	8	50	100	145	170	195
51a	albino	*cc Hh Aa*	9	45	90	130	170	200
14a	black	*Cc Hh aa*	8 (3)	60	100	135	170	210
60a	agouti	*Cc Hh AA*	6 (1)	55	100	140	170	220
89b	agouti hooded	*Cc hh AA*	8	50	105	150	170	200

F_2 Females ($S_1 \times S_3$) weighing 115 grams or less at 90 days of age.

51b	agouti hooded	*Cc hh Aa*	10	30	60	90	115	170
44c	p. e. yellow	*CC HH Aa*	6	40	75	100	115	140
92a	black	*Cc Hh aa*	9 (1)	30	60	95	115	200
5b	black	*Cc HH aa*	10 (2)	35	55	95	115	135
7b	agouti	*Cc Hh AA*	10 (2)	35	55	100	115	130
43b	p. e. yellow hooded	*CC hh AA*	7	20	50	80	110	160
16b	agouti	*Cc Hh Aa*	8 (3)	30	50	75	110	160
15b	agouti	*Cc Hh Aa*	8 (3)	40	55	80	110	140
95a	albino	*cc Hh aa*	9 (1)	30	50	80	110	160
93a	agouti	*Cc Hh AA*	9 (1)	30	60	85	110	155
18b	p. e. hooded yellow	*CC hh Aa*	8 (3)	40	60	80	110	150
77b	p. e. hooded yellow	*CC hh Aa*	8	25	50	90	110	140
79c	agouti	*Cc hh Aa*	9 (5)	25	50	75	105	105
86a	albino	*cc HH aa*	8 (4)	25	50	70	100	190
85a	p. e. yellow	*CC Hh Aa*	8 (4)	30	50	75	100	165
14b	agouti	*Cc Hh AA*	8 (3)	40	60	80	100	140
81c	p. e. hooded yellow	*Cc hh Aa*	9 (5)	25	45	70	100	145
83a	black	*CC Hh aa*	8 (4)	30	45	70	90	160
84a	agouti	*CC Hh AA*	8 (4)	30	40	60	85	150

genes linked with the gene for chromogen and genes carried on the Y chromosome. The same condition exists in the case of males of the agouti (*A*) and non-agouti (*a*) gene group, but again the females of the same gene grouping fail to show any indication of growth genes being carried on the same chromosome with the agouti gene.

Grouping of the Heavy Weight and Light Weight rats

The data of table 5 do not throw any definite light upon the cause of the greater variability in weight of F_2 rats when compared to F_1 rats, and it will be of interest to group the heavy and light F_2 rats of each sex and study their genetic constitution. Tables 6 and 7 contain such groups and in connection with this grouping complete data on each rat are given.

At this point it might be well to indicate the significance of the small letters following the number of each rat and also the numbers in parenthesis following the number of rats in the litter to which these rats belong. The system used in ear marking the rats did not extend beyond ninety-nine; therefore, the numbers of the first ninety-nine F_2 rats are followed by a small "a," the second ninety-nine by a small "b" and the third by by a small "c" to distinguish whether they belong to the first, second or third group. The numbers in parenthesis indicate that more than one rat in the male or female division of the table belongs to the same litter, and this same number is placed after each male or female coming from one litter.

Table 6 includes the F_2 male rats weighing 225 grams or more at 90 days of age and the F_2 male rats weighing 135 grams or less at 90 days of age. This table shows that among 141 male rats there were 17 falling in the heavy group and 19 falling in the light group. The 17 heavy weight rats came from 11 different litters and the size of the litters from which they came varied from five to ten young per litter. The 19 light weight rats came from 11 different litters and the size of the litters from which they came varied from six to ten young per litter.

The weights of nine rats (numbers 1b, 3b, 4b, 8b, 10b, 79a, 80a, 81a, and 82a) in the light group can be explained on a nutritional basis and should not be considered from the standpoint of heredity. Rats bearing numbers 1b, 3b, 4b, 8b, and 10b are litter mates from a litter of ten in number. This litter was marked at weaning time as being in an unthrifty condition. This unthrifty condition was indicated by rough coats and lack of vitality. There were six male rats and four females in the litter. One male died when fifty-five days of age and the remaining five males all fall into the light group of males. Two of the four females of this litter

(numbers 5b and 7b) are to be found in the light group of females, table 7. Rats bearing numbers 79a, 80a, 81a, and 82a are litter mates and from a litter of eight in number. This litter was noted at weaning time as being in the same physical condition as the litter previously discussed. There were four males and four females in this litter. All males are found in the light group and all their litter sisters (numbered 83a, 84a, 85a, and 86a) are found in the light group of females (table 7). These are the only rats included in tables 6 and 7 of which a poor physical condition was observed during the time they were on the experiment. By eliminating the nine rats of these two litters there remain ten male rats in the light weight group and these ten rats represent nine different litters.

In studying the remaining rats of these two groups, there is no evidence of any linkage between the known genes and growth genes. Their known genetic combinations are as varied as could be expected in so small a number. They come from a relatively large number of litters and from litters of large size as well as from litters of medium size. There is no evidence that the rats of the heavy group are from smaller sized litters than are the rats of the light group. In fact by the elimination of only one of the litters as previously discussed there would not remain a single rat in the light group coming from a litter above nine in number, while there are five rats in the heavy group belonging to three different litters of ten in number. This would indicate that size is probably inherited as a multiple gene condition, and that chromosomes other than those studied carry the major growth genes, if such exist.

The diploid number of chromosomes of the rat (*Rattus Norvegicus*) according to the recent work of PINCUS (1927) is 42. He found an unequal pair in the spermatogonial divisions which he concluded were the sex chromosomes. Since the present study involves only six diploid chromosomes there is still an ample number of chromosomes not included in the study for an assumption that there are size genes carried on the unstudied chromosomes.

Table 7, which has been referred to in my discussion of table 6, includes the F_2 female rats weighing 170 grams or more at 90 days of age and the F_2 female rats weighing 115 grams or less at 90 days of age. This table shows that among 133 female rats there were 14 falling in the heavy weight group and 19 falling in the light weight group. The 14 heavy weight rats came from 10 different litters and the size of the litters from which they came varied from five to ten young per litter. The 19 light weight rats came from 9 different litters and the size of the litters from which they came varied from six to ten per litter. If we eliminate rats

of the light group belonging to the two litters discussed in connection with table 6, there will remain 13 rats in the light weight group. These 13 rats came from seven different litters and the size of the litters from which they came varied from six to ten young per litter.

The same conclusions can be drawn from the data of table 7 as were drawn from the data of table 6. There is no evidence that size genes are carried on the three pairs of chromosomes studied and no evidence that the size of the litters from which the two groups of rats came influenced the

TABLE 8

Variation in litter size and weight and correlation between litter size and weight of 141 F_2 ($S_1 \times S_3$) males at 90 days of age.

	SIZE OF LITTER										
WEIGHT IN GRAMS	3	4	5	6	7	8	9	10	11	12	TOTALS
100–105					1	1		1			3
110–115							1	2			3
120–125						2	1	2	1		6
130–135					1	5	1				7
140–145					1	4	2	3	3		13
150–155		1		3	3	1	4	2			14
160–165		1		1	4	3	1	1			11
170–175					2	2	5	2			11
180–185	1				4	7	1	5			18
190–195					2	6	3	2			13
200–205	1		1			2	6	3			13
210–215			2		1	3	1	2			9
220–225				1		3	2	3			9
230–235						3	1	1			5
240–245						2		1			3
250–255				1				1			2
260–265											
270–275			1								1
TOTALS	2	2	4	6	19	44	29	31	4		141

Mean litter size = 8.30 Mean weight = 177.2 grams
Standard deviation = 1.54 Standard deviation = 35.54 grams
Coefficient of variation = 18.55 percent Coefficient of variation = 20.05 percent
Coefficient of correlation (litter size and weight) = 0.10 ± 0.05

size of the rats at ninety days of age. The only explanation which we can offer as to the size difference of these two groups of F_2 rats is that size is inherited as a multiple gene condition and that the major growth genes are carried on the unstudied chromosomes.

Correlation Between Litter Size and Weight

Tables 6 and 7 indicate that size of litter has little if any effect upon the weight of F_2 ($S_1 \times S_2$) rats. In order to know the definite relationship between litter size and weight, correlation tables have been made for both male and female rats. Tables 8 and 9 show that a very slight correlation,

TABLE 9

Variation in litter size and weight and correlation between litter size and weight of 133 F_2 ($S_1 \times S_3$) females at 90 days of age.

WEIGHT IN GRAMS	SIZE OF LITTER 3	4	5	6	7	8	9	10	11	TOTALS
80–85						1				1
90–95						1				1
100–105						3	2			5
110–115				1	1	3	4	3		12
120–125				1	3	5	3	4		16
130–135		1			3	5	4	6	5	24
140–145		1	2	2	3	6	3	2	2	21
150–155			1	1	1	6	7	5	1	22
160–165					3	7	3	3		16
170–175			1	2		3	1	2		9
180–185			1			2		1		4
190–195				1		1				2
TOTALS:		2	5	8	14	43	27	26	8	133

Mean litter size = 8.38 — Mean weight = 141.30 grams
Standard deviation = 1.52 — Standard deviation = 21.52 grams
Coefficient of variation = 18.13 percent — Coefficient of variation = 15.23 percent
Coefficient of correlation (litter size and weight) = 0.12 ± 0.06

but of doubtful significance, exists between the litter size and weight of F_2 rats at 90 days of age, the coefficient of correlation being 0.10 ± 0.05 for the male rats and 0.12 ± 0.06 for the females. These coefficients of correlations indicate that we are safe in saying that the size of the litter had very little effect upon the weights of the rats of the F_2 generation. These tables include the two litters which were eliminated from tables 6 and 7 on the ground that their small size could not be due to heredity.

Various Gene Combinations

Table 10 gives the average growth weights of $F_2(S_1 \times S_3)$ rats of various gene combinations. This table included all tested F_2 rats, or 141 males and 133 females. The rats were first grouped according to the number of

dominant genes and then according to the homozygous or heterozygous condition of the genes. After a careful study of the data of this table,

TABLE 10

Average weights of $F_2(S_1 \times S_3)$ animals of various gene combinations at ages 30–150 days.

SEX	GENE COMBINATION	NUMBER OF INDIVIDUALS	AGE IN DAYS				
			30	50	70	90	150
Males	3 Dominant	67	42.98	88.95	134.32	180.37	266.41
"	2 "	55	40.90	85.72	131.45	175.09	241.27
"	1 "	15	44.33	84.33	128.33	176.66	242.00
"	0 "	4	32.50	68.75	108.75	150.00	222.50
Females	3 "	59	40.00	80.33	141.61	139.70	176.77
"	2 "	55	40.54	78.81	112.00	139.40	177.72
"	1 "	15	40.33	82.66	113.00	141.66	182.33
"	0 "	4	43.75	91.25	135.00	161.25	197.50
Males	3 Homozygous	26	39.61	80.38	117.69	165.60	232.69
"	2 "	56	43.05	89.28	134.10	179.00	248.30
"	1 "	47	42.97	88.29	135.51	179.20	243.51
"	3 Heterozygous	12	38.75	81.25	132.08	180.40	241.66
Females	3 Homozygous	16	39.06	82.18	117.50	142.80	183.75
"	2 "	46	42.93	82.60	114.67	139.90	180.65
"	1 "	46	40.10	78.15	109.13	140.10	179.02
"	3 Heterozygous	25	38.20	78.80	110.80	140.20	176.80

I am convinced that there is no relation between the size of rats and the number of known dominant genes, or between size and the homozygous and the heterozygous condition of the genes studied.

CONCLUSIONS ON EXPERIMENTAL WORK

In this study of three known pairs of allelomorphic genes there is no evidence that the known dominant genes, or that the heterozygous condition of the genes studied has any influence on the size of F_2 rats of the S_1 and S_3 cross.

There is no definite evidence that growth genes are linked with the genes studied, but on the other hand there is no evidence that growth genes are not carried on chromosomes not studied. The rats of the F_2 generation of the S_1 by S_3 cross were more variable than the F_1 rats of this cross, and when the heavy and light rats of the F_2 generation are grouped for study there is evidence that the difference in size of the rats of these two groups

must be due to hereditary size genes probably carried on the unstudied chromosomes.

This study does not give an answer to the question as to the cause of hybrid vigor or heterosis, but it does give additional information on the three pairs of chromosomes studied.

SUMMARY OF EXPERIMENTAL RESULTS

1. Hybrid vigor or heterosis was shown by the F_1 rats in each cross studied.

2. Heterosis was more marked in the F_1 rats of the S_1 by S_2 cross than in the F_1 rats of the S_1 by S_3 cross, as would be expected since there was a greater difference in the size of the parent races in the former cross.

3. There was a distinct loss of vigor shown by the F_2 rats of each cross as compared to the F_1 rats.

4. This loss of vigor was more marked in the case of the F_2 rats of the S_1 by S_3 cross.

5. The F_1 rats of each cross were less variable in weight than the rats of the respective parent strains.

6. The F_2 rats of each cross were more variable in weight than F_1 rats, although the difference in the variability was not sufficient to be significant in the case of the F_2 rats of the S_1 by S_2 cross.

7. The F_2 rats of each cross were less variable than the rats of the respective parent strains.

8. The grouping of F_2 rats of the S_1 by S_3 cross according to known allelomorphic genes does not show any definite evidence that the three pair of chromosomes studied carry growth genes.

9. The grouping of the heavy weight and light weight F_2 rats does not show any relation between the size of the rats and their known genetic constitution. This grouping also fails to indicate that size of the litters, from which the heavy weight and light weight rats came, has influenced the weight of the F_2 rats.

10. There exists a very slight correlation between the litter size and the weight of F_2 rats, but this correlation is too small to account for the extreme difference in the weights of rats contained in the heavy weight and the light weight groups of tables 6 and 7.

11. The grouping of F_2 rats according to the number of known dominant genes in their genetic constitution does not show any evidence that these genes influence the size of the rats.

12. The grouping of F_2 rats according to the homozygous or heterozygous condition of the known allelomorphic genes does not show any evi-

dence that either the homozygous or heterozygous state has any influence on the size of the rats.

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