EFFECTS OF INBREEDING ON LITTER SIZE, BIRTH WEIGHT, WEANING WEIGHT, AND CERTAIN OTHER TRAITS IN GUINEA PIGS

by

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INTRODUCTION

Inbreeding, the mating of related individuals, as a mating system used in livestock breeding is not new. As early as the latter part of the eighteenth century, Robert Bakewell, "the father of modern animal breeding," by inbreeding and intense selection caused remarkable improvement in the quality and desirability of his cattle, sheep, and horses. His success was so outstanding that other livestock producers patterned their breeding programs after the principles he followed. In the early part of this century, East and Jones (1919) published their book "Inbreeding and Outbreeding" in which they reviewed most of the work that had been published at that time and set forth many theories concerning the effects of inbreeding that are true today.

In spite of the noteworthy achievements of Bakewell, Bates, and a few other breeders during the latter part of the eighteenth and early part of the nineteenth century, the general opinion that inbreeding produced only harmful effects continued to exist. Most breeders and writers felt that inbreeding usually resulted in a decrease in growth rate, size, vigor, reproductive performance, and an increase in the frequency of abnormalities. Research has, in general, added support to this belief; however, Helen D. King's classic papers concerning the effects of inbreeding published during the early part of the twentieth century indicated that inbreeding of white rats accompanied by rigid selection of breeding stock actually caused an improvement in the inbred individuals over the outbred individuals.

In 1951, an inbreeding experiment was initiated with pigs in the Guinea Pig Colony of the Animal Husbandry Department at Kansas State University. The purpose of this investigation was to determine the effects of inbreeding on birth weight, weaning weight, litter size, sex ratio, gestation length, age of sexual maturity, and livability in the guinea pig where no selection was practiced.

REVIEW OF LITERATURE

Effect of Inbreeding on Birth Weight

One general criticism of inbreeding is that it reduces the size of the animals. Many breeders feel that one reason inbred animals are smaller than outbred animals is that inbred animals are smaller at birth. However, some research with swine indicated that inbreeding did not affect birth weight (Godbey and Starkey, 1932; Hays, 1919; and Hodgson, 1935), but research results have varied. Willham and Craft (1939) reported that inbred pigs weighed about 0.34 pound less at birth than outbred pigs.

In sheep, inbreeding caused a reduction in birth weight of lambs born as singles, but not that of lambs born as twins (Ragab and Asker, 1954). Inbreeding coefficients below 0.20 did not affect the birth weight of calves, but in cases where the inbreeding coefficients were above 0.20, birth weight of Jerseys, and Guernsey-Holstein grade calves was decreased (Rollins et al., 1949; and Woodward and Graves, 1933, 1946). Rollins et al. (1949) reported that the decrease in birth weights of calves was due to the effect of inbreeding on prenatal rate of growth.

Bartlett et al. (1942) selected outstanding dairy cattle from several different herds and used these individuals as foundation stock for an inbreeding experiment. They subsequently selected the best progeny as replacements, and their results indicated that inbreeding did not decrease birth weights of their calves.

Wright (1922a) reported that birth weights of guinea pigs vary greatly, and animals which ultimately reach maturity may have weighed from 40 to 150 grams at birth. In his data, average birth weight for guinea pigs was 80 grams. Eaton (1932) worked with the same inbred guinea pigs as Wright and reported that birth weight declined only slightly more than 12 per cent in 25 years of sister-brother matings. Eaton and Wright reported that litter size was an important factor in determining the pig's birth weight. Rice (1940), working with guinea pigs, found that birth weight was greatly influenced by the condition and size of the dam, and by the size of the litter. Most authors who reported a decrease in birth weight also reported decreases in mature body size and vigor.

Effect of Inbreeding on Litter Size

Experiments with swine indicated that inbreeding reduced litter size (Bradford et al., 1958; Comstock and Winters, 1944; Craft, 1953; Hays, 1919; Hetzer et al., 1940; Hodgson, 1935; Willham and Craft, 1939; and Winter et al., 1943). Craft (1953) reported that the reduction in litter size was not pronounced until the inbreeding coefficient for the litter was at least 25 to 35 per cent. Winter _et al_. (1943) reported a decrease in litter size of 0.058 pig born alive per litter for each per cent increase in inbreeding for the litter. Bradford _et al_. (1958) reported a decrease of 0.20 pig farrowed per litter for each 10 per cent increase in inbreeding for the litter. Willham and Craft (1939) observed that litter size decreased from an average of 8.9 pigs in the first inbred generation to 5.3 pigs in the eighth inbred generation. Hodgson (1935) found so much variation in litter size among the inbred groups as well as among the outbred groups of swine that he concluded that inbreeding did not adversely affect litter size. However, overall litter size among inbred litters averaged two pigs less than those within outbred groups.

Inbreeding and intense selection for litter size actually increased litter size by one rat per litter in King's (1918b) inbreeding experiments. Wright (1922b) reported that inbreeding in his guinea pigs reduced litter size by one pig. Eaton (1932) confirmed Wright's report that inbreeding decreased litter size by one pig in 25 years of inbreeding.

The decrease in litter size can be due to the fact that inbreeding decreases fertility (Harris _et al_., 1960; Stringam _et al_., 1950; and Woodward and Graves, 1933, 1946). In King's experiment (1918a), the decrease in fertility caused by inbreeding was more than offset by her rigid selection. Harris _et al_.

(1960) conducted physical examinations and semen evaluations to determine the reason for low fertility among inbred bulls. They found a non-significant difference in physical suitability between inbred and outbred bulls, but inbreeding appeared to adversely affect sperm morphology. They concluded that inbreeding apparently affected sperm morphology more than any of the other semen characteristics. They also compared fertility among the inbred lines and found that low fertility was more pronounced in bulls of certain inbred lines than in others, and that in most of the lines fertility was not affected by inbreeding.

Woodward and Graves (1946) found that inbred cows required an average of 2.65 services per conception while the outbred cows required an average of 1.95 services per conception. Squiers et al. (1952) compared the number of corpora lutea on the ovaries of sows with the number of embryos, and found that fertilization rate was not affected by inbreeding and that prenatal loss was within the normal range. Therefore, they concluded that the reduction in litter size was due to the observed reduction in number of ovulations.

Hodgson (1935) observed that inbred boars were reluctant to mate with their litter mates. Therefore, the boars' sexual desires were not fully stimulated and the semen ejaculated was either of low quantity or low quality. These factors might have caused the reduction in fertility observed in the inbred individuals.

Effect of Inbreeding on Sex Ratio

The normal sex ratio in the guinea pig, determined by the number of males born for every 100 females, varied from 102.4 to 106.9 (Risty, 1928; Schaumburg, 1923; and Summer, 1926) with an average of about 103.

Wright (1922a) found that the sex ratio in guinea pigs was not affected by inbreeding. Eaton (1932), working with the same guinea pigs as Wright, found that the percentage of male pigs remained about 50. He reported that in some years as high as 68 per cent of the pigs were males while in other years the percentage was as low as 38. King (1918c) found that inbreeding with no selection for high or low sex ratios did not affect the sex ratio in rats. Hays (1919) reported that inbreeding produced more males in cattle and swine.

Effect of Inbreeding on Weaning Weight

Another harmful effect of inbreeding is that it tends to decrease weaning weights of inbred individuals. Bradford _et al_. (1958), Godbey and Starkey (1932), Hays (1919), Hodgson (1935), and Willham and Craft (1939) reported that weaning weight in swine decreased as a result of inbreeding. Hodgson (1935) reported no decrease in birth weights, and that inbred and outbred pigs grew at the same rate during the first 16 weeks, and then the outbred pigs began to grow faster than the inbred pigs. Bradford _et al_. (1958) reported that an increase of 10 per cent in the inbreeding coefficient for the litter resulted in decreases of approximately six pounds in total litter weight at birth and 75 pounds in total litter weight at five months of age. Godbey and Godley (1961) stated that the mean 56-day weight of pigs decreased approximately 33 per cent as inbreeding increased from an average of 3.12 to 56.9 per cent. Stringam et al. (1950) practiced inbreeding with intense selection and reported that the decrease in pig's rate of gain caused by inbreeding was offset by the effects of selection. Ragab and Asker (1954) reported that inbreeding reduced the weaning weight of lambs and caused an even larger reduction in their market weight.

Inbreeding in cattle caused a reduction in weaning weight by causing a slower preweaning growth rate (Laben et al., 1955; Rollins et al., 1949; Woodward and Graves, 1933, 1946). Rollins et al. (1949) reported that inbred calves were smaller at birth and grew more slowly until about the sixth month than the outbred calves, but the inbred calves grew faster than outbred calves from the sixth to the twelfth month of age. Swiger et al. (1961), and Alexander and Bogart (1961) found that birth weight of calves was affected very little by inbreeding, but inbreeding caused a decrease in feed consumption and growth rate. Inbreeding significantly affected suckling gains, age at 500 pounds body weight, and age at 800 pounds body weight. Woodward and Graves (1946) reported that inbred individuals were easily identified in their herd by their general appearance, i.e., smaller size and lack of vigor. Bartlett et al. (1942) began a project with desirable foundation dairy stock and reported that among their cattle the rate of growth was not affected by inbreeding.

King (1916, 1918a, 1919), as a result of her inbreeding studies with rats, reported that decreases in size and rate of growth caused by inbreeding were more than offset by selection. Her selection resulted in an improvement of size and growth rate of the inbred over the outbred rats. Wright (1922) and Eaton (1932) reported that inbreeding resulted in a reduction in weaning weight among guinea pigs, but that weaning weight was dependent on birth weight and also was affected by size of litter, condition of dam, and other hereditary effects.

Eaton (1938, 1939) performed autopsies on inbred guinea pigs, and Swett et al. (1949) performed autopsies on inbred dairy cattle to determine why inbred animals were smaller than outbred animals. Eaton (1938, 1939) and Swett et al. (1949) found a non-significant difference in bone measurement even though there were large variations in body size and weight. They also found that organs of smaller inbred individuals were larger in proportion to their body weights. Eaton (1938) divided organs into three groups: high variability - lungs, thyroids, and adrenals; medium variability - blood, heart, liver, kidneys, pituitary, and testicles; and low variability - intestines and spleen. He concluded that decreases in body size caused by inbreeding were not due to decrease in size of the different organs.

Effect of Inbreeding on Age at Puberty

Wright (1922a) reported that guinea pigs reach sexual maturity at an early age. He reported several cases where females gave birth to young at about 100 days of age. These cases indicated that the females reached puberty when they were about 32 days of age, assuming the average gestation period was 68 days. The minimum age at which a male may sire a litter appeared to be about 60 days, although Wright (1922a) had one apparently reliable record of a male siring a litter at 48 days of age. The average age at puberty for the male was three months.

Experimental evidence indicated a negative correlation between rate of growth and age at which puberty was reached. The faster growing individuals reached sexual maturity quicker. Harris et al. (1960) and Menge et al. (1958), working with cattle, and Craft (1953) and Squiers et al. (1952) with swine, reported that inbred animals grew more slowly and that their age at sexual maturity was increased. However, King (1918a) reported that inbred rats grew faster and matured earlier than outbred rats. She also reported that early sexual maturity and vigorous growth were genetically correlated.

Effect of Inbreeding on Gestation Length

Inbreeding did not affect the gestation length in Jersey cattle (Rollins et al., 1956). Musson (1951) reported that inbreeding had very little or no effect on gestation length in swine. Thirteen per cent of the variance observed in gestation length was caused by line differences. Litter weight accounted for 3 per cent of the variance. Inbreeding, age of dam, size of litter, and environmental conditions accounted for only 3 per cent of the variation in gestation length. Wright (1922a) reported that litter size and environmental conditions caused most of the variation in gestation lengths. Large litters were born earlier than small litters, and unfavorable environmental conditions caused a shorter gestation period. With the average gestation length of 68 days in the guinea pig, Wright (1922a) reported that young born before 65 days of gestation are seldom raised or even born alive, and Eaton (1932) reported that no pigs were found alive in litters of less than 62 days of gestation.

Effect of Inbreeding on Livability

Hays (1919), Laben et al. (1955), and Woodward and Graves (1933, 1946) reported that inbred calves had a higher mortality rate than outbred calves. They reported that the loss of vigor made the inbred calves less resistant to infectious diseases such as scours and pneumonia which caused a large percentage of the deaths among their calves. Woodward and Graves (1946) reported that a pneumonia epidemic killed 15 per cent of the inbred calves as compared with only 10 per cent of the outbred calves in the same herd.

Bradford et al. (1958), Craft (1953), and Willham and Craft (1939) reported that inbreeding increased the mortality rate among pigs. Bradford et al. (1958) reported that inbreeding produced a decrease of about 0.45 pig raised per litter for each

10 per cent increase in inbreeding for the litter. Godbey and Godley (1961) reported a decrease in number of pigs raised and an increase in number of pigs born dead per litter as inbreeding increased. Willham and Craft (1939) reported that sows in the eighth inbred generation weaned 2.3 fewer pigs per litter than the outbred sows.

Stringam et al. (1950) reported that the increased mortality caused by inbreeding could be cancelled by intense selection. Hodgson (1935) concluded that it was difficult to determine if deaths among the pigs were due to inbreeding since most of the pigs died as a result of having been crushed by the sow. These deaths could have been due to inbreeding if inbreeding reduced the sow's ability to raise her litter or the pig's ability to stay out of the sow's way. King (1918b) reported that vigor was the most important factor in reducing mortality and increasing longevity. Her inbred individuals lived longer than her outbred individuals and had a lower mortality rate because she selected for vigor. Wright (1922a) reported that inbred guinea pigs were inferior to outbred pigs in disease resistance. He inoculated pigs with tubercle bacilli and found that inbred animals died about 12 days sooner, and a larger number of inbred individuals died with diseases other than tuberculosis such as pneumonia and inflammation of the bowels than the outbred pigs. Eaton (1932) found that during the 25 years covered by his study, the inbred guinea pigs had a higher prenatal and postnatal mortality rate. The high mortality was apparently due to the lessened vigor of the parents and of the young themselves.

MATERIAL AND METHODS

The material used for this thesis was obtained by reviewing the records involving 5,035 guinea pigs in the Animal Husbandry Department's Guinea Pig Colony from 1951 to 1961. The pigs used in this experiment were traced to pigs which were set aside in 1951 to start an inbreeding experiment. As the number of pigs increased or as unique characteristics appeared, the original inbred lines were subdivided into new lines. Each pig was identified by a letter designating his inbred line, digits to the left of the decimal point designating his litter number, and a digit to the right of the decimal point designating his number within the litter.

All pigs were maintained in the same room and in the same type and size of cages, and were fed the same general ration throughout the experiment. The only major change in the environment during the ten-year period was the addition of an air conditioner to the room in 1960. Therefore, the data were not corrected for the effects of environment during the years.

The pigs were mated with other individuals within their inbred line; the most frequent types of mating were those between full sibs and between parent and offspring. The coefficient of inbreeding for each pig was determined by Wright's Path Coefficient Method (Wright, 1922c). The inbreeding coefficients ranged from 0 to 84 per cent.

The following information was collected on each guinea pig when possible: birth weight within 24 hours after birth, sex of the pig, litter size, sex ratio in the litter (derived by dividing the number of males in the litter by the total number of pigs in the litter), weaning weight at 21 days of age, age of the female when she had her first litter, gestation length (number of days between a female's consecutive litters if less than 75 days), and age of the pig at time of its death.

Correlation coefficients and regression coefficients between each characteristic and other associated characteristics were determined by using an IBM Data Processing Machine and a Desk Calculator. Path coefficient analysis was utilized to show the associations among certain traits. The characteristics which could have been affected by sex were separated and analyzed on a within sex basis. The data were also corrected for the effects of size of litter on birth weight and on weaning weight (Searle, 1960).

RESULTS AND DISCUSSION

Effect of Inbreeding and Certain Other Traits on Birth Weight

Average birth weights of guinea pigs used in this experiment were 89.87 grams for the males and 88.51 grams for the females. The average birth weights of these pigs were higher than the average birth weight of 80 grams reported by Wright (1922a, 1922b) and Eaton (1932).

A total of 1,899 guinea pigs; for which birth weight, weaning weight, litter size, and sex were known; was used to determine the effect of litter size and sex on birth weight and weaning weight (Table 1). The data in Table 1 were corrected by Searle's (1960) Method.

Table 1. Mean birth and weaning weights by sex and litter size.

Sex*	Litter size	Number of observations	Mean birth weight	Mean weaning weight
			grams	
1		928	88.49	180.81
2		971	90.69	180.94
	2	472	100.58	206.54
	3	852	90.16	181.47
	4	434	82.37	163.97
	5	111	71.88	139.50
	6	30	72.20	151.49
1	2	235	99.01	205.29
1	3	419	88.53	179.87
1	4	216	81.41	165.38
1	5	48	70.76	142.08
1	6	10	77.26	145.58
2	2	237	102.14	207.78
2	3	433	91.73	183.03
2	4	218	83.31	162.57
2	5	63	72.73	137.53
2	6	20	69.67	154.45

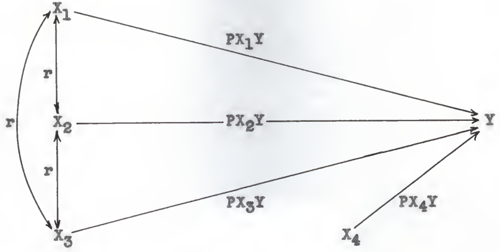
* Code for sex:

1 is female
2 is male

The correlation between inbreeding coefficient of the pig and the pig's birth weight was 0.0075 (N = 3,759), indicating that birth weight was not affected by inbreeding. The regression coefficient revealed that as inbreeding increased 1 per cent, birth weight increased 0.007 gram. There was no selection for or against heavier birth weights in this experiment, thus, the small increase in birth weight as inbreeding increased, disagreed with results reported by other workers who practiced no selection for birth weight (Willham and Craft, 1939; Rollins et al., 1949; and Eaton, 1932). An explanation for the slight positive correlation between birth weight and inbreeding coefficient possibly can be obtained by studying the effects of litter size and gestation length on birth weight.

The data in Table 1 indicate that as litter size increased, birth weight decreased. Birth weight was greatly affected by litter size since the correlation between the two variables was -0.583 ($N = 4,403$, $P < .01$). A path coefficient analysis (Fig. 1) indicated that 27.57 per cent of the variation in birth weight was caused by variation in litter size. Inbreeding caused a decrease in litter size. Litter size also indirectly affected birth weight by influencing gestation length.

A total of 388 observations was used to determine the effect of litter size on gestation length. The correlation between the two variables, -0.279 ($P < .01$), indicated that as litter size increased, the litter had a shorter gestation length. The regression of gestation length on litter size was -0.46 day. The correlation between birth weight and gestation length was 0.396 ($N = 939$, $P < .01$); the longer the pigs stayed in the dam's uterus, the larger they were at birth. The regression coefficient showed that each day of gestation increased birth weight by 1.698 grams.



Y = birth weight of individual pig

X_1 = litter size

X_2 = gestation length

X_3 = inbreeding coefficient for the pig

X_4 = other effects

PX_1Y, etc. = value of the path between the X_1 and Y, etc.

rX_1X_2, etc. = correlation coefficient between X_1 and X_2, etc.

Values for the lines are:

rX_1X_2 = -0.296	rX_1Y = -0.583	PX_1Y = -0.524
rX_1X_3 = -0.096	rX_2Y = 0.396	PX_2Y = 0.214
rX_2X_3 = 0.094	rX_3Y = 0.0075	PX_3Y = -0.088
		PX_4Y = 67.14%

Fig. 1. Path coefficient analysis of the effects of litter size, gestation length, and inbreeding coefficient on birth weight.

A path coefficient analysis (Fig. 1) was made to determine the percentage of the variation in birth weights that was caused by inbreeding, litter size, and gestation length. The results indicated that variations in inbreeding, litter size, and gestation length accounted for 0.78, 27.51, and 4.57 per cent of the variation in birth weight, respectively. This left 67.14 per cent of the variation in birth weights to be caused by other factors; such as environment, heredity, and other factors pertaining to the dam (age, size, health, etc.).

Two factors which could have affected birth weight were inbreeding of the dam, and litter number for the dam. As the inbreeding coefficient of the dam increased, birth weight of her pigs increased slightly as the correlation between these two traits was 0.026 (N = 3,389). The regression of birth weight on inbreeding coefficient for the dam was 0.127 gram. The apparent reason for this positive correlation was the fact that as the inbreeding of the dam increased, the size of the dam's litter decreased. This reduction in litter size could have been due to a decrease in number of ova ovulated as reported by Squiers _et al_. (1952), thus the smaller the litter, the larger the pigs at birth. The more litters a dam had, the smaller the average birth weight of the pigs in the litter because the correlation between litter number of the dam and birth weight of the pigs in the litter was -0.018 (N = 2,065). This reduction in birth weight was possibly due to the fact that as the dam matured, the size of the litter increased ($r = 0.205$, $N = 4,285$, $P < .01$).

Effect of Inbreeding and Certain Other Traits on Litter Size

Guinea pigs in this experiment were born in litters of one to six pigs. The average litter size was 2.97 pigs with a standard deviation of 1.5 pigs, which agreed with data reported by Wright (1922a). The correlation between inbreeding coefficient of the litter and the size of the litter was -0.096 ($P < .01$, $N = 4,215$). There was no selection for litter size in this experiment, so the slight decrease in litter size as a result of inbreeding was in agreement with the findings of Wright (1922b) and Eaton (1932). The regression coefficient indicated that the number of pigs per litter decreased 0.005 pig for each per cent increase in inbreeding for the litter.

The data were also analyzed to determine the effect of inbreeding of the dam on the size of her litters. The correlation between the dam's inbreeding coefficient and the size of her litter was -0.088 ($N = 1817$, $P < .01$). The regression of the dam's litter size on her inbreeding was -0.004. Therefore, inbreeding of the dam tended to cause a very slight decrease in the size of her litters similar to that caused by inbreeding of the litter. The regression coefficients indicated that the decrease in litter size caused by inbreeding of the dam was less than the reduction caused by inbreeding of the litter, therefore, most of the reduction in litter size could have been due to embryonic death caused by the increase in inbreeding of the litter. No observations; such as fertilization rate, ovulation rate, prenatal deaths, or semen evaluation; were made in this experiment to determine how the reproductive efficiency of the guinea pigs was affected by inbreeding.

Effect of Inbreeding on Sex Ratio

Of the 5,035 guinea pigs included in this experiment, 2,709 were males and 2,326 were females, or a sex ratio of 116.46 males to every 100 females. This ratio was higher than the sex ratios which ranged from 102.4 to 106.9 males to 100 females reported by Eaton (1932), Risty (1928), Schaumburg (1923), and Summer (1926).

The correlation coefficient between inbreeding coefficient and sex ratio among pigs in 1,727 litters was 0.029, which indicated that inbreeding had little or no effect on sex ratio. The sex ratio of 116.46 males to 100 females was significantly different (chi-square test, $P < .005$) from the sex ratio of 103 males to 100 females reported by Schaumburg (1923) and Summer (1926). Some possible reasons why there was a high sex ratio in this experiment are: inbreeding decreased the female embryo's chance of survival, more female pigs died at birth and were not recorded, or as in the case of the experiment reported by Hays (1919), inbreeding resulted in the birth of more males than females. There were 863 pigs born in 434 all-male litters and 675 pigs born in 367 all-female litters. The author believes that the sex ratio was not affected by inbreeding as reported by Eaton (1932), King (1918c), and Wright (1922a).

Effect of Inbreeding and Certain Other Traits on Weaning Weight

The pigs in this experiment were weaned at 21 days of age, whereas the pigs studied by Wright (1922a, 1922b) and Eaton (1932) were weaned at 33 days of age. This was undoubtedly the main reason that the pigs in this experiment had much lower weaning weights than the 240 and 249 grams reported by Wright (1922a, 1922b) and Eaton (1932). The mean weaning weight of the pigs in this experiment was 188.3 grams with a standard deviation of 32.4 grams. The mean weaning weight of the males was 189.6 and that of the females was 186.9 grams.

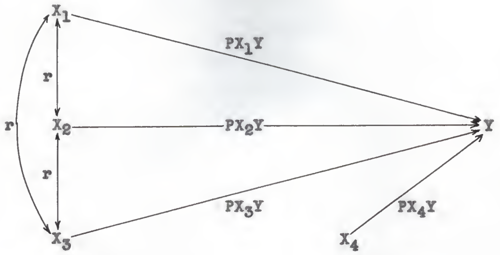
Inbreeding had very little effect on the weaning weights of the pigs since the correlation between inbreeding of the pig and his weaning weight was -0.002 (N = 3,130). Each per cent increase in inbreeding resulted in a decrease of 0.051 gram in weaning weight. These results were in agreement with those reported by other investigators (Bradford _et al._, 1958; and Godbey and Starkey, 1932).

The pig's birth weight is a large percentage of his weaning weight, indicating part-whole automaticity which contributed to the correlation between the two variables ($r = 0.653$, $N = 3,388$, $P < .01$). The regression of weaning weight on birth weight was 2.04 grams. Since birth weight represents the pig's prenatal growth rate, the pigs that grew fast before birth continued to grow fast after birth.

Weaning weight of the pig decreased as litter size increased (Table 1). The correlation between litter size and weaning weight was -0.46 (N = 3,621, $P < .01$) which indicated that weaning weight was greatly affected by litter size. The regression of weaning weight on litter size was 17.32 grams. A possible reason why litter size had so much effect on weaning weight was that the dam, with only two teats, cannot produce enough milk to care for over three pigs at one time. It was observed in this experiment that in litter size of four or more pigs, in most cases, only two or three pigs survived to weaning, or in some cases, one or two pigs had a large weaning weight while the other pigs were smaller. The reason weaning weight of litters of six pigs showed an increase was that only two or three pigs were alive at weaning (Table 1).

A path coefficient analysis was used to determine the portion of the variation in weaning weight that was caused by inbreeding, birth weight, and litter size (Fig. 2). Inbreeding caused 0.02 per cent, litter size caused 1.4 per cent, and birth weight caused 52.17 per cent of the observed variation in weaning weight.

A particular characteristic of guinea pigs is that they are about the only rodent that is born in an advanced state of development, i.e., with a thick hair coat, open eyes, have the ability to run about at once, and begin eating regular feed at one or two days of age. Wright (1922a) reported that some vigorous pigs survived even when their dam died at parturition. Therefore, vigor plays an important part in determining whether



Y = weaning weight

X_1 = birth weight

X_2 = litter size

X_3 = inbreeding coefficient for the pig

X_4 = other effects

PX_1Y, etc. = value of the path between the X_1 and Y, etc.

rX_1X_2, etc. = correlation coefficient between X_1 and X_2, etc.

Values for the lines are:

rX_1X_2 = -0.583	rX_1Y = 0.653	PX_1Y = 0.722
rX_1X_3 = 0.007	rX_2Y = -0.46	PX_2Y = 0.118
rX_2X_3 = -0.096	rX_3Y = -0195	PX_4Y = -0.013
		PX_4Y = 46.41%

Fig. 2. Path coefficient analysis of the effect of litter size, birth weight, and inbreeding coefficient on weaning weight.

or not a guinea pig survives. Since research has proven that inbreeding reduces vigor, a possible cause of the reduction in weaning weights of inbred guinea pigs was that they were not as vigorous as non-inbred pigs. The lack of vigor possibly was reflected by the fact that the inbred pigs were of average size at birth, but possibly lacked strength and alertness, so they began eating later than if they had not been inbred; consequently, inbred pigs grew more slowly.

Effect of Inbreeding and Birth Weight on Age at Puberty

In this experiment, the age at puberty was estimated by determining the age of the female at the time she had her first litter. It was assumed that the females were in cages with mature males and were bred at their first estrual period (though undoubtedly some females did not have an opportunity to be bred during their first estrus period). Results from 759 observations indicated that inbreeding had little or no effect on age of the female pig at puberty, as the correlation was only -0.001. A truer picture of the actual situation would have been indicated by the correlation involving only the females that had a chance to be bred during their first estrus. No attempt was made to determine the age at which males reached puberty. There were several observations on females which had their first litter at about 100 days of age as reported by Wright (1922a).

The data were analyzed to determine the effect of size of the pig at birth on age of the female pig at puberty. The correlation between birth weight of the female pig and age at which she reached puberty was -0.0329 (N = 707). The regression coefficient indicated that as birth weight increased one gram, the female reached puberty 1.76 days earlier. Therefore, pigs which were heavier at birth grew faster and sexually matured earlier as reported by King (1918a).

Effect of Inbreeding and Litter Size on Gestation Length

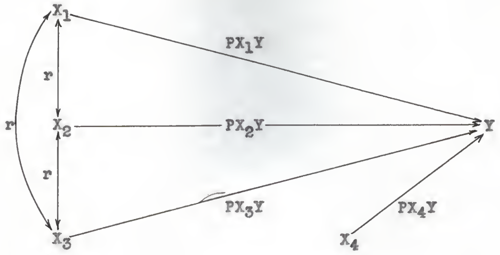
The female guinea pig has an estrual period soon after parturition. Wright (1922a) reported that in vigorous stock, 50 to 60 per cent of the matings at this post partum estrus resulted in pregnancy so that one litter follows another after an interval of 65 to 74 days. In this experiment, all intervals of 75 days or less between successive litters were considered as gestation lengths for the respective litters. A total of 378 observations were made to determine the effect of inbreeding of the litter on gestation length for the litter. The correlation between the inbreeding coefficient of the litter and the gestation length for the litter was 0.094. This lack of influence of inbreeding on gestation length agreed with results reported by Musson (1951) in swine and Rollins *et al*. (1956) in cattle.

The correlation between inbreeding in the dam and gestation length of her litters was 0.1358 (N = 377, $P < .01$). Each 10 per cent increase in inbreeding for the dam was associated with a third of a day increase in gestation length of her litter. A probable reason for this increase in gestation length was that the inbred dams had smaller litters and the smaller litters were carried in the dam's uterus a longer length of time.

The data showed that gestation length of the litter was significantly affected by litter size. The correlation between the two variables was -0.2969 ($N = 388$, $P < .01$). The regression coefficient indicated that gestation length decreased 0.46 day as litter size increased one pig.

Two possible explanations of why larger litters are born sooner are: hormonal, an unknown hormone secreted by the fetus, when it is anatomically and physiologically mature enough to be born, that stimulates the dam into parturition; the more fetuses present; more hormone secreted; therefore, the dam's stimulating level is reached sooner; or mechanically, the movement of the fetus in the dam's uterus stimulates the uterine nerves which stimulates the dam into parturition, more fetuses present, more movement in the uterus, and the dam is stimulated into parturition sooner.

A path coefficient analysis (Fig. 3) was used to determine the portion of the variation in gestation length due to inbreeding of the litter, inbreeding of the dam, and litter size. The values of the paths indicated that inbreeding of the litter accounted for 1.64 per cent; inbreeding of the dam accounted for 0.08 per cent; and litter size accounted for 8.47 per cent of the observed variation in gestation length. These results agreed with those of Wright (1922b) when he reported that size of litter, and environmental conditions of the dam (which, in the present



Y = gestation length of the litter

X_1 = inbreeding coefficient for the litter

X_2 = inbreeding coefficient for the dam

X_3 = litter size

X_4 = other effects

PX_1Y, etc. = value of the path between the X_1 and Y, etc.

rX_1X_2, etc. = correlation coefficient between X_1 and X_2, etc.

Values for the lines are:

rX_1X_2 = 0.74	rX_1Y = 0.094	PX_1Y = 0.128
rX_1X_3 = 0.964	rX_2Y = 0.136	PX_2Y = -0.028
rX_2X_3 = -0.0884	rX_3Y = -0.297	PX_3Y = -0.291
		PX_4Y = 89.81%

Fig. 3. Path coefficient analysis of the effects of inbreeding coefficient of the litter, inbreeding coefficient of the dam, and litter size on gestation length.

analysis, would be included among the "other effects") caused most of the variation in gestation length.

The gestation length of all-male litters and of all-female litters was compared to determine if gestation length was affected by sex of the pigs within the litter. The mean gestation length for the all-male litters was 67.99 $\pm$ 5 days and for the all-female litters the mean was 68.56 $\pm$ 4.5 days. The all-male litters were 0.15 pig larger than the all-female litters, and the fact that smaller litters have a longer gestation may account for the reason that the females were carried 0.6 day longer than males.

Effect of Inbreeding and Birth Weight on Livability

The results from this experiment indicated that inbreeding had little or no effect on livability (defined as the age of the pig when it died) of the guinea pig because the correlation coefficient between the two traits was only 0.01 (N = 1535). These results disagreed with those from other research concerning the effects of inbreeding, without selection, for longevity. Some possible reasons why these results differed were that no information was kept on abortions, or on pigs that were dead at birth or died before birth weight was recorded, or for pigs used in other experiments, or pigs that were discarded.

Most of the pigs in the present study that lived to weaning, lived to a year or more of age. The correlation between birth weight and livability was 0.245 ($N = 1451$, $P < .01$), indicating that increases in birth weight significantly increased the life span of the pig. Each gram increase in birth weight meant an average increase of 3.39 days to the life of the pig. Therefore, the larger pigs were probably more vigorous, and got a better start in life, which enabled them to live longer than pigs that were smaller at birth.

SUMMARY

In 1951, an inbreeding experiment was initiated in the Guinea Pig Colony maintained by the Animal Husbandry Department. The purposes of this experiment were to determine the effects of inbreeding on birth weight, weaning weight, litter size, sex ratio, gestation length, age at puberty, and livability in the guinea pig, and the associations among these characteristics.

The results of ten years of inbreeding involving 5,035 guinea pigs (inbreeding coefficients were as high as 84 per cent) indicated that each per cent increase in inbreeding decreased litter size, and weaning weight, 0.005 pig, and 0.051 gram, respectively. Inbreeding had little or no effect on birth weight, sex ratio, age of female at sexual maturity, gestation length, and livability.

The associations among the following characteristics were: males were about two grams heavier than females at birth; sex of the all-male or all-female litters had no effect on gestation length; gestation length decreased 0.46 day for each one pig increase in litter size; regression of birth weight on gestation

length was 1.698 grams; that of weaning weight on birth weight was 1.841 grams; each gram increase in birth weight caused the female to reach sexual maturity 1.76 days earlier, and livability increased 3.39 days for each increase of one gram in birth weight.

In general, the results of this experiment have added support to previously established theories concerning the effects of inbreeding. Inbreeding has generally caused a decrease in all of the characteristics studied. Path coefficient analyses indicated that the effects of inbreeding were minor; variations in inbreeding accounted for less than 2 per cent of the total variation in the characteristics studied. Most of the variation in characteristics studied was caused by other characteristics; for example, inbreeding accounted for only 1.64 per cent of the variation in gestation length, and litter size caused 8.47 per cent of the variation in gestation length. Inbreeding apparently decreased litter size and vigor. Variation in litter size and vigor accounted for most of the variation in all the other traits studied. Since inbreeding caused only a small portion of the variation, the harmful effects of inbreeding could probably be offset by intense selection.

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EFFECTS OF INBREEDING ON LITTER SIZE, BIRTH WEIGHT, WEANING WEIGHT, AND CERTAIN OTHER TRAITS IN GUINEA PIGS

by

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In 1951, an inbreeding experiment was initiated with pigs in the Guinea Pig Colony of the Animal Husbandry Department at Kansas State University. The purpose of this experiment was to determine the effect of inbreeding on certain characteristics in the guinea pig that are economically important in livestock production. The results of the first ten years, involving 5,035 guinea pigs, of this inbreeding experiment are reported.

The following information was collected on each individual when possible: birth weight, sex, sex ratio of the litter, size of the litter, weaning weight, age of female when she had her first litter, gestation length, and age of pig at death.

Correlation coefficients and regression coefficients, and path coefficients of each characteristic with other associated characteristics were determined. Inbreeding coefficients, ranging from 0 to 84 per cent, were determined by Wright's Path Coefficient Method. Characteristics affected by sex and litter size were adjusted for these effects.

The results from this experiment indicated that litter size, and weaning weight decreased 0.005 pig and 0.051 gram, respectively, as inbreeding increased 1 per cent. Inbreeding had little or no effect on birth weight, sex ratio, age of female at puberty, gestation length, and livability.

The following associations among characteristics were found: males were about two grams heavier than females at birth; sex, in the case of all-male or all-female litters, had no effect on gestation length; gestation length decreased 0.46 day for each one-pig increase in litter size; an increase of one day in gestation length increased birth weight 1.698 grams; an increase in birth weight of one gram increased the weaning weight by 1.841 grams; each increase of a gram in birth weight caused the female to reach sexual maturity 1.76 days earlier, and livability increased 3.39 days for each gram increase in birth weight.

Path coefficient analyses indicated that variations in inbreeding coefficients accounted for 0.78, 1.64, and 0.002 per cent of the total variation in birth weight, gestation length, and weaning weight, respectively.

It appeared that inbreeding had no great effect on any characteristic studied. Therefore, inbreeding must have had a direct effect on some characteristic not studied that affects the overall physiological efficiency of the individual.