A GENETIC STUDY
ON
HETEROSIS INVOLVING TWO INBRED LINES OF MICE

Thesis

Submitted to the
RAJENDRA AGRICULTURAL UNIVERSITY, BIHAR
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF SCIENCE (ANIMAL HUSBANDRY)
IN
ANIMAL BREEDING AND GENETICS

By
Ramadhar Roy
B. V. Sc & A. H.
I. C. A. R. JUNIOR FELLOW
Post-Graduate Department of Animal Breeding & Genetics
BIHAR VETERINARY COLLEGE
PATNA.

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DEDICATED

TO

HEAVENLY MOTHER.

BIHAR VETERINARY COLLEGE
PATNA
Acc. No. 13433
Date 3-9-2005

Dr. H.R. Mishra,
M.S., Ph.D. (Minn.), U.S.A.,
Head of Department
Animal Breeding and Genetics,
Rajendra Agricultural University, Bihar
and
Principal, Ranchi Veterinary College,
Kanke, RANCHI-7.

RANCHI-7,

Dated, the 10-2- ,1974.

This is to certify that the work embodied in this THESIS entitled "A Genetic Study on Heterosis Involving Two Inbred Lines of Mice" is the bonafide work of Shri Ramadhar Roy and was carried out under my guidance and supervision.

10.2.

(H.R. Mishra).

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C E R T I F I C A T E

Certified that the research work incorporated in this Thesis have not been published in part of in full in any other journal.

Ramadhar Roy

(Ramadhar Roy).

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A C K N O W L E D G E M E N T

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Ramadhar Roy

(Ramadhar Roy).

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ABBREVIATION AND SYMBOLS FREQUENTLY USED

B_{28}	-	body weight at 28 days.
B_{42}	-	body weight at 42 days.
C.D.	-	Critical difference.
C.V.	-	co-efficient of variation.
d.f.	-	degree of freedom.
F.	-	F value.
gms.	-	gramme.
L.S.	-	litter size.
L.C.	-	lines and control crossbreds.
M.S.	-	Mean sum of square.
N.S.	-	non-significance.
%	-	percent.
S.E.	-	standard error.

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INTRODUCTION

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I N T R O D U C T I O N

Heterosis constitutes the heart of the commercial livestock production as being practiced today. This in turn depends upon the degree of heterozygosity which again is principally affected by the genetic architecture of the populations crossed. "Although free crossing is a danger on the one side which everyone can see, too close inbreeding is a hidden danger on the other". Crosses of distinct genetic groups can be made either for direct production of commercial animals, or to develop new seed stocks which will be used eventually as parental strains.

The term heterosis is defined as superiority of the offspring over the average of the parents. Heterosis is opposite to inbreeding depression (Falconer 1960). When inbred lines are crossed the progeny show an increase in those characters that previously suffered a reduction from inbreeding. Hybrids are usually more vigorous and productive than their pure bred parents and this superiority of the crossbreds in the form of increased vigor is termed "heterosis" which includes greater pre and post natal viability, faster growth rate, fertility and improved mothering ability. The phenomenon is not restricted to hybridisation but is also exhibited in strains or line crosses of the same breed. The amount of heterosis obtainable, usually, depends upon the extent of heterozygosity attained by the hybrid, which in turn depends upon the diversity of

the lines or strains to be crossed and level of dominance for which heterosis is being exploited. If the population crossed do not differ in gene frequency there will be no heterosis, and the heterosis will be greatest when one allele is fixed in one population and other allele in other population.

Amount of heterosis exhibited by a particular cross depends upon the difference of the gene frequencies between the two populations crossed. This indicates that the amount of heterosis will increase with the degree of genetic differences between the two populations and is limited only by barrier of interspecific sterility. Heterosis is also produced by the joint effect of all the loci as the sum of their separate contributions. Hence genes combine additively to produce heterosis (Falconer 1960). Heterosis also depends upon directional dominance i.e. dominant gene should have similar effect for one particular character; if some loci are dominant in one direction and some are in the other, their effects will be neutralised and ultimately there will be no heterosis.

The conditions under which inbreeding and crossing are likely to be better means of improvement than selection without inbreeding is when much of genetic variance of the character is non-additive. Lower heritabilities and large inbreeding depression for characters long and intensely selected in one direction indicates higher degree of dominance as compared to those selected in varying directions (Dickerson 1952).

Crossbreeding and line breeding are of great value in

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evolving lines of desired character and in exploitation of heterosis and in studying specific combining ability of the lines or strains. In large animals crossing inbred lines or strains at different levels of inbreeding is almost prohibitive as the majority of lines die-out mainly because of infertility, decreased survival rate- before attaining desired inbreeding level, and also because of high financial involvement, and long generation interval. Feasibility of conducting any research work in mice is more because the desired level of inbreeding can be achieved in a short period without more expenditure.

Applicability of mice results to large animals should obviously be checked before complete confidence can be placed in application; preliminary results may be obtained with relatively less expenditure and in short period. Mouse is more similar to a cow and a pig than Drosophila; results from the mouse may be much more readily applied to the large animals inspite of species variation.

Considering the importance of heterosis in Animal Genetics and Breeding, it was considered to be of value to conduct a study like this with specific populations of diverse genetic architecture under a particular set of environment. Although such studies have been conducted else where also, in view of differing genetic materials and environmental conditions, the studies made may be of use in interpreting heterotic studies in farm animals. The plan during this work has been to study the magnitude of heterosis while crossing two inbred lines of mice at different levels of inbreeding. The lines have been separately crossed to a randomly bred control

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population. The magnitude of heterosis along with other estimates of genetic and phenotypic parameters viz. phenotypic correlations alongwith other supporting items have been studied as reported in the subsequent chapters.

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GENETIC THEORIES OF HETEROSIS.

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GENETIC THEORIES OF HETEROSIS

Keeble and Pellew (1910) proposed "Dominance theory" of hybrid vigour and they suggested that the greater height and vigour observed in F_1 hybrid pea was possibly due to meeting in zygote of dominant growth factor in more than one allelomorphic pairs. Bruce (1910) proved mathematically that there were fewer homozygous recessives at a particular locus in the F_1 population than the mean number of two parent stocks. He assumed without evidence that dominance was positively related to fitness and cross of two pure breeds produces a mean vigour greater than mean vigour of parents.

Theory of "Dominance of linked factor hypothesis" was advanced by Jones (1917, 1918). This theory rests on the assumption that vigour is dominant over lack of vigour; when two lines which are homozygous for certain characters having their genotypes as AAbb x aa BB are crossed the resultant offspring would be AaBb. Since it carries one dominant gene at each locus, the offspring would be more vigorous than either of the parents.

The term heterosis was coined by Shull (1914) in place of heterozygosis. At early stage, heterosis was usually stated to be increased vigour in hybrid due to rapid cell division as stimulated by heterozygous condition of the genotype. Shull (1912) attributed "hybrid vigour to the effects of a changed nucleus and unaltered cytoplasm upon each other".

East (1936) suggested that heterozygosity itself is a cause of heterosis which was also an extension of non-linear gene action postulated earlier by Rasmusson (1933) in order to explain the inheritance of quantitative characters. East's hypothesis did not find widespread acceptance but the idea of heterosis from intra-locular intraction was favoured (Singleton, 1943; Jones, 1945; Rendel, 1953).

The theory of over-dominance introduced by Hull (1945) which explains a situation where a heterozygous individual (Aa) excels either of the homozygotes (AA or aa) in performance. Over-dominance is the result of both the intraction of allelic genes of increased non-allelic action.

Lerner (1954) concluded that over-dominance is related to fitness and is very important.

Falconer (1960) stated that heterosis does not merely depend upon the dominance of the loci but also on their directional dominance. That is the dominant loci should be dominant in one direction. Heterosis is also produced by joint effects of all the loci as the sum of their separate contributions, so genes combine additively to produce heterosis.

If the populations crossed do not differ in gene frequency there will no heterosis, and the heterosis will be greatest when one allele is fixed in one population and other allele in the other. Amount of heterosis exhibited by particular cross depends upon differences of the gene frequencies between the two populations

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crossed. This indicates that the amount of heterosis will increase with the degree of genetic differences between the two populations.

Epistatic effects and divergence of allelic factors and interaction involving several loci play important role in production of heterosis.

None of the above mentioned theories can adequately explain the real mechanism of heterosis, and to explain it more research work needs to be done.

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REVIEW OF LITERATURE.

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REVIEW OF LITERATURE

The available relevant literatures have been reviewed under the following heads:-

1. (a) Heterosis in body weight.
   (b) Heterosis in litter size.
2. Inbreeding depression.
3. Environmental and maternal effects.

1. (a) Heterosis in body weight :-

Bell et al. (1953) concluded that the crossing of the inbred lines was superior to any other method of breeding for obtaining maximum heterosis for the character which was not highly heritable. Recurrent Selection and Reciprocal Recurrent Selection were less effective for obtaining maximum heterosis for the character of low heritability.

Taketome and Natsuo (1957) studied the performance of incrosses between inbred lines in mice; they studied mortality from birth to 20 days in two lines D and sc. The F_1 crosses between these lines, the F_2 animals and the back crosses between DxF_1 and sc x F_1, F_1 were intermediate between the parental lines in the mortality rate whereas the F_2 and the back crosses showed lower rates. The number of offsprings per litter increased markedly when F_1 females were used. The F_1 females were also superior in milking

ability, as judged by increased body weight of suckled young at 10 to 20 days of age.

Butler (1958) found that the amount of heterosis for body weight in a cross between two inbred lines in the mice, increased with age. At 60 days of age F_1 were heavier, but the differences were not significant at 30 days. He concluded that 30 day weight was largely a maternal character. However, the same F_1 genotypes, when themselves used as mothers, increased the 30 day weight of their offspring by 10 to 20%.

Mason et al. (1960) reported negative heterosis in growth rate in a cross of 4 inbred strains according to diallel scheme. They explained this result in terms of physiological function - in that inbred mother may not be able to meet all requirements of her crossbred offspring.

Frank et al. (1962) observed reduced growth rate at all stages in one of the five crosses of inbred mice.

Carmon (1963) mated four strains of mice in a complete diallel form. Out of four strains, only one was highly inbred, all his crosses showed considerable heterosis for body weight at 21 and 45 days of age. He also analysed the data in terms of general combining ability which was the average performance of a line in hybrid combination and specific combining ability, which measured whether specific crosses deviated from expectations based on the average performance of the parental lines.

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Comstock et al. (1963) crossed a strain selected for increased growth described by Rahnefeld et al. (1963) to a long inbred line at each generation of selection, the superior growth of the crosses over the inbred level did not differ significantly.

Bruell (1964) reported on inheritance of behavioral and physiological characters of mice and problems of heterosis, over 4000 mice belonging to 13 inbred stains and 31 groups of F_1 hybrids. He found heterosis influenced only traits which had been subjected to selection.

Champman (1965) studied reproductive performance in hybrid female mouse. Crossbred dams were more suitable than inbreds for obtaining hybrid pregnancy for sire evaluation owing to the more uniform influence on the sire progeny.

Bentvelizen et al. (1966) while studying heterosis and inbreeding depression in respect of reproduction in mice observed fewer young ones in all the inbred strains than the crosses (due to smaller number of litters) and showed sterility in the both sexes, smaller litter size at birth and higher at preweaning mortality. The first two characters above were due to the individual deleterious recessive genes.

Heterozygosity of the dam and an important influence on litter size at birth while heterozygosity of the embryos resulted in increased parental viability and litter size. A good correlation between genes and in heterozygous combination and parental viability were also observed.

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Shibata (1966) made a genetical and biometrical study of the variabilities of the body weight in the F_1 and F_2 hybrids between two highly inbred albino strains of mice. Two Reciprocally crossed inbred lines also produced F_2 generation. Litter size averaged 6.12 and 8.75 in the two purebred lines respectively. Litter size was 7.56 and 8.13 for DM male x SWR female and reciprocal matings respectively. F_1 had a litter size of 10.50; F_1 exhibited marked heterosis for body weight at 28 days but there was little heterosis thereafter. There was little or no heterosis in F_2s. Body weight was less variable in F_1s than in purebreds and F_2s.

Body weight and litter size study of some inbred strains and their F_1 and F_2 hybrids by Shibata (1967) involved 3 inbred strains of mice and their F_1 and F_2 hybrids. Significant strain differences in average litter size (5.84, 6.25, 6.67, in the three strains respectively) in brother-sister matings were recorded. The F_1 animals produced larger litters than in the parental strains. Males were more in number than females and were also heavier than females at birth and at 21, 28, and 60 days. Heterosis was observed in early stage of growth. Highest coefficient of variations (C.V.) at weaning or 1st week after weaning were recorded and the same were lowest at 60 days. Variability was not higher in F_1 hybrids than in parental strains at corresponding stages; the F_2 hybrids showed greatest variability at all stages. Significant negative correlation between litter size and average body weight at the various stages were found. Very high genetic correlation was

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found between body weight at 21 days and 28 days of age and between 40 and 60 days, but correlation between body weight at weaning and one week after weaning and that at 60 days of age were very low. The heritability estimates for body weight at birth and at 40 days were in F_1 hybrids than in the parental strains.

Roberts (1967) showed results of crosses between previously selected line and out crosses. The lines that had reached the limit for large size were crossed to form a base population for further selection for nigh size weeks weight. Similarly the small lines selected to the limit were crossed and the crossbred population was selected for low size week weight. In every case, cross between two selected lines resulted in heterosis increasing body weight.

Kownacki (1968) reported heterotic effect of inbred x outbred matings. Matings between inbred male and outbred female were much more successful than the reverse matings in respect of mean number and young weaned (8.56 v 6.64); mean individual weights of offspring at 20 days (8.6 g v 7.16 g for male and 8.42 g v 7.32 g for female) and mean individual weights of offspring at 4 month was not significant (29.90 g v 24.44 g). Female offspring from two types of matings also did not differ significantly in the size of the litters (6.80 v 6.88) when they were mated to unrelated outbred male.

Randomska et al. (1970) reported heterosis resulting from crossing of certain inbred strains of laboratory mice single

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cross reciprocals and double cross reciprocals. No heterosis was observed in the litter size but body weight at 21 days showed heterosis. Significant differences between the parental strains and their hybrid (upto 84 days) and also significant sex differences were noted.

Heterosis occurred in respect of litter size when double crossbreds were obtained. But significant differences in types of mating were not found. Body weight of the double crosses were much higher than that of single crosses especially at 12 days.

Nagai (1971) studied heterosis, combining abilities and maternal abilities in mouse litter weight. Four inbred strains of mice were mated in all possible combinations to produce inbred and F_1 hybred litters. Each litter was divided into two groups on the basis of sex. The total weight of the individuals in each group (group weight) and number of individuals within each group (group sex) were recorded at birth and 12, 25 and 45 days of age. The average weight of individual within a group was calculated for each group. Least square analysis of group weight, group size and average weight were performed. Significant sex difference in group weight only at 25 and 45 days was observed. The 4 inbred strains did not differ significantly in group weight at any age. Group weight was higher in F_1 hybrids than in outbreds at 4 ages. Heterosis in group weight was mainly due to heterosis in average weight.

Sharma (1971) crossed inbred mice of two groups reciprocally and out crossing was also done. Crossbreds were found to be

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inferior by 0.70 g and 1.84 g to their respective mid-parental values.

(b) Heterosis in litter size:

Eaton (1941, 1953) crossed nine inbred strains to test their fertility. About half of the crosses produced F_1 litters exceeding those of either parent strain, though some crosses were even inferior. The combination of three inbred strains, using a hybrid dam, gave a greater increase in litter size.

Forsthaefel (1954) took one inbred strain and split some litter. Some females were mated to their brothers while their litter mates were mated to inbred males of another strain. Crossbreeding increased litter size from 4.8 to 6.8. The increase seemed to be brought about by masking the recessives that reduced viability in the uterus.

Falconer (1955) and Bateman (1965) concluded that male had no direct influence on litter size when mated at random to groups of dams. On the other hand, Finn (1964) found a statistically significant effect. But it is possible that males may occasionally have a low fertilising capacity as Krzanowska (1960) found in one inbred line. Litter size was partly determined by the genetic constitution of the dam and as well of litter itself. Butler(1958) crossed two inbred strains reciprocally. One strain showed an increase in litter size whereas the other did not. Butler concluded that crossbreeding in the dam had a greater and more uniform

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effect in increasing fertility than cross breeding in the litter.

Bogart et al. (1958) reported that crossing does not always result in increased fertility. Four inbred strains according to diallel scheme were crossed. Heterosis in respect of litter size in first cross was obtained only in three out of 12 possible crosses (treating as reciprocal). In five crosses, litter size was near the mid parental value. In remaining four crosses, litter size was reduced markedly. They interpreted the result as due to endocrine function and also due to highly specific Vitamin requirements of some crossbreds which the pure strain mother were unable to provide.

In mice experiments of Roberts (as cited by Falconer 1960) after third generation of inbreeding, crosses were made at random between the lines; in the next generation crosses between the F_1s were made so as to give crossbred mother and the non-inbred young. The mean litter size observed at the different stages are given below.

	Litter size
Inbred (litters F_x= 50%)-	5.7
Crossbred -	8.5

In this experiment heterosis observed 2.8.

Frans et al. (1962) crossing an inbred strain with five others observed heterosis in respect of litter size in four crosses and inferior litter size than either parents in the remaining crosses.

Martin et al. (1963) crossing four strains in complete

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diallel form found non-significant heterosis in litter size at birth.

McCarthy (1965), reported the effect of crossing inbred strains on litter size in mice. Three of his four inbred strains showed an increase in litter size on crossing, whereas the fourth did not.

Bentvelzan et al. (1966) while studying heterosis and inbreeding depression in respect of reproduction, found that all the inbred strains had fewer young ones than the crosses and showed sterility in both sexes, also smaller litter size at birth and higher preweaning mortality. Heterozygosity of the dam and embryo resulted in an increase in prenatal viability and thus increasing litter size.

Randomska et al. (1970) reported heterosis resulting from crossing of certain inbred strains of laboratory mice. No heterosis in litter size in single reciprocal cross was observed but heterosis in respect of litter size in double crosses was found.

Evsikov et al. (1972) studied embryo mortality and its effect on litter size of mice in two lines and their reciprocal crosses. Postnatal mortality at 5 weeks age was 14.9, 27.2, 7.9, 22.8 respectively. Significant differences between different types of matings were also observed. Heterosis of the offspring reduced both pre and post implantation mortality, and reciprocal differences indicated that dams genotype also affected embryo mortality.

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2. Inbreeding depression:

Butler (1958) reported inbreeding effect on Mac Arthur's large and small strains through 20 generations of brother sister mating. Some of the lines failed to survive the inbreeding but among the survivors, the large mice became smaller when inbred, while the small one became larger. The decrease in large mice was due to inbreeding depression; the increase in the small mice was explained as due to differential fertility, as smallest mice failed to reproduce, some line became extinct.

From an outbred population Roberts (1960) derived 30 partially inbred strains and crossed these in random manner, when the inbreeding coefficient had reached 50% with no selection during the inbreeding stage, except for natural selection operating within lines. Litter size was found to decline markedly during the inbreeding stage at the rate of about half a mice per 10% inbreeding.

Bowman and Falconer (1960) investigated the influence of (a) artificial selection for large litter size during inbreeding and (b) selection between lines. Lines become exinct as they became too infertile to maintain. From the same base population as in Roberts (1960) study, twenty inbred lines were derived and maintained by full sib matings. A decline in litter size of 0.56 mouse per 10% of inbreeding was observed which is in close agreement with that of Roberts. An inbreeding depression in litter size of roughly 0.5 mouse per generation was observed both by Roberts and by Bowman and

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Falconer as a result of rapid inbreeding due to full-sib mating. Falconer (1960) found no reduction in litter size from inbreeding in a population even after 31 generations of inbreeding while the inbreeding coefficient was 0.32.

Krzanowska (1964) tried to determine the causes of lower rate of pregnancy observed in inbred mice as compared with cross bred animals. Reciprocal cross of two inbred strains and outbred strains were used. The percentage of females that delivered litters within 23 days of pairing was much lower in inbred lines than in crossbred and outbred only.

McCarthy (1967) reported effect of inbreeding on component of litter size in mice. Twenty four lines were bred from a base population of out bred females by continued full-sib mating. For inbreeding levels in dams and their litter of 0 to 25% respectively litter size reduced non-significantly by 0.8 offspring and there were significant reductions of 1.2, 2.3, 3.0, and 2.7 offspring inbreeding level of 25 (dam) and 38 (litter),38 and 50, 50 and 59, 59 and 67% respectively. In the first inbred generation the decline in the litter size was due to reduction in the ovulation rate of inbred dams and due to increased pre-implantation mortality from inbreeding of dams.

McCarthy (1968) reported the effect of inbreeding on birth weight and foetal and plancental growth in mice. Inbreeding did not cause depression in birth weight. Foetal weight at 17½ days of the gestation was significantly depressed in the 2nd, 3rd,

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and 4th generation of inbreeding by 0.042 gms, 0.043 gms and 0.076 gms respectively. This depression was attributed both to inbreeding in the litter and in the dam. In outbred litters produced by partially inbred dams, foetal weight reduced but not significantly.

Sharma (1971) studied the effect of brother sister matings for two generations in three inbred groups and found decline with 42 days average male weight by 3.32 gms, 0.51 gms and 2.71 gms respectively and the female average weight by 3.49 gms, 0.63 gms and 2.30 gms respectively as compared to their respective base populations. Decline in body weight in two groups was highly significant for both sexes.

Sharma (1971) observed that for every 10% increase of inbreeding coefficient there was inbreeding depression in litter size of roughly 0.53 mouse per litter in 1st group 0.16 per litter in 2nd group and 0.24 per litter in the third group.

White (1972) studied effect of inbreeding upon growth and maternal ability in mice. Increasing level of inbreeding in the both sets of experiments significantly depressed birth weight and weight at 12, 21, 42, and 56 days and also litter size.

3. Environmental and maternal effect on body weight and litter size:

MacDowell et al. (1929) noted that the larger mice tended to produce larger litters and the smaller ones the smaller litter. This is a great maternal effect on the litter size associated with the body weight of the dam. A large mouse tended to

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produce a large litter, with the result that the individual weights of her daughters were depressed. When these daughters were mated, they tended to produce smaller litters.

Falconer (1953) calculated standardised regression coefficients relating litter size to the body weight of the dam and size of the litter in which the dam was born. The body weight of the dam was negatively correlated with the size of the litter in which she was born, but was positively correlated with the size of the litter which she produced.

Butler and Metrakos (1950) studied the maternal effect on the body weight by cross-fostering experiment. Whenever strains of mice were crossed reciprocally, the reciprocal reflected the maternal and environmental differences in their growth.

Butler (1958), Carmon (1962), Franks et al. (1962), Mason et al. (1960) had found maternal effects on these characters.

Barnett (1964) studied heterozygosis and survival of young mice in two temperatures. At both temperatures litter size tended to be greater when inbred females were mated with males of another strain than for within strain matings. Random bred mice had the largest litter size at both temperatures. Survival between birth and weaning was better at 21°F, in one cross than the reciprocal ones.

Nagai (1971) studied maternal abilities in mouse litter weight. Maternal effects on group weight differed significantly

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among the 4 strains studied at 12, 25 and 45 days. These differences in maternal effects were mainly due to the differences in the maternal effect on group sizes. When group weight was adjusted for group size, a shift in ranking of strains was observed in the inbred strains due to maternal effect.

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MATERIALS AND METHODS.

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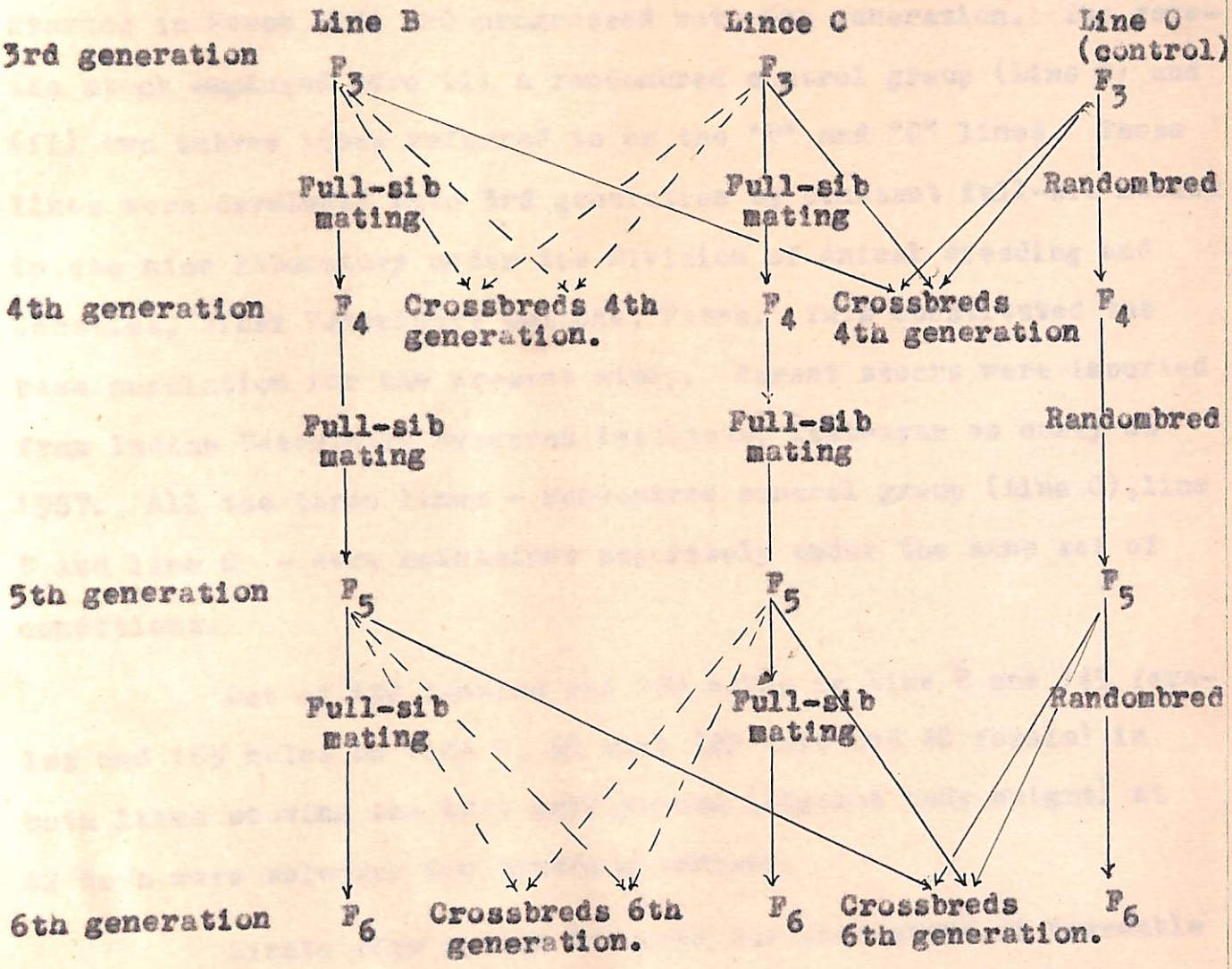
MATERIALS AND METHODS

Diagram showing plan for experimental mating:



Third generation individuals of line B, C and control were treated as base population for this experiment.

M A T E R I A L S.

The data used in this present study were obtained in a research experiment (cross breeding study for heterosis), which was started in March 1973 and progressed upto 6th generation. The genetic stock employed were (i) a randombred control group (Line O) and (ii) two inbred lines referred to as the "B" and "C" lines. These lines were developed upto 3rd generation by constant full-sib mating in the mice laboratory under the Division of Animal Breeding and Genetics, Bihar Veterinary College, Patna. This constituted the base population for the present study. Parent stocks were imported from Indian Veterinary Research Institute, Izatnagar as early as 1967. All the three lines - randombred control group (Line O), line B and line C - were maintained separately under the same set of conditions.

Out of 150 females and 160 males in line B and 145 females and 165 males in line C, 60 mice (20 male and 40 female) in both lines showing the best performance (highest body weight) at 42 days were selected for breeding purpose.

Single sire system was used for each group of breedable females. The number of females allotted to a male mice varied according to number of females selected from each family 1 : 1 to 1 : 5. The male was allowed to remain with the female for a period of 16 days. Pregnant females were removed in separate cages for littering on the 17th days. The females unable to produce litters

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after 21 days of separation from male mice were culled and not taken into account.

For the litter size, the live young ones born in each litter were counted as soon as possible after birth. Litters at 28 days were weaned, weighed, marked with picric acid and sexed. The different sexes were separated and reared in separate cages. All the mice were weighed at 28 days and 42 days after birth. Abnormal mice were culled.

First phase of mating:

Forty females and twenty males of full-sib family were selected in both the lines. Among the full brothers those showing best performance at 42 days were selected for mating. Selected brothers and sisters were allowed to remain in the breeding cage for 16 days and after that the male was removed andimmediately culled. The pregnant females were separated and kept in separate cages for littering.

At about 19th to 20th days of gestation, sterilised cotton was provided in cages of female mice for nesting. Out of 40 females, 28 in line B and 26 in line C produced 158, 192, litter respectively in the 4th generation. At 28 days litter was weaned, weighed marked with picric acid.

Second phase of mating:

Out of 106 mice in line B, 60 were females and 46 were

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male, and out of 118 in line C, 60 were female and 58 were males. Sixty females and twenty males in both lines were selected for breeding purpose. The rest were culled and discarded. Such families having no brother or sisters were also discarded from the experiment. Sexually mature full-sibs were allowed for breeding and to remain to together for 16 days. After 16th days, males were removed and females were separated in separate cages for littering. Out of 60 mice, 50 in line B and 38 in line C produced 258 and 228 litters respectively in the fifth generation.

Third phase of mating:

At fifth generation of inbreeding, 15 full-sibs in each lines having 40 females and 15 males were selected for breeding in each lines. Those selected mice were kept in breeding cages for 16 days for breeding. Twenty three and 32 out of 40 female in line C and B respectively could litter. Total litter number at birth was 104 and 148 for line C and B respectively.

Crossing between line B and C at third generation of inbreeding:

Forty females in each lines were randomly grouped in 8 groups in both lines and 10 males were selected on the basis of their highest performance at 42 days in terms of body weight. Selected males were numbered from 1 to 10. Groups consisting of 5 females chosen randomly were made and numbered from 1 to 8. Each groupsof females of line B were randomly allotted to a male of line C and simillarly females of line C to male of line B were

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allotted. Males were removed from the females after 16 days and pregnant females were separated in separate cages for littering. Twenty six mice in line B and 20 in line C could litter out of 40 mice having 158 and 122 litters respectively at birth. Litters were weaned, weighed marked with picric acid at 28 days.

Crossing the lines at the 5th generation of inbreeding:

Forty females and 10 males in both lines were chosen for breeding purpose. Females were randomly grouped in 8 groups in each line. Each group of females was randomly allotted to a male of the other line. Thirty four mice of line C and 21 mice of line B produced litter. The litter number in crossing of C females x B males and B female x C males were 177 and 159 respectively.

Crossing between control and lines:

Thirty breedable females and 6 males were chosen in control population as well as in lines. Females were grouped in five groups. Each group of control females was randomly allotted to a selected male mouse of lines B and C. Out of six males, three were from line B and three from line C. Females of lines were randomly allotted to males of control population. Twenty three female out of thirty of control group could litter and 20 females out of 30 in lines produced litter when 5th generation individuals were utilised for breeding. Similarly crossing between control and lines were done with the individuals of the 3rd generation.

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Control group:

For control, a group of mice was maintained all along the experiment. They were mated randomly but without any selection of parents in respect of performance in terms of body weight and litter size. Total strength of this group in each generation was 40; in which 32 were females and 8 were males; Groups were made and each group was allotted one male randomly.

Housing and management:

Mice were maintained in the Mice Laboratory of Department of Genetics and Animal Breeding, Bihar Veterinary College, Patna. Experimental mice were kept in metallic cages of galvanised iron sheet having size specification of 10"x7½"x6" fixed on 4" iron stand in right with wire net roof. Normally 4 to 5 adult mice were maintained in each cage. Half inch Paddy husk was provided as bedding material which is also a good absorbent of dropings. Bedding materials were changed twice a week. All possible measures were taken in the laboratory throughout the experimental period in order to maintain the mice in good health. Floor of the laboratory was washed twice a week by phenyl. Cages were washed once in a week with Dettol water and after complete drying the mice were shifted in them. Every time cleaned cages were used for transfer of mice. A small amount of cotton was placed on bedding material as the gestation period approached its completion. Cotton was utilised by mice in nesting the young ones and continued to keep their young in

it for several days. Cotton also served as protection against adverse climatic rigors.

The experiment lasted from March to November, 1973. Temperature of the laboratory was maintained within a range of 76° - 96°F, throughout the experimental period with the help of Khas-Khas during summer.

All the doors and windows were covered by Khas-Khas mats and these mats were kept moist by frequent sprinkling of water. Exhaust fans and electric fans were kept on for all the 24 hours during the summer and the rainy season. Excessive moisture was controlled by exhaust fan and electric fans during rainy season.

Feeding:

Mice were provided with semi-liquid meal ad-libitum. They were given unrestricted balanced diet, sufficient to meet the body requirement even during the stress period of pregnancy and lactation. Semi-liquid meal was prepared by boiling cow milk with wheat flour. Shark liver oil and Uni-vite C choline were added after cooling the meal. The following constituted the feed per 100 mice:-

Milk -	½ litre.
Wheat -	½ Kg.
Shark liver oil -	11.5 ml.
Uni-vite C choline -	6.5 ml.
Common salt -	1 tea spoonful.

Empty penicillin vials fitted with glass jets were used

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for providing water to mice. Such vials filled with water were inserted up side-down from the roof of the cages. Mice sucked the water through the tip. It also allowed them some means of exercise in climbing up and getting down.

Feeding utensils were cleaned every day and every time after meals. Young mice from a day old to two weeks old were unable to take any food except suckling. Young mice opened their eyes at about 10 to 15 days after birth and after 15 to 16 days they started taking meals. The milk provided were supplied by the Milk Union, Patna. All along wheat from ration shops was fed. There was great scarcity of wheat during the latter part of the experiment necessitating the use of damaged wheat of Food Corporation of India obtained through Government Cattle Farm, Patna.

M E T H O D S:

Means, Standard Error, Coefficient of Variation of different traits were calculated as per methods outlines by Snedecor (1967). Correlation coefficient between litter size at birth and body weight at 28 days and 42 days, as well testing the significance of the difference between different group means by t test were also done as per Snedecor (1967).

Heterosis:

Heterosis was taken as superiority of the offspring over the average of the parents. Heterosis is produced by joint effect

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of all the loci as well directional dominance. If some loci are dominant in one direction and some in the other their effect will tend to cancel out, and no heterosis may be observed, inspite of the dominant loci. The amount of heterosis expressed as the difference between the F_4 and the mid-parental values, is obtained by subtracting the mid-parental value from the mean (genotypic) value of the F_4 (Falconer). Heterosis in respect of body weight at 28 days and 42 days alongwith litter size at birth were measured by following formula in the 4th generation :-

$$HF_4 = MF_4 - \overline{MP}$$

Where,

HF_4 - Magnitude of heterosis measured in the 4th generation.

MF_4 - Stands for mean value of the crossbred (F_4).

$\overline{MP}$ - Stands for mid-parental value of the 3rd generation.

The amount of heterosis shown by the F_6 was the difference between the F_6 crossbred and mid-parental value (parents were of fifth generation).

$$HF_6 = MF_6 - \overline{MP}$$

Where,

HF_6 - Magnitude of heterosis measured in 6th generation.

MF_6 - Stands for mean value of the crossbred (F_6).

$\overline{MP}$ - Stands for mid-parental value of 5th generation.

Inbreeding coefficient:

Lines were developed and maintained from generation to

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generation by full-sib mating. The intensity of inbreeding was similar for all individuals of both lines. The inbreeding coefficient of individuals of 3rd generation, 4th generation, 5th generation and 6th generation was calculated by formula given by (Wright 1922).

$$F_x = \sum \left(\frac{1}{2}\right)^{n+1}(1+F_A)$$

F_x - inbreeding coefficient of individual x.

$\sum$ - summation of all independent paths of inheritance which connect sire and dam of x.

n - number of segregations in a specific path between sire and dam of x.

F_A - inbreeding coefficient of common ancestor for each path.

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RESULTS AND DISCUSSION.

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RESULTS AND DISCUSSION

Litter size :

Mean litter size in F_4 crossbred offspring of C ♀ x B ♂ and reciprocal crosses were inferior to the mid-parent by 0.80 mouse per litter and 0.81 mouse per litter respectively (Table 4), but these mean differences of litter size between offspring and mid-parent value were found to be non-significant (Table 4). The mean difference of litter size at birth of F_6 crossbred offspring of C ♀ x B ♂ crosses were inferior to mid-parent value by 1.50 mice per litter (Table 5) and the difference was highly significant (Table 5). Average litter size in F_6 reciprocal crosses (B ♀ x C ♂) were superior to that of mid-parent value by 1.03 mice per litter (Table 5). Highly significant negative heterosis in respect of litter size of 1.50 mice per litter was observed in the crosses of C ♀ x B ♂ whereas in reciprocal crosses non-significant heterosis amounting to 1.03 mice per litter was noted (Table 5). Similar results of negative heterosis was observed by Bogart *et al.*(1960) and Frank *et al.*(1962).The negative heterosis might be due to fluctuating endocrine function and may be attributable to a general heterotic factor that does not always yield measurable amount of non-additive genetic variance.The heterosis observed in reciprocal crosses in F_6 seems to be consistent with the findings of Martin *et al.* (1963). More or less similar

results were observed by Eaton (1941, 1955). Forsthaefel (1954), Butler (1958), McCarthy (1965) where they observed heterosis in litter size in some crosses and in some crosses litter size were near to mid-parent value and in some crosses even inferior to the mid-parent value.

The negative heterosis as observed in F_4 and F_6 crosses of C ♀ x B ♂ might be due to reduced viability of embryo in uterus and decreased rate of ovulation in inbred dams along with increased pre-implantation mortality. Lack of non-additive heterotic factor and genetic constitution of faetus might also be playing important role in production of negative heterosis. Non-significant heterosis in F_6 reciprocal crosses might be due to heterozygosity of the embryo and additive gene action of dominant genes.

Body weight :

Mean body weight of F_4 crossbred offspring of C ♀ x B ♂ and reciprocal crosses at 28 days were inferior to the mid-parent value by 0.80 gms and 0.03 gms respectively of which the former was significantly different from the mid-parent value whereas the latter was non-significant. Mean body weight of the same individuals of cross C ♀ x B ♂ at 42 days was inferior by 0.70 gms to the mid-parent value but their mean body weight at 42 days for reciprocal crosses was superior to the mid-parent value by 0.19 gms (Table 4). At 42 days, both were found to be non-significant (Table 4). Negative heterosis in the hybrids at 28 days might be due to physiological function of dams-in that inbred mother might not be able to

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meet all the requirements of her crossbred offspring. Mason et al. (1960) found significant departures in growth rate in the direction of reduced growth. Moreover similar result of reduced growth rate in crossbreds was observed by Franks et al.(1962) and they explained it as negative heterosis. The present finding is also in coincidence with Sharma's (1971) findings which were made on the same genetic stock.

Mean body weight in F_6 crossbred offspring of C ♀ x B ♂ and reciprocal crosses at 28 days excelled the mid-parent value by 0.72 gms and 0.65 gms respectively. Non-significant heterosis of 0.72 gms and 0.65 gms (Table 5) in crosses of C ♀ x B ♂ and reciprocals respectively was observed in this generation. This is in agreement with the findings of Comstock et al. (1963) and Rahnefeld et al. (1963). Mean body weight of the same individuals at 42 days were superior to the mid-parent value by 2.28 gms and 0.77 gms respectively. Crossbreds of cross C ♀ x B ♂ and reciprocals exhibited heterosis amounting to 2.28 gms and 0.77 gms respectively. Heterosis exhibited in cross of C ♀ x B ♂ was highly significant whereas those of reciprocals were non-significant (Table 5). Mean body weight at 42 days surpassed the parental limit of the better parent in both the crosses (transgressive variation). Butler (1958), Carmon (1963), Shibata (1966, 1967), Roberts (1967) and other workers also found similar results. Heterosis exhibited in F_6 in the crosses of C ♀ x B ♂ might be due to the non-additive heterotic factor as well as additive gene action of dominant genes and their directional dominance.

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The present study showed that with the increase in the value of inbreeding coefficient there was also increase in heterotic effect in the growth rate. At the 5th generation of full-sib mating, maximum heterotic effects was observed as the inbreeding coefficient approached 67.2%. But in the F_4 when the inbreeding coefficient of the parents reached 50% level, the heterotic effect was not found to be so high. Heterosis measured in F_4 were either in negative direction or little in positive direction.

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TABLE - 1

Table showing average litter size at birth in different groups and generation with S.E. and C.V. %.

Groups/lines	Generation	Number of dams littered.	Mean ± S.E.	C.V.%
Line B	3rd	13	7.07 ± 0.44	22.63
	4th	27	5.85 ± 0.35	30.94
	5th	25	5.16 ± 0.36	35.07
	6th	32	4.62 ± 0.27	33.54
Line C	3rd	12	6.58 ± 0.51	27.05
	4th	26	7.42 ± 0.44	30.45
	5th	19	6.00 ± 0.45	32.83
	6th	22	4.72 ± 0.23	23.51
Line C (control)	4th	11	6.00 ± 0.68	38.00
	5th	28	5.42 ± 0.44	43.54
	6th	30	5.13 ± 0.35	37.81
Crossbreds of C ♀ x B ♂	4th	20	6.10 ± 0.37	27.70
Crossbreds of B ♀ x C ♂	4th	26	6.07 ± 0.18	32.28
Lines x control mated reciprocally.	4th	21	6.25 ± 0.43	31.52
Crossbreds of C ♀ x B ♂	6th	34	5.20 ± 0.38	43.36
Crossbreds of B ♀ x C ♂	6th	21	7.57 ± 0.34	20.60
Lines x control mated reciprocally	6th	31	5.35 ± 0.35	37.19

N.B. - Mean ± S.E., C.V.% of litter size at birth for F_2 control could not be calculated as observations were not available.

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TABLE - 2

Table showing average weight at 28 days in different groups and generation with S.E. and C.V. %.

Groups/lines	Generation	Number of observations	Mean ± S.E. in gms	C.V.%
Line B	3rd	69	12.45 ± 0.43	24.05
	4th	106	11.29 ± 0.33	30.91
	5th	81	9.25 ± 0.27	26.27
	6th	96	8.59 ± 0.17	19.70
Line C	3rd	71	11.18 ± 0.42	21.50
	4th	118	10.50 ± 0.27	28.09
	5th	89	8.79 ± 0.18	19.56
	6th	66	8.41 ± 0.37	11.29
Line O (control)	4th	51	11.39 ± 0.51	32.13
	5th	136	9.54 ± 0.16	37.21
	6th	99	8.25 ± 0.13	16.00
Crossbreds of C ♀ x B ♂	4th	85	10.77 ± 0.21	18.19
Crossbreds of B ♀ x C ♂	4th	114	11.78 ± 0.30	28.08
Crossbreds of lines x control	4th	90	11.14 ± 0.29	25.22
Crossbreds of C ♀ x B ♂	6th	88	9.67 ± 0.22	21.82
Crossbreds of B ♀ x C ♂	6th	69	9.68 ± 0.30	26.23
Lines x control crossbreds.	6th	113	8.26 ± 0.15	19.53

N.B. - Mean ± S.E. and C.V. % for F_3 control could not be calculated as body weight at 28 days was not available.

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TABLE - 3

Table showing average weight at 42 days in different groups and generations with S.E. and C.V. %.

Groups/lines	Generation	Number of observations	Mean ± S.E. in gms	C.V.%
Line B	3rd	69	19.65 ± 0.60	21.45
	4th	104	18.46 ± 0.46	25.46
	5th	81	15.53 ± 0.33	19.63
	6th	96	15.08 ± 0.30	19.49
Line C	3rd	67	17.58 ± 0.59	17.70
	4th	116	17.56 ± 0.27	27.93
	5th	89	15.18 ± 0.30	18.31
	6th	64	13.64 ± 0.23	13.26
Line D (control)	4th	51	17.56 ± 0.55	24.96
	5th	128	15.03 ± 0.18	28.07
	6th	99	15.54 ± 0.17	11.13
Crossbreds of C ♀ x B ♂	4th	81	17.78 ± 0.26	13.21
Crossbreds of B ♀ x C ♂	4th	114	18.85 ± 0.51	29.07
Lines x control crossbred.	4th	88	17.82 ± 0.33	17.45
Crossbreds of C ♀ x B ♂	6th	88	17.41 ± 0.35	19.24
Crossbreds of B ♀ x C ♂	6th	69	16.41 ± 0.43	21.81
Lines x control crossbreds	6th	112	13.85 ± 0.21	16.53

N.B. - Mean ± S.E. and C.V. % for F_3 control could not be calculated as body weight at 42 days was not available.

TABLE - 4

Table showing magnitude of heterosis for litter size and body weights of F_4 offspring.

Characters	Mean mid-parent value C ♀ and B ♂ (B ♀ and C ♂)	Mean off-spring value for F_4.	Differences between off-spring and mid-parent values.	D.F.	t value calculated
Litter size at birth.	6.90 (6.88)	6.10 (6.07)	-0.80 N.S. -(0.81)N.S.	42 43	1.35 1.58
Body weights at 28 days in gms.	11.57 (11.81)	10.77 (11.78)	-0.80* -(0.03)N.S.	131 160	2.10 0.05
Body weights at 42 days in gms.	18.48 (18.66)	17.78 (18.85)	-0.70 N.S. (0.19)N.S.	128 160	1.45 0.22

N.B. - The values in the parenthesis indicate those of the reciprocal crosses.

* denotes significance at 5% level.

N.S. denotes non-significance.

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TABLE - 5

Table showing the magnitude of heterosis for litter size and body weights of F_6 offspring.

Characters	Mean mid-parent value C ♀ and B ♂ (B ♀ and C ♂)	Mean off-spring value for F_6.	Differences between off-spring and mid-parent values.	D.F.	t value calculated
Litter size at birth.	6.70 (6.54)	5.20 (7.57)	-1.50** (1.03)N.S.	52 41	2.83 1.94
Body weights at 28 days in gms.	8.95 (9.03)	9.67 (9.68)	0.72 N.S. (0.65)N.S.	130 95	1.72 1.25
Body weights at 42 days in gms.	15.13 (15.64)	17.41 (16.41)	2.28** (0.77)N.S.	130 95	3.95 1.07

N.B. - The values in the parenthesis indicate those of the reciprocal crosses.

** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.

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Interline crossbreds, line x control crossbreds versus control performance.

Litter size:

Mean litter size at birth in F_4 of cross C ♀ x B ♂, reciprocal and lines x control were superior to the control by 0.10, 0.07 and 0.25 mouse per litter respectively (Table 6). Non-significant difference exhibited in the litter size at birth in cross of lines x control was more than the interline crosses in all cases (Table 6a, 6Ia). Mean litter size at birth in F_6 of cross C ♀ x B ♂, reciprocal and lines x control was superior to the control by 0.07, 2.44 and 0.22 respectively. Highly significant difference between reciprocal cross of lines and control was observed though other differences were non-significant (Table 9).

Body weight :

Mean body weight at 28 days in F_4 of cross C ♀ x B ♂ and lines x control were inferior to control mean by 0.62 gms and 0.25 gms respectively whereas mean body weight of cross B ♀ x C ♂ was superior to that of control by 0.39 gms (Table 6b). Both the differences either in negative or in possitive direction were non-significant (Table 6Ib). The same at 42 days of cross C ♀ x B ♂, reciprocal and lines x control exceeded that of the control by 0.22 gms, 1.29 gms and 0.26 gms respectively (Table 6b), but the superiority inrespect of growth rate of crossbreds over the control population was found to be non-significant (Table 6Ic). Highest mean

difference in body weight at 28 and 42 days was observed in the crossbred offspring of cross B ♀ x C ♂ over the control population (Table 6b,c).

Mean body weight in F_6 at 28 days of cross C ♀ x B ♂, reciprocal and lines x control was found to be superior in growth performance over the control by 1.42 gms, 1.43 gms and 0.01 gm respectively, in which the 1st two differences were highly significant whereas the other was non-significant (Table 7). Mean body weight at 42 days of the same individual in the cross of C ♀ x B ♂ and reciprocal exceeded that of the control by 1.87 gms and 0.87 gms respectively whereas lines x control crossbred mean was exceeded by the control by 1.69 gms (Table 8); of this, the 1st value was highly significant whereas 2nd was found to be significant, however, the last value, though negative in direction, was significant(Table 8).

In this experiment it was observed that better fertility and growth rate could be obtained by crossing highly inbred lines as the interline crossbreds were always found to be superior to the control as regards the traits in question. Similarly F_6 lines x control crossbred offspring were not found to be superior to interline crossbred offspring in respect of litter size at birth and body weights.

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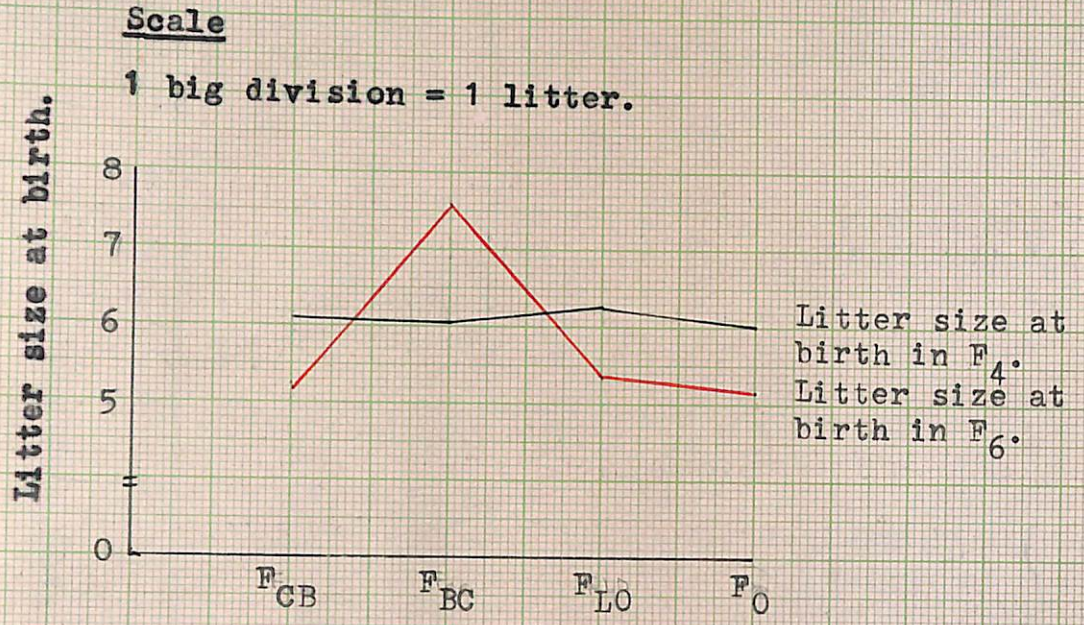

Fig. 1
Showing effect of different crossing on litter size.

Scale

1 big division = 1 gm

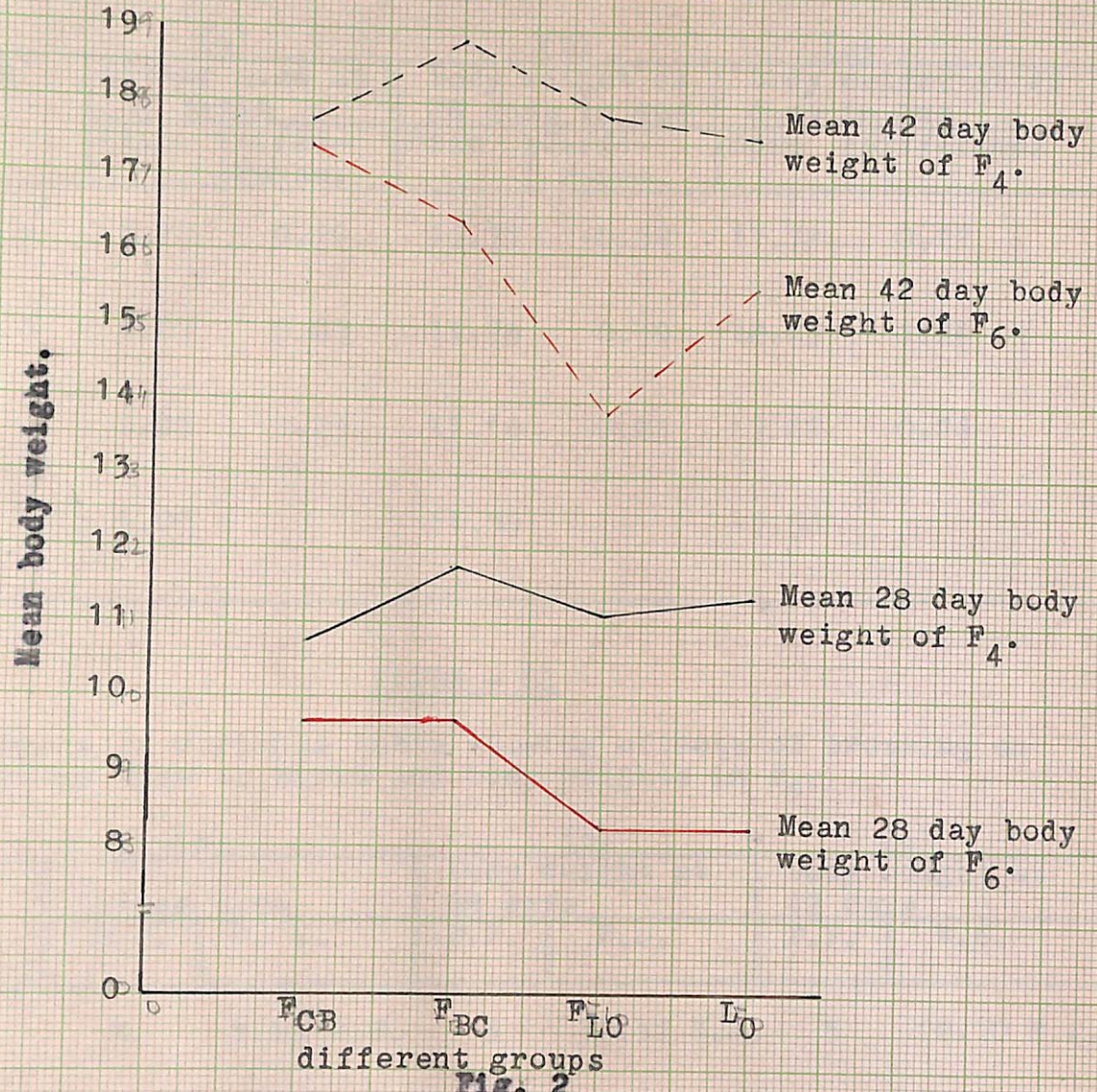

Fig. 2

Showing mean body weight of different crossbred groups and control at 28 and 42 days.

TABLE - 6

Table showing difference in crosses and control population for different traits of F_4.

Comparison between groups.	(a) Litter size at birth		(b) Body weight at 28 days in gms		(c) Body weight at 42 days in gms	
	Mean	Difference.	Mean	Difference.	Mean	Difference
C ♀ and B ♂ cross.	6.10	0.10	10.77	-0.62	17.78	0.22
B ♀ and C ♂ cross.	6.07	0.07	11.78	0.39	18.85	1.29
Lines x control.	6.25	0.25	11.14	-0.25	17.82	0.26
Line O (control)	6.00		11.39		17.56	

TABLE - 6I

Analysis of variance table showing effects of crossing on litter size at birth and body weights in F_4.

Sources	(a) Litter size		(b) Body weight at 28 days		(c) Body weight at 42 days	
	D.F.	M. S.	D.F.	M.S.	D.F.	M.S.
Between crosses.	5	3.12 N.S.	5	12.37 N.S.	5	22.70 N.S.
Within crosses.	115	39.53	430	8.16	425	15.48
Total.	120		435		430	

N.S. denotes non-significance.

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TABLE - 7

Analysis of variance table showing effects of crossings on 28 days body weight (6th generation).

Sources	D.F.	M.S.	F.
Between crosses	5	36.39	10.45**
Within crosses	435	3.48	
Total.	440		

Table showing significance of different crosses on body weight at 28 days.

Comparison between groups.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of 5%	1%
F_{6CB} - F_{5P}	88 - 44	0.72*	0.66	0.87
F_{6CB} - F_{6LO}	88 - 113	1.41**	0.51	0.66
$F6_{CB}$ - $F_{6\ 0}$	88 - 99	1.42**	0.52	0.69
F_{6BC} - F_{5P}'	69 - 28	0.65 N.S.	1.02	1.40
F_{6BC} - F_{6LO}	69 - 113	1.42**	0.54	0.72
F_{6BC} - $F_{6\ 0}$	69 - 99	1.43**	0.54	0.72
F_{6LO} - $F_{6\ 0}$	113 - 99	0.01 N.S.	0.55	0.76

N.B.- ** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.
F_{6CB} - Crossbred offspring of cross C ♀ x B ♂ (F_6).
F_{6BC} - Crossbred offspring of reciprocal cross (F_6).
F_{6LO} - Crossbred offspring of lines x control (F_6).
$F_{6\ 0}$ - 6th generation control.
F_{5P} - Parents of F_{6CB}, F_{5P}' - parents of F_{6CB}.

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TABLE - 8

Analysis of variance table showing effects of crossings on 42 days body weight (6th generation).

Sources	D.F.	M.S.	F.
Between crosses	5	137.43	18.64**
Within crosses	433	7.35	
Total.	438		

Table showing significance of different crosses on body weight at 42 days.

Comparison between groups.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of 5%	C.D. value at the level of 1%
F_{6CB} - F_{5P}	88 - 44	2.28**	0.98	1.28
F_{6CB} - F_{6LO}	88 - 112	3.56**	0.74	0.97
F_{6CB} - $F_{6\ O}$	88 - 98	1.87**	0.76	1.00
F_{6BC} - F_{5P}'	69 - 28	0.77N.S.	1.33	1.83
F_{6BC} - F_{6LO}	69 - 112	2.56**	0.80	1.05
F_{6BC} - $F_{6\ O}$	69 - 98	0.87*	0.82	1.08
F_{6LO} - $F_{6\ O}$	112 - 98	-1.69**	1.22	1.68

N.B. - ** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.
F_{6CB} - Crossbred offspring of cross C ♀ x B ♂ (F_6).
F_{6BC} - Crossbred offspring of reciprocal cross (F_6).
F_{6LO} - Crossbred offspring of lines x control (F_6).
$F_{6\ O}$ - 6th generation control.
F_{5P} - Parents of F_{6CB}, F_{5P}' - parents of F_{6CB}.

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TABLE - 9

Analysis of variance table showing the effects of crossing on the litter size at birth in F_6.

Sources	D.F.	M.S.	F.
Between crosses	5	24.76	6.97**
Within crosses	152	3.55	
Total.	157		

Table showing effects of crossing on litter size at birth in F_6.

Comparison between groups.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of 5%	C.D. value at the level of 1%
F_{6CB} - F_P	34 - 20	- 1.50**	1.20	1.38
F_{6BC} - F_P'	21 - 22	1.03 N.S.	1.29	1.78
F_{6BC} - F_{6LO}	21 - 31	2.22**	1.20	1.66
F_{6CB} - F_{6LO}	34 - 31	-0.15 N.S.	1.04	1.44
F_{6CB} - $F_{6\ O}$	34 - 30	0.07 N.S.	1.06	1.47
F_{6BC} - $F_{6\ O}$	21 - 30	2.44**	1.20	1.66
F_{6LO} - $F_{6\ O}$	31 - 30	0.22 N.S.	1.08	1.50

N.B. - ** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.
F_{6CB} - Mean litter size at birth of cross C ♀ x B ♂ (F_6).
F_{6BC} - Mean litter size at birth in reciprocal cross(F_6).
F_P - Mean litter size at birth of parents of F_{6CB}.
F_P' - Mean litter size at birth of parents of F_{6BC}.
F_{6LO} - Mean litter size at birth of cross lines x control.
$F_{6\ O}$ - Mean litter size at birth of control (F_6).

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L I N E - B.

Litter size :

Decline in mean litter size at birth from F_3 to F_4, F_4 to F_5 and F_5 to F_6 by 1.22 mice, 0.69 mouse and 0.54 mouse per litter respectively were observed. The reduction in mean litter size from F_3 to F_4 was found to be significant whereas F_4 to F_5 and F_5 to F_6 were non-significant (Table 10). This result is in close agreement with that of Robert (1960) in which he observed decline in litter size of roughly 0.5 mouse per generation. Bowman and Falconer (1960) found similar result as that of Robert. Sharma (1971) reported that for every 10% of inbreeding coefficient there was depression in litter size roughly 0.53 mouse in one group, 0.16 mouse in second group and 0.24 mouse per litter in third group.

Depression in the litter size as observed in F_4, F_5 and F_6 might be due to reduction in the ovulation rate of inbred dams and increased pre-implantation mortality from inbreeding of dam.

Body weight :

Decline in mean body weight of mouse from F_3 to F_4, F_4 to F_5 and F_5 to F_6 at 28 days were 1.16 gms, 2.02 gms and 0.66 gms respectively (Table 11). Mean body weight of the same individuals at 42 days was found to decline by 1.19 gms, 2.93 gms and 0.45 gms (Table 12) respectively. Decline in mean body weight at 28 and 42 days from F_3 to F_4 and F_4 to F_5 was significant at 1% (Table 11,12) except from F_3 to F_4 at 42 days which was significant at 5%

(Table 12) whereas the decline in mean body weight from F_5 to F_6 at both ages were non-significant (Table 11, 12). MacCarthy(1968) reported depression in mean body weight due to inbreeding. Sharma (1971) on the same genetic stock and White (1971) observed significant depression in mean body weight at different ages.

Decline in body weight, as observed in this experiment might be due to rapid inbreeding caused by pairing of recessive genes.

TABLE - 10

Analysis of variance table showing effects of inbreeding on litter size at birth in line B.

Sources	D.F.	M.S.	F.
Between generations	3	20.87	7.17**
Within generations.	93	2.91	
Total.	96		

Table showing significance of difference for different generations on litter size at birth.

Comparison between generations.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of 5%	C.D. value at the level of 1%
3rd - 4th	13 - 27	1.22*	1.13	1.49
3rd - 5th	13 - 25	1.91**	1.15	1.52
3rd - 6th	13 - 32	2.45**	1.11	1.47
4th - 5th	27 - 25	0.69 N.S.	0.93	1.23
4th - 6th	27 - 32	1.23**	0.87	1.15
5th - 6th	25 - 32	0.54 N.S.	0.89	-

** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.

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TABLE - 11

Analysis of variance table showing effects of inbreeding on body weight at 28 days in line B.

Sources	D.F.	M.S.	F.
Between generations	3	263.20	37.33**
Within generations	348	7.05	
Total.	351		

Table showing significance of difference of different generations on body weight at 28 days.

Comparison between generations.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of	
			5%	1%
3rd - 4th	69 - 106	1.16**	0.80	1.05
3rd - 5th	69 - 81	3.20**	0.84	1.10
3rd - 6th	69 - 96	3.86**	0.80	1.05
4th - 5th	106 - 81	2.02**	0.76	1.00
4th - 6th	106 - 96	2.70**	0.72	0.95
5th - 6th	81 - 96	0.66 N.S.	0.78	-

** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.

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TABLE - 12

Analysis of variance table showing effects of inbreeding on body weight at 42 days in line B.

Sources	D.F.	M.S.	F.
Between generations.	3	411.99	31.04**
Within generations.	346	13.27	
Total.	349		

Table showing significance of difference of different generations on body weight at 42 days.

Comparison between generations.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of 5%	C.D. value at the level of 1%
3rd - 4th	69 - 104	1.19*	1.09	1.44
3rd - 5th	69 - 81	4.12**	1.15	1.51
3rd - 6th	69 - 96	4.57**	1.11	1.46
4th - 5th	104 - 81	2.93**	1.03	1.36
4th - 6th	104 - 96	3.38**	0.99	1.31
5th - 6th	81 - 96	0.45 N.S.	1.05	1.39

** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.

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L I N E - C.

Litter size :

Mean litter size in F_4 was superior to F_3 by 0.84 mouse per litter (Table 13). But the decline in the mean litter size from F_4 to F_5 and F_5 to F_6 were 1.42 mouse, 1.28 mouse (Table 13) per litter respectively. The increase in litter size from F_3 to F_4 was non-significant but the decline in litter size from F_4 to F_5 and F_5 to F_6 were significant at 5% (Table 13). Similar results of depression in litter size were reported by Roberts (1960), Falconer and Bowman (1960), McCarthy (1969), Sharma (1971) and White (1972).

Non-significant increase in litter size of F_4 to F_3 was unexpected and this might be due to some environmental factor. But the decrease in litter of F_4 to F_5 and F_5 to F_6 was because of rapid inbreeding due to full-sib mating, causing reduction in the rate of ovulation and increased pre-implantation mortality of inbred dams. Out of 40 dams, only 23 littered the F_6. Even these dams showed lower rate of pregnancy. Khazanowska (1964) observed lower rate of pregnancy in inbred dams. The decrease in pregnancy rate might be due to inbreeding.

Body weight :

Decline in mean body weight of mouse from F_3 to F_4, F_4 to F_5 and F_5 to F_6 at 28 day was 0.68 gms, 1.71 gms, 0.38 gms (Table 14) and 0.02 gms, 2.38 gms, 1.54 gms (Table 15) at 42 day respectively.

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The decrease in body weight at 28 day from F_3 to F_4 was significant at 5% and F_4 to F_5 was significant at 1% level whereas F_5 to F_6 was non-significant (Table 14). The decrease in body weight of the same individuals at 42 day in F_3 to F_4 was non-significant whereas that of F_4 to F_5, F_5 to F_6 was significant at 1% (Table 15). Butler (1958), McCarthy (1968), Sharma (1971) on the same genetic stock, and White (1972) observed significant depression in body weight.

This depression was attributed both to inbreeding in the litters and in the dams. The reduction in body weight might be the result of pairing of recessive genes and increased homozygosity of recessive genes.

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TABLE - 13

Analysis of variance table showing effects of inbreeding level on litter size in line C.

Sources	D.F.	M.S.	F
Between generations.	3	29.71	8.58**
Within generations.	75	3.46	
Total.	78		

Table showing significance of difference for generations on litter size at birth.

Comparison between generations.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of	
			5%	1%
3rd - 4th	12 - 26	-0.84 N.S.	1.27	1.69
3rd - 5th	12 - 19	0.58 N.S.	1.35	1.79
3rd - 6th	12 - 22	1.86**	1.31	1.74
4th - 5th	26 - 19	1.42*	1.11	1.48
4th - 6th	26 - 22	2.70**	1.05	1.40
5th - 6th	19 - 22	1.28*	1.15	1.53

** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.

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TABLE - 14

Analysis of variance table showing effects of inbreeding on body weight at 28 days in line C.

Sources	D.F.	M.S.	F
Between generations.	3	136.65	25.68**
Within generations.	340	5.32	
Total.	343		

Table showing significance of difference of different generations on body weight at 28 days.

Comparison between generations.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of 5%	1%
3rd - 4th	71 - 118	0.68*	0.66	0.87
3rd - 5th	71 - 89	2.39**	0.70	0.92
3rd - 6th	71 - 66	2.77**	0.76	1.00
4th - 5th	118 - 89	1.71**	0.62	0.82
4th - 6th	118 - 66	2.09**	0.68	0.89
5th - 6th	89 - 66	0.38 N.S.	0.72	0.95

** denotes significance at 1% level.
* denotes significance at 5% level.
N.S. denotes non-significance.

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TABLE - 15

Analysis of variance table showing effects of inbreeding on body weight at 42 days in line C.

Sources	D.F.	M.S.	F
Between generations.	3	282.11	20.88**
Within generations.	328	13.51	
Total.	331		

Table showing significance of difference of different generations on body weight at 42 days.

Comparison between generations.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of 5%	C.D. value at the level of 1%
F_3 - F_4	67 - 116	0.02 N.S.	1.09	-
F_3 - F_5	67 - 89	2.40**	1.17	1.54
F_3 - F_6	67 - 64	3.94**	1.23	1.62
F_4 - F_5	116 - 89	2.38**	1.01	1.33
F_4 - F_6	116 - 64	3.92**	1.11	1.46
F_5 - F_6	89 - 64	1.54**	1.17	1.54

** denotes significance at 1% level.
N.S. denotes non-significance.

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Scale

1 big division = 1 litter.

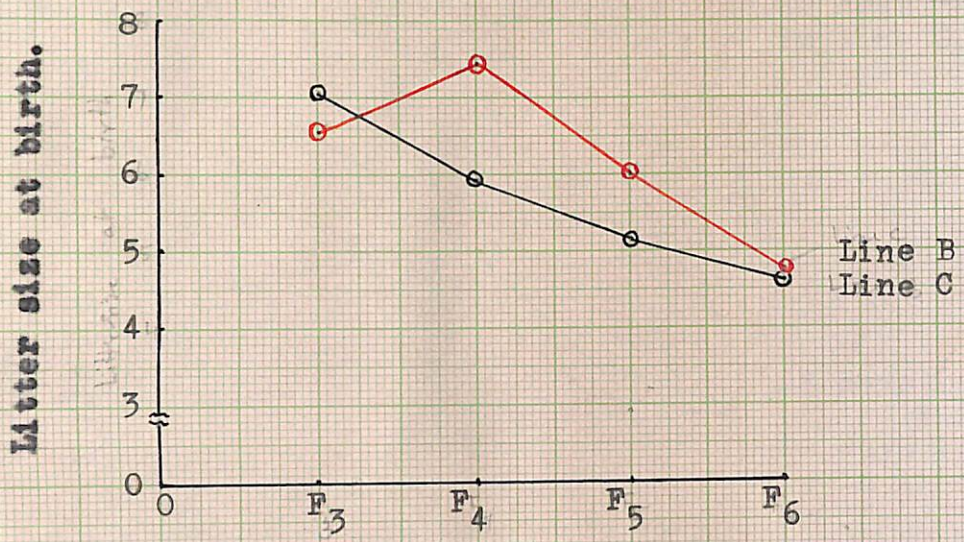

Fig. 3

Showing inbreeding depression on litter size at birth in line B and line C.

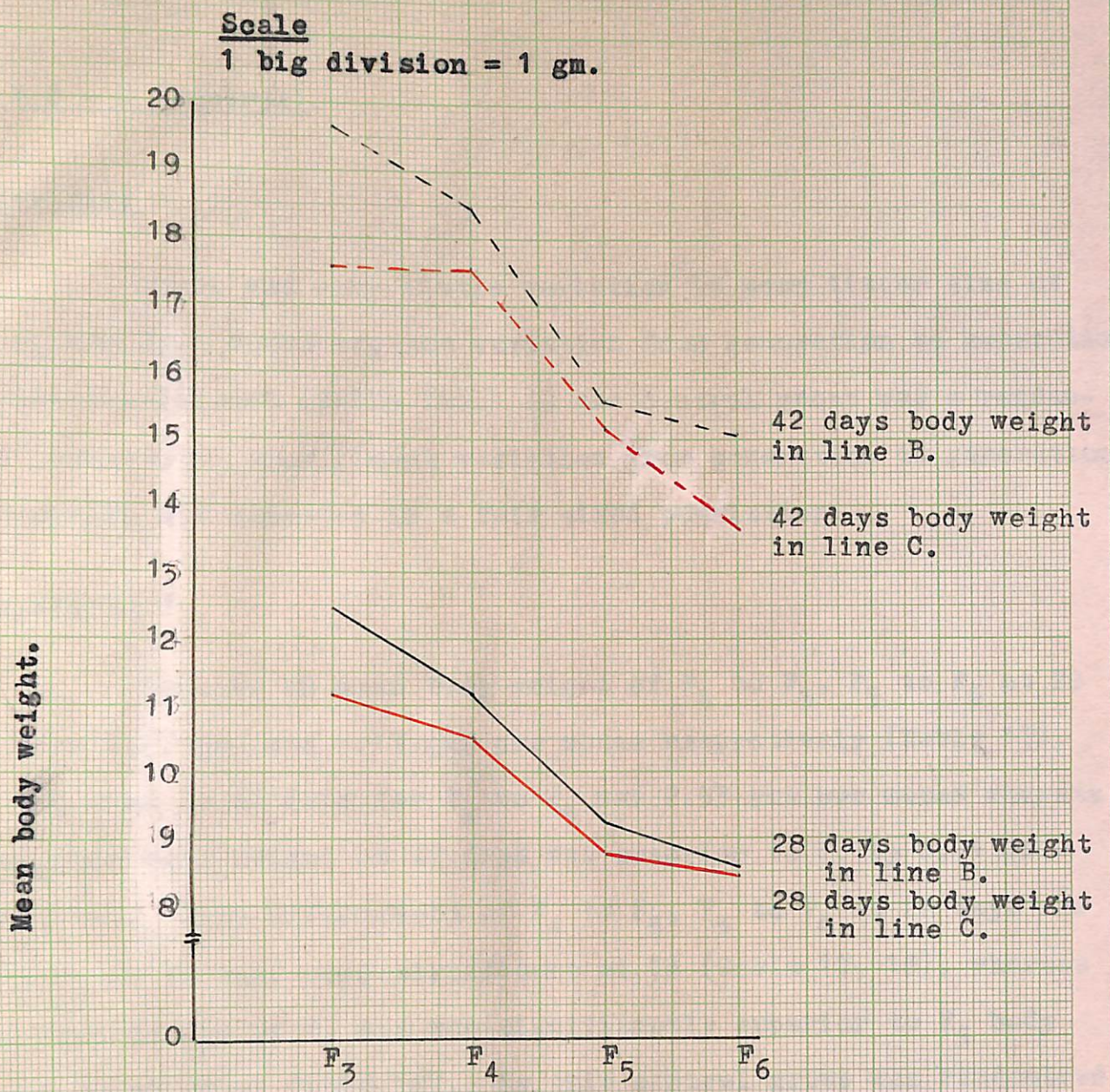

Fig. 4
Showing inbreeding depression on body weight in line B and Lince C.

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L I N E - O (control).

Litter size :

There was very little variation in mean litter size of F_4, F_5 and F_6. Moreover, the variation from generation to generation was non-significant (Table 16). As the control group was a random-bred population, significant variation from generation to generation is normally not expected in a fair sized population.

Body weight :

Decline in mean body weight of F_4 to F_5, F_5 to F_6 at 28 day were 1.97 gms and 1.17 gms per mouse respectively (Table 17), and the same at 42 days for F_4 to F_5 was 2.53 gms per mouse whereas F_6 average body weight at 42 days was superior to F_5 by 0.51 gms (Table 18). Mean differences of F_4 to F_5, F_5 to F_6 at 28 days and F_4 to F_5 at 42 days were significant at 1% (Table 17, 18), whereas mean body weight of F_6 was non-significantly superior to F_5 body weight at 42 days(Table 18). As this control group was randombred population and significant variation in body weight from generation to generation is not normally expected but significant variation was observed. This unexpected variation might be due to some environmental fluctuation or sampling error.

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TABLE - 16

Analysis of variance table showing effect of generation on litter size at birth in line O (control).

Sources	D.F.	M.S.	F.
Between generations.	2	3.06	0.65N.S.
Within generations.	66	4.73	
Total.	68		

TABLE - 17

Analysis of variance table showing effect of generation on body weight at 28 days line O (control).

Sources	D.F.	M.S.	F.
Between generations.	2	167.04	18.49**
Within generations.	283	9.03	
Total.	285		

Table showing significance at differences of different generation on body weight at 28 days.

Comparison between generations.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of	
			5%	1%
4th - 5th	51 - 136	1.97**	0.92	1.21
4th - 6th	51 - 99	3.14**	0.99	1.31
5th - 6th	136 - 99	1.17**	0.76	1.00

** denotes significance at 1% level.
N.S. denotes non-significance.

TABLE - 18

Analysis of variance table showing effects of generation on body weight at 42 days in line 0 (control).

Sources	D.F.	M.S.	F
Between generations.	2	118.19	9.63**
Within generations.	274	12.27	
Total.	276		

Table showing significance of difference for different generation on body weight at 42 days.

Comparison between generations.	Number of observations N_1 and N_2	Mean difference	C.D. value at the level of 5%	C.D. value at the level of 1%
4th - 5th	51 - 128	2.53**	1.13	1.49
4th - 6th	51 - 98	2.02**	1.18	1.55
5th - 6th	128 - 98	-0.51N.S.	0.92	1.21

** denotes significance at 1% level.
N.S. denotes non-significance.

Phenotypic correlation between litter size and body weights :

Simple phenotypic correlation co-efficients were calculated for the litter size and the body weights and the estimates obtained are contained in Table 19.

Barring one estimate, all other correlation co-efficients turned out to be negative. The estimates were significant statistically indicating thereby that the relationship between the two characters is negative i.e. the mice of larger litter size have lower body weight and vice versa. Comparable figures in literatures could not be available and hence no comparison could be made.

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TABLE - 19

Table showing phenotypic coefficient between litter size at birth and body weight at 28 and 42 days.

Groups/lines	Generations.	Number of pairs at 28 days.	Correlation coefficent ($L.S.xB_{28}$)	t-value for correlation coefficient ($L.SxB_{28}$) calculated.	Number of pairs at 42 days.	Correlation coefficient ($L.S.xB_{42}$).	t-value for correlation coefficient ($L.SxB_{42}$) calculated.
1	2	3	4	5	6	7	8
Line B	3rd	69	-0.43**	4.68	69	-0.10**	0.87
	4th	106	-0.69**	12.78	104	-0.56**	8.56
	5th	81	-0.46**	5.63	81	-0.42**	5.03
	6th	96	-0.48**	5.45	96	-0.37**	4.53
Line C	3rd	71	-0.67**	9.72	67	-0.68**	9.81
	4th	118	-0.55**	13.54	116	-0.63**	11.36
	5th	89	-0.53**	7.26	85	-0.406*	4.79
	6th	66	-0.74**	11.60	64	-0.45**	4.78
Line O (control)	4th	51	-031**	2.74	51	-0.15**	1.14
	5th	136	-0.44**	6.87	128	-0.55**	9.21
	6th	99	-0.49**	6.78	98	-0.45**	5.95

Cont'd...

TABLE - 19 (Cont'd)

1	2	3	4	5	6	7	8
Crossbred offspring of cross C ♀ x B ♂	4th	85	-0.60**	8.66	82	-0.37**	4.18
Crossbreds of reciprocal crosses.	4th	114	-0.77**	17.44	114	-0.40**	5.50
Crossbred offspring of control x lines.	4th	90	-0.58**	8.50	88	-0.50**	6.70
Crossbred offspring of cross C ♀ x B ♂	6th	88	-024**	2.55	88	-0.31**	3.45
Crossbreds of reciprocal crosses.	6th	69	0.15**	1.32	69	-0.38**	3.98
Crossbred offspring of control x lines.	6th	113	-0.53**	8.20	112	-0.37**	4.91

N.B. - L.S. indicates litter size at birth.
B_{28} indicates body weight at 28 days.
B_{42} indicates body weight at 42 days.
** indicates significance at 1% level.

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SUMMARY.

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S U M M A R Y

With the objective to measure the magnitude of heterosis exhibited on crossing inbred lines of mice at 50% and 67.2% inbreeding level, the present experiment was conducted. The characters under study were litter size at birth and body weight at 28 and 42 days. The genetic stock involved in this experiment were line B, Line C and a control group designated as Line O. The experiment was designed to cross line B and Line C reciprocally as well as with a control population at 3rd and 5th generation so as to give F_4 and F_6 crossbred offspring and side by side these lines were maintained separately also.

L i n e - B:

The decline in litter size at birth from F_3 to F_4, F_4 to F_5 and F_5 to F_6 were 1.22, 0.69 and 0.54 mice per litter respectively of which the 1st was significant and rest turned out to be non-significant. The decline in mean body weight from F_3 to F_4, F_4 to F_5 and F_5 to F_6 at 28 days were 1.16, 2.02 and 0.66 gms and at 42 days were 1.19, 2.93 and 0.45 gms respectively. Except F_5 vs F_6 these decline in mean body weight from F_3 to F_4 and F_4 to F_5 were found to be satistically significant.

L i n e - C:

Mean litter size at birth in F_4 was superior to F_3 by

0.84 mouse per litter but was non-significant whereas litter size from F_4 to F_5 and F_5 to F_6 declined significantly by 1.42 and 1.28 mice per litter respectively.

The decline in mean body weight of mice from F_3 to F_4, F_4 to F_5 and F_5 to F_6 at 28 days was 0.68, 1.71, 0.38 gms and 0.02, 2.38, 1.54 gms at 42 days respectively. The decrease in mean body weight at 28 days from F_3 to F_4 was found to be significant whereas F_4 to F_5 was highly significant and F_5 to F_6 was non-significant. The decrease in mean body weight of the same individuals at 42 days in F_3 to F_4 was found to be non-significant whereas from F_4 to F_5 and F_5 to F_6 were highly significant.

<u>Interline crossbreds, line x control crossbreds versus control performance</u>:

Mean litter size at birth in F_4 offspring of cross C ♀ x B ♂, reciprocal and lines x control were superior to the control by 0.10, 0.07 and 0.25 mice per litter respectively, but these difference were found to be non-significant. Mean body weight at 28 days in F_4 offspring of cross C ♀ x B ♂ and lines x control were non-significantly and inferior to control mean by 0.62 and 0.25 gms respectively whereas mean body weight of reciprocal cross was non-significantly superior to control mean by 0.39 gms. The mean body weight of the same individuals at 42 days of cross C ♀ x B ♂, reciprocal and lines x control were superior to control by 0.22, 1.29, 0.26 gms respectively. In F_4 crossbred mean litter size in lines x control cross was observed to be more than that of interline crosses whereas

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mean body weight was more in reciprocal crosses at both ages.

Mean litter size at birth in F_6 of cross C ♀ x B ♂, reciprocal and lines x control were each superior to control group by 0.07, 2.44 and 0.22 mouse per litter respectively. Highly significant difference between control and of lines was observed though other differences turned out to be non-significant.

Mean body weight in F_6 at 28 days of cross C ♀ x B ♂, reciprocal and lines x control was found to be superior in growth performance over the control by 1.42, 1.43 and 0.01 gms respectively, in which the 1st two were observed to be highly significant. Mean body weight of the same individuals at 42 days in the cross C ♀ x B ♂, reciprocal exceeded that of the control mean by 1.87, 0.87 gms respectively whereas lines x control crossbreds was exceeded by the control by 1.69 gms, of which the former value was highly significant and latter was found to be significant, however, the last value though negative in direction was significant.

In F_6 crossbreds mean litter size of reciprocal crosses was superior to C ♀ x B ♂ and lines x control crosses. The mean body weight in F_6 crossbreds of interlines crossbreds was found to be superior to that of lines x control crossbreds. The above result suggested that to exploit heterosis, interline crossing seemes to be better than crossing of highly inbred lines with randombred population.

Interline crossing:

Non-significant negative heterosis in F_4 mean litter size of

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C ♀ x B ♂ and reciprocal crosses was found to be 0.80 and 0.81 mouse per litter respectively. The magnitude of negative heterosis in average body weight of crossbred offspring at 28 days was 0.80 and 0.03 gms in C ♀ x B ♂ and reciprocal crosses respectively, of which the former was significant whereas latter turned out to be non-significant. Non-significant negative heterosis in body weight at 42 days in crossbred offspring of C ♀ x B ♂ crosses was estimated to be 0.70 gms whereas in reciprocal crosses magnitude of non-significant heterosis was observed to be 0.19 gms.

Highly significant negative heterosis in F_6 litter size of cross C ♀ x B ♂ was estimated to be 1.50 mice per litter whereas in reciprocal crosses the magnitude of heterosis was 1.03 mice per litter. The magnitude of heterosis in F_6 mean body weight at 28 days was 0.72, 0.65 gms and 2.28, 0.77 gms at 42 days in crossbreds of C ♀ x B ♂ and reciprocal crosses respectively. Heterosis exhibited in mean body weight at 28 days was non-significant whereas it was highly significant in the case of cross of C ♀ x B ♂ mice and in reciprocal crosses it was noted to be non-significant.

These results suggest that the magnitude of heterosis in respect of litter size at birth as well as body weight at 28 and 42 days increases with increase in inbreeding coefficient of lines at the two levels.

Phenotypic correlation coefficients were found to be significantly negative in respect of these characters indicating thereby that mice of larger litter size have smaller body weight and vice-versa.

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