Measurements and effects of size in white leghorns and white leghorn bantams
by Inyang Mecha

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Animal Science
Montana State University
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Abstract:
In a study of measurements and effects of body size, 227 birds, including White Leghorns, White
Leghorn Bantams and their reciprocal crosses, were used.

The following characters were measured: body weight at time of laying the first egg, body weight at
end of the experiment, which lasted until, the females were 58 weeks of age, feed consumption, egg
mass, changes in weight during the faying period, shank index (shank length multiplied by shank
width), length of shank, number of eggs laid per day, and the average weight of the eggs laid. The
multiple. correlation coefficient (R2) was used to determine the proportion of the variation accounted
for by the relationship among the factors, involved in the conversion of feed to eggs. The main factors
in prompting the highest results in the ability of the chickens to convert feed to eggs, as indicated by
the standard partial regressions coefficients, are as. follows: body weight at 58 weeks, i.e. final body
weight, shank index, number of eggs laid per day, and the average weight of the eggs laid. -R2
values rose above .80 as a result of using either of the two measurements of body size, namely, final
body weight and shank index plus the two egg factors, namely, number of eggs laid per day and
average egg weight.

Any meaningful genetic selection affecting feed conversion, it appears, must take into account these
four factors since they were responsible for such a large proportion of the variation accounted for in the
relationship of the independent variables and feed conversion.
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Date July 31, 1970
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by

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A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Animal Science

Approved:

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ABSTRACT

In a study of measurements and effects of body size, 227 birds, including White Leghorns, White Leghorn Bantams and their reciprocal crosses, were used.

The following characters were measured: body weight at time of laying the first egg, body weight at end of the experiment, which lasted until the females were 58 weeks of age, feed consumption, egg mass, changes in weight during the laying period, shank index (shank length multiplied by shank width), length of shank, number of eggs laid per day, and the average weight of the eggs laid. The multiple correlation coefficient ($R^2$) was used to determine the proportion of the variation accounted for by the relationship among the factors involved in the conversion of feed to eggs.

The main factors in promoting the highest results in the ability of the chickens to convert feed to eggs, as indicated by the standard partial regressions coefficients, are as follows: body weight at 58 weeks, i.e. final body weight, shank index, number of eggs laid per day, and the average of total weight of eggs laid. $R^2$ values rose above 0.80 as a result of using either of the two measurements of body size, namely, final body weight and shank index plus the two egg factors, namely, number of eggs laid per day and average egg weight.

Any meaningful genetic selection affecting feed conversion, it appears, must take into account these four factors since they were responsible for such a large proportion of the variation accounted for in the relationship of the independent variables and feed conversion.
MEASUREMENTS AND EFFECTS OF SIZE IN WHITE LEGHORNS AND WHITE LEGHORN BANTAMS

INTRODUCTION

What Size Means

Observations of the birds maintained at the Montana State University Agricultural Experiment Station in Bozeman indicate that the body weight of chickens varies several times in a day depending on whether or not they had just been fed, drank water, laid an egg or excreted fecal matter before being weighed. The way the feathers of birds are arranged and the manner they expose their bodies to view tend to make birds of the same standard weight appear different in size.

However, the meaning of size in one situation may be different from what it means in another. Size depends on the purpose for which the measurement is being obtained. The term "size" may mean existing or occurring in space, dimension, proportion, magnitude or bulk of anything, for example, the size of a piece of land.

It may mean some series of graded measures of items such as boots, children's clothing, ladies and men's garments. Size also expresses extent, amount or range. People may talk of wealth of great size. In talking about the actual condition, state of affair or situation of a thing people may wish to say that it is just about the size of it.

Size is a general word for other synonyms such as mass, volume, bulk and so on, each of which has a shade of meaning from the other
but all of which refer to dimension of what has magnitude and occupies space. Usually, dimension refers to measurement in width, length and specific thickness. Therefore, shank length in chickens would not appear to be adequate in measuring dimension because it is one dimensional, although it is easy to measure. It should be remembered that the shank of a chicken has not only length but also has width and depth (thickness or diameter), all of which are involved in what make up the size of both the leg and the entire body. Researchers have been using shank length as a representative of skeletal size in birds for many years.

Of all the leg bones, the shank has been regarded as the best positively correlated portion of leg to the body size. The shank length alone would be a partial representative of the body size as the shank width and shank depth are not considered. Hutt (1949) reported that the Cornish chickens have short and thick legs, whereas Leghorns have long and narrow ones.

The best method of measuring size would be that which accounts for any existing length, width and depth of the object being measured. Objectives

In this experiment, measurements were obtained from shank depth and width for the construction of a shank index. The usefulness of this shank index for assessment of body size, as well as the comparative value of the index with the shank length or body weight for measuring size in White Leghorns, White Leghorn Bantams, and their
crosses, were determined. In addition, the effects of body weight, shank index, egg mass, egg number and other independent variables on the conversion of feed into eggs, in the birds being studied, were also determined.

This experiment is a part of a program which embodies the following objectives:

1. To find reliable measurements of size in the chickens
2. To determine the factors that control the conversion of feed to eggs.
3. To make a genetic analysis of body size, using crosses of Leghorns and Leghorn Bantams
4. To determine the correlated changes that result from selecting for feed conversion.
Measuring Body Size

Burmester and Lerner (1937) used shank length measurements in growth studies on the axial skeleton of fowl. The technique used in their earlier work involved the killing of birds so that the bones might be made available for measurements. This technique was wasteful and was subsequently replaced by a simpler type of device, an instrument which required the foot of live birds to be placed against a pedal and pushed forward until the hock joint slipped into a shoe. The length of the shank, which at that position was fully stretched, was then read on a meter attached to the pedal. The new instrument was extremely accurate in measuring shank length, as determined by the positive correlation of $0.968 \pm 0.007$ between live measurements and the actual length of the tarso-metatarsus from their earlier works on prepared bones.

The measuring device was later used to determine the distribution of shank length in a flock of birds maintained at the University of California, according to the report of Burmester and Lerner (1937). The distribution revealed definite differences in size among strains used in recent years in that flock and also emphasized the validity of live shank length as a criterion of inheritance of body size.

Lerner (1939) used White Leghorns in studying the relationship between body weight and shank measurements. The calculation was based on the logarithms of shank length and body weight. He concluded that
either shank length or body weight could be used at an early age to determine body weight at a later age, and that body weight and shank length are not as closely correlated in mature birds as during the growing stages.

In order to modify, by selection, the shank growth ratio of a group of chickens originating from crosses, Lerner (1958) suggested the use of what he called a growth equation, \( Y = bX^\alpha \), where \( Y \) is the shank length, \( X \) represents the body weight, \( b \) is a constant and \( \alpha \) used as an index of conformation. The exponent \( \alpha \) assesses the rate at which the shank grows in relationship to the growth rate of the whole body.

Hutt (1949) stated that the size of the chick is dependent on the egg size and that large hens, to some extent, lay bigger and more eggs than do the smaller ones. The point at which the second part of the statement ceases to be true, that is, the point at which the larger hens stop laying bigger and more eggs, was not specified by Hutt.

Godfrey and Williams (1955) found that the percentage of the body weight of day-old chicks over the original egg weight was positively correlated to body weight of these same chicks at the age of 12 weeks. Their objective was to determine the suitability of using this percentage body size over the original egg weight as a measure of body size. Although the male and female groups of birds in this experiment had the same original egg weight, the percentage chick weight of the original egg weight was higher in males than the females. The difference was attributed to inequality in the ability of the embryos of both sexes
to utilize the nutrients provided by the egg contents rather than difference in the size of the eggs. The relationship existing between the body weight of the chicks at 12 weeks and the percentage the chick body weight was of the original egg weight was highly significant but the coefficient of determination (r²) revealed that only about 5% of the variation was accounted for. Therefore, this method of body size assessment proved to be unsuitable.

Using the intraclass correlation method, Gyles, Kan and Smith (1957) reported the following results for repeatability of the measurements of body size in 252 birds:

- Live weight of both sexes: .85
- Live weight of males: .85
- Live weight of females: .70

According to Nordskog and Briggs (1968), body size not only involves variation in condition, which is mainly environmental, being controlled by factors of nutrition, management and diseases, but is also associated with genetic factors such as the function of bone frame work with regard to skeletal size and the influence of many genes. They also stated that body weight could be used both as a measure of size and condition and that variation in size is mainly a genetic function.

Influence Of Genes On Body Size

Jull (1940) stated that the size of the body in general would appear to be determined by many genes while specific genes have
particular effects on certain parts of the body. Creeper and Dark Cornish fowl, whose length of leg is controlled by specific genes, are some exceptions rather than examples. Juli (1940) also said that Maw (1935) observed, in a study of inheritance of skeletal dimensions in the domestic fowl, that the skeletal size of a fowl is determined by a number of genes having a general effect. All breeds of poultry, except bantams, have a common basic genetic complex with regards to the type of growth of parts of the body in relation to the whole body.

Of the three leg bones, the femur, tibiotarsus and the tarso-metatarsus, the length of the tarso-metatarsus in live birds is observed to be good index of inherent body size. The shank length in live birds is a measurement of the bone, tarso-metatarsus. Juli (1940) indicated that Lerner (1939) observed that shank length and body weight are more closely correlated in growing birds than in mature ones. With regards to bone length, the greatest difference between the sexes in White Leghorns exists in the bigger portion of the shank bone. In female birds the shank length stops to grow at five months as opposed to six months in the case of the males.

Of the following four linear measurements in different conformation groups of observed birds: shank length, keel length, anterior body weight and width of breast, respectively, compared to the cube root of their body weight, the shank length-body weight relationship most suitably reflected the single basis of the quality of market conformation
in these birds, according to Jull (1940).

In comparing the rates of growth of leg bones and body weight in the fowl, Jull (1940) stated that in 1927 Latimer observed that the rate at which the leg bones grow is greater than that at which the body weight grows. However, he did not state the specific time when the rate of growth of leg bones is greater than that of the body weight. Also, the extent of increase from hatching time to maturity is greater in the male than the female bones, except the femur which showed no difference in the rate of growth.

Jull (1940) suggested that if selection of breeding stock was based on the relationship between shank length and body weight for purpose of achieving uniform body conformation, it should result in considerable improvement in the uniformity of body conformation. The sire transmits his body weight to the progeny. Growth of different parts of the body added together make up the final shape of the fowl. He also said that from statistical analysis of the bones of inbred White Leghorns Jull (1940) reported that Wright concluded that the inheritance of bone length was due primarily to a general effect of genes on size but that Schneider and Dunn (1924) stated that it is not so much of a general effect as it is of a relatively large number of genes involved in size inheritance.

Hutt (1949) said that it is both difficult to measure and to describe shape accurately. In the case of genes controlling the body
size, he maintained that variations in shape is not the effect of single gene mutations but that of many factors which are probably similar. Variations in shape are made up of variations in the rate and duration of growth in various portions of the skeleton or the muscles associated with the skeleton. Hutt (1949) added that it would appear to be a universally accepted fact that differences in shape arise from the growth processes exerting on some bones certain effects that are different from the effects exerted on other bones. He suggested that the other side of the argument is that the skeletal growth could be controlled by genes that have general effects and that different bones react in different ways to these genes.

Examples of genetic effect that cause results on certain parts of the skeleton of the fowl to be out of proportions is the creeper mutation which shortens the legs more than it shortens the wings. Another example is the genetic effect that causes rumplessness. Hutt (1949) said that Kopec made reciprocal crosses between White Leghorns and Buff Orpingtons, took measurements of various body dimensions in both F1 and F2 generations and found out that the inheritance of certain dimensions of the body is independent of the inheritance of others. Data collected for F1 females from both crosses and for F1 males from the Leghorn dams indicated that the length of the sternum in all the three populations was as short as that of the Leghorn parent, if not shorter. Contrasting this situation was the tibial region which, on
comparative basis, was long as in the Orpingtons. An index of shape (Depth of thorax/sternum length) was greater in the Orpingtons than in Leghorns, and in all the F1 populations that index continued to be greater. Kopec's Leghorn X Orpington cross indicated that special genes determine the relative length of the sternum.

**Effects Of Sex-Linked Dwarf Genes In Chickens**

Hutt (1959) explained that dwarfism is caused by a sex-linked gene, dw, recessive in heterozygous males. Retardation in the growth of the dwarfs as a result of effect of dw gene may be noticeable about six weeks of age. At times the gene may be effective as early as two weeks after hatching. However, classification of individuals may not be certain sometimes until about 10 to 15 weeks of age or even later. His work revealed that the dw gene does not retard the growth of the chicks during incubation. Unlike the gene causing pituitary dwarfism in the mouse, the dw gene merely slows down growth through the entire normal growth period instead of stopping growth at a certain stage. He said also that at the initial stage of growth, the size of chicks has direct relationship to the size of the eggs from which they were hatched.

At the adult age, Hutt (1959) identified the dwarfs by recording the weights of the chickens and maintaining growth curves for the dwarfs and their normal siblings to show the effect of the dwarf, dw, gene on body size. The gene, dw, reduces the size of adult homozygous males, in comparison to heterozyotes by about 43 percent. Comparisons of 223
non-dwarfed hens with their 236 dwarfed full sisters indicated that the size of the dwarfed full sisters was reduced 25.7 to 32.1 percent in different matings.

Bernier and Arscott (1966) in their study of characters among the dwarfs and the normal birds, found that shank length percentage of the dwarfs was 85.6 and 79.6 that of the normal birds at 8 and 17 weeks of age, respectively. Jaap (1969) explained the effect of the two sex-linked genes, namely, dw gene and a bantam gene. The former reduces both body weight and leg length about 33% in small-bodied groups while the latter neither reduces much of the size nor shortens the long bones out of proportion. Either as a dominant allele of dw, the major "bantam gene" of the Sebright Bantam does not exert enough effect to cause dwarfism in the manner the dw gene does or as a non-allelic gene at an adjacent locus, the interaction between the major "bantam" and the Dw+ genes prevents the latter from expressing their normal effect.

He also said that the male back cross from mating between F1 (Sebright sires X dw Leghorn dams) sires and the dw Leghorn maternal group showed such a variation in weights at the age of 8 weeks that produced a bimodal frequency distribution as against a unimodal distribution in the females. At 16 weeks of age the shank length of the females also showed a bimodal distribution characteristic of two distributions that overlap.

Jaap and Mohammadian (1969) stated that the progeny of normal sires
x dwarf dams grow with equal rapidity as do the chicks from normal dams. Hence, for the dams of broiler chicks, dw-allele may be desirable.

Hutt (1959) showed that the percentage reduction of eggs laid by the dwarfs as compared to those laid by their big sisters in three months ranged from 12.7 to 18.6, showing a statistically significant difference in each case. Hutt (1964) found that the eggs produced by the dwarfs were 18% fewer than those produced by their normal sisters. Bernier and Arscott (1966) observed that although two populations of dwarf and normal White Leghorns both produced the first egg during the 19th week, it took the dwarfs 25 weeks of age to reach 25% production as opposed to 23 weeks in the case of the normal size pullets. Jaap and Mohammadian (1969) agreed that the sex-linked, dw, exerts a great influence in the reduction of egg production in egg-type hens but they believe that it has no such effect on the rate of lay in broiler-type dams. Jaap (1969) compared the sibs of the dw and the "bantam gene" types and reported that pullets obtained from the mating of F₁ Sebright Sire and dw Leghorn dam had the Bantam sex-chromosome. The egg production of the crosses slightly exceeded that of dw Leghorn during the first four months after the production of each type was up to 50%. Jaap (1969a) indicated that, at present, there is evidence, though limited, showing that "bantam gene" may be superior to dw gene, from the economic standpoint, for use in small-bodied females for egg production.
Hutt (1959) said that average egg size is higher for dwarfs, when related to body size, showing that the dwarfs lay comparatively large eggs with reference to their body weight. He maintained that there is a tendency for smaller birds to lay eggs that are large with regard to body size, whether they carry dw gene or not. Bernier and Arscott (1960) stated that the size of eggs produced by the dwarfs were 10% less per dozen than those of their normal sisters in an experiment they conducted with 240 birds for the study of some characters including egg size among sex-linked dwarfs and their normal sisters. Since dwarfs lay both fewer and smaller eggs than their big sisters, their total egg material would be remarkably lower.

Hutt (1964) indicated that a bimodal curve shows that a trait being studied would reflect some variation which is not continuous as one group but is made up of two separate overlapping populations. Body size is one of the examples of quantitative characters. Sex-linked gene, dw, is completely recessive. In fowl, it reduces the adult size markedly. In a study of the distribution of the adult weight of the daughters of one sire, Hutt (1964) found that the sire, heterozygous for sex-linked gene, dw, transmitted to his daughters the following allelic genes: dw to daughters which were smaller than their big sisters and Dw, normal allele, to their big sisters. The two groups came from the same mothers. In each group, the distribution of size was normal but the difference in size between the two classes was so great that overlapping
was very little.

He also observed that the dw gene exerts a major effect on a quantitative character which is principally under the ordinary influence of many unknown number of genes. He concluded that to find the genes that have major effects on quantitative characters is not common but that the existence of one such gene is likely to be first indicated by a bimodal distribution.

Bernier and Arscott (1968) have selected for egg number and egg size but do not use very large dwarf females, thereby restricting body size. Thus, by working with the sex-linked recessive dwarf gene they attempt to improve egg production and egg size under restricted body size. Their objective is either to increase efficiency or reduce cost of egg production.

Van Tienhoven, Williams, Tomlinson and MacInnes (1966) suggested that, dw, causes limitation of growth hormone in the circulation of dwarf female. Jaap and Mohammadian (1969) indicated that inadequate rate of yolk deposition in the ovary could arise in both broiler and egg-type females. They maintained that body size exerts such an effect over the action of the dw gene that the rate of yolk deposition in the ovary, but not the rate of egg production in the pullets weighing 2.6 kg. at 36 weeks of age, is reduced. In this experiment, it was found that the dwarfs laid fewer defective eggs than did the normal females with Dw genes. This result suggested that, to some degree, the dw-
allele reduces the defective egg problem of the broiler pullet.

In an experiment involving the study of shell quality, among other characters, Bernier and Arscott (1960) said that the dwarfs laid eggs with thinner shells than those of their normal sisters. They also said that the susceptibility of the dwarf hens to cage fatigue, their possession of proportionately smaller skeleton and their ability to lay eggs of less shell may be the evidence that their requirements for calcium, phosphorus and Vitamin D are more critical.

Hutt (1959) concluded that a greater portion of the feed consumed by small animals is utilized for maintenance. Therefore, it seems unlikely that the dwarf hens could fill an important position in an increasingly efficient agriculture unless feed consumption of the dwarfs was correspondingly decreased. He also said that the dwarfs do not seem to have a bright prospect in the poultry industry which is highly competitive. He would appear to suggest that there is an optimum body size in the animals that favors economic progress. However, Bernier and Arscott (1960) maintained that egg production efficiency of dwarf layers was greater than that of their normal sisters; their feed requirements were 74% as much feed, when figured on egg number, and 84% as much feed per dozen eggs and per dozen of 24 ounce eggs, respectively. Bernier and Arscott (1966) observed two populations of chicks, each of which was made up of 700 White Leghorn males. One group were offspring of dwarf males X normal-size female mating, while the other belonged to
normal-size males × normal-size females mating. Each population was equally divided in two pens and fed on the following schedule:

(a) 0–8 weeks, a high-energy starter diet with 20.90% protein and 1370 K Cal of metabolizable energy/pound

(b) 8–23 weeks, a medium-energy grower diet with 14.9% protein and 1285 K Cal/lb.

The result revealed that the dwarfs had better feed conversion than the normal throughout the growing period.

Bernier and Arscott (1960) in their study of several characters in the dwarfs and their normal sisters said that the sexual maturity age of the dwarf females was reached later than that of their normal sisters, perhaps due to the fact that sex-linked dwarfism had been inherited through a grandparent which was a very large male that was late, too, in coming up to sexual maturity age. Hutt (1959) said that viability, fertility and hatchability of eggs were equal in both dwarf and large birds. Bernier and Arscott (1966) maintained that mortality in dwarfs up to 17 weeks was no different from that in normal birds.

Body Weight Versus Egg Production

Nordskog and Briggs (1968) said that commercial poultry breeders endeavor to develop the small-bodied type of chickens laying satisfactory egg size and at a high rate of production. The feed consumed by small birds, according to these workers, is relatively small for body maintenance. A random sample egg laying test revealed that Leghorn type having
intermediate body weight produced the highest average income. An optimum body weight exists below which egg per pullet housed declined 5 to 10 eggs for each one-tenth of a pound by which hens fall below the optimum size.

Yao (1959) studied three Leghorn inbred lines and the diallel crosses of the inbred lines and stated that the highly significant additive and dominance effects of genes are present in both egg production and 10-week body weight of the crossbred chickens. In egg production, the total dominance effects are higher than the additive effect while it is the opposite in the case of 10-week body weight. Additive effect is expressed, for certain characters, as heritability estimate.

A performance test at Texas Agricultural Experiment Station (1968-69) involved birds selected at random, caged in accordance with weight classes, i.e. light, medium and heavy, and observed for 168 days of egg production. Thirteen commercial strains took part in the test. The result showed that mortality was highest in light weight class. Birds in the heavy weight class were highest in the hen-day egg production while those in the light class had the poorest performance through six periods of production. The ages of the birds, through these six periods, were not given. During period six, rate of egg production favored birds in the light weight class more than either of the medium or heavy weight classes. The length of the six periods of egg production was not specified but this genetic environment performance test took place from
Effects Of Body Weight On Egg Size

Texas Agricultural Experiment Station test (1968-69) showed also that egg size and body weight were highly positively correlated; the heavy weight class produced the largest eggs.

Festing and Nordskog (1967) reported that it could be possible to manipulate egg weight independent of body weight. Bernier (1970) explained this point with reference to the White Leghorn, a lighter bird than most other breeds, yet it lays good egg size. With another co-worker, Arscott, Bernier (1970) said that they have been able to improve egg size, through nutrition, to the extent that it is a few percentage points lower than that of the normal size birds. He also pointed further to the remarkable achievement made by the Hy-Line in producing the smallest commercial Leghorn which, in spite of the smallness of the body size, lays very large eggs. In contrast to this strain are some of the very large meat producing strains with very small eggs.

Olsen and Knox (1940) found that it is possible to increase the average egg weight of progeny by means of selection by the progeny test method. Increase in annual egg weight would result in corresponding decrease in time required by pullets to lay eggs of standard weight. In other words, as the average egg weight increased, eggs of standard weight (24 ounces per dozen) would be laid earlier, each year, even though sexual maturity did not change.
Maloney, Gilbreath and Morrison (1963) observed that "if two characters are uncorrelated genetically, then a correlated response would not be expected". These workers investigated the effect of selecting for twelve-week body weight on other traits. The study was made from data collected from a selection for high and low body weight at twelve weeks of age and from studying the effect of relaxed selection on twelve-week body weight following five generations of selection. Selection for high and low twelve-week body weight involved ten generations while the relaxed selection for twelve-week body weight concerned five generations. The result showed that in the high line the six-week body weight increased by 0.09 pounds per generation and that the March egg weight in the high line had an increase of 0.2 grams per generation in the regression analysis, indicating a positive correlated response but statistical calculation revealed that it was non-significant rate of increase. The low line analysis of data for March egg weight showed a highly significant decline of 0.6 grams per generation.

Effects Of Body Size On Feed Consumption

Bernie and Arscott (1968) said that feed consumption and the depreciation of laid out hens are some of the factors that curtail the profit that a poultryman should make. Determination and control of the variable that exerts a significant influence on both factors would markedly improve the economic situation of the poultry breeders by saving more feed during the growing and laying periods. Depreciation would be lower,
rearing costs reduced and less space required for the birds. Removal of waste matter would be less expensive and efficiency of labor would increase.

The most important function of feed intake is the maintenance of body size. A larger bird thus consumes more feed than does the smaller layer because it is the body size that determines growth requirements. For the maintenance of smaller birds less feed is required. Consequently, they utilize the greater portion of the total feed intake for egg production. In this way feed conversion is greater in smaller birds than it is in larger ones.

Selection of animals for efficiency in utilizing feed, not depending on size, should be based on the highest relative productive capacity. In this experiment Bernier and Arscott (1968) defined the relative productive capacity as yield per unit of metabolic size or \( \frac{Y}{W^{3/4}} \).

The significant influence of body size on egg production may have stimulated the interest of these investigators in the dwarf layers found in their flock of Leghorns sometime ago at the Oregon State University. This flock of dwarf layers has since been expanded in experiments involving breeding and nutrition phases.

Bernier and Arscott (1968) believe that they are making progress, particularly in egg size relative to body size. They stated that the belief of the poultrymen, substantiated by the researchers, is that
heavier birds offer better resistance against environmental stress than do the smaller birds. They observed that the same study showed that small birds are, however, genetically superior but they did not seem to explain in what respect to which the genetic superiority is referred. This means that there is a conflict between genetic and environmental effects and this conflict deserves further studies. It is this conflict that makes justifiable the tendency to produce eggs under controlled environmental conditions.

The minilayers (dwarf hens) require higher protein level in their ration, and the plateau for egg production is believed to be 16%. However, egg size continues to increase, it is reported, with additional protein and it is now not yet certain whether or not the plateau is above 21%. There is no indication whether or not this is a correlated response.

In spite of recent improvements, these minilayers do not lay as well as normal size hens and their eggs are still smaller than those of normal birds. Nevertheless, Bernier and Arscott (1968) still look forward to the potentiality of the minilayers with optimism, and think that even though increasing egg size can bring about a positively correlated response in body size, it is not impossible to avoid this corresponding increase in the body size as the egg size increases. They believe that in the dwarf layers they have been able to improve egg size as the body size is restricted.
Effect Of Body Size Upon Reproductive Performance In Birds

Lerner (1946) used shank length as the criterion in selecting for size. One of the objectives was to determine whether or not the size differentiation of the flock of single comb White Leghorn pullets divided into production and size lines, respectively, has any effect on the associated character of sexual maturity.

The result appeared to reveal that selection for increased body size also resulted in delaying sexual maturity. Within the line, identified by smaller body size, correlation between age at sexual maturity and the mean weight of the first ten eggs is significant both being independent on body size. In the line with larger body size, early egg weight is not dependent on maturity but is positively correlated with body size.

In the flock of heavy Broad Breasted commercial turkeys, large, medium and small hens bred to larger toms and smaller toms, respectively, Rooney (1957) observed that approximately 11% and 16% more eggs were fertile from small than from the medium and the large hens, respectively.

Berg and Shoffner (1954) conducted an experiment to find out the effect of 24-week body measurement on the reproductive ability of turkeys and reported that large body weight had a depressing effect on both fertility and hatchability of fertile eggs, and that selection for heavier birds with wider breasts would tend to reduce reproductive performance.
MATERIALS AND METHODS

Experimental Animals

White Leghorns used in the experiment were from a strain that has been maintained at the Agricultural Experiment Station, Bozeman, while the White Leghorn Bantams were purchased from a commercial producer.

Methods Of Mating

For 4 weeks the following number and kind of matings were used:
10 BB (Bantam X Bantam) males, 20 BB females and 10 LL (Leghorn X Leghorn) males, 20 LL females. During the first 3 weeks the 10 Leghorn males were each mated to 2 Bantam females while the 10 Bantam males were each mated to 2 Leghorn females. In the 4th and last week, Leghorn males were mated to Leghorn females and Bantam males were mated to Bantam females in the same ratio mentioned above.

The offspring obtained from the matings of Bantam sire X Bantam dam are referred to as (Bantam X Bantam) while (Leghorn X Leghorn) mean the offspring whose sire was a Leghorn and the dam, a Leghorn, too. All the offspring obtained from the matings of Bantam sire X Leghorn dam are referred to as BL (Bantam X Leghorn) whereas the crosses belonging to the reciprocal matings of Leghorn sire X Bantam dam are represented by LB (Leghorn X Bantam).

Data collected on 227 birds made up of males and females of all mating types were studied for statistical analysis.

Since size of the Leghorns hindered natural mating with the Bantams and the individual cages had room enough for only one bird, artificial
insemination was used for securing fertile eggs from these chickens. After the feathers around the cloaca of the males had been trimmed, prior to serious collection of semen, these males were trained to ejaculate. The inseminated birds were marked on the individual cards attached to the cages for purpose of identifying and saving their eggs for incubation and hatching.

**Incubation Of Eggs**

The eggs were incubated in a Jamesway 242 incubator at 100°F. for the first 14 days and at 99°F. for the remaining 7 days with an average humidity of 87 percent. The chicks that hatched after 21 days were pedigreed and their weights at hatching time recorded before being transferred to the brooder pens.

In order to provide for sufficient number of chicks for experiments, two hatches, with a two-week interval intervening, were used.

**Brooding**

The brooder floor which had previously been cleaned was covered with new wood shavings to keep the floor dry. The chicks were housed in four brooder pens 12' X 17'. The temperature was at 90°F. for about a week before being reduced to about 85° - 80°.

The heating fuel was natural gas and the ventilation was by forced draft. Artificial lighting provided 12 hours of light and 12 hours of darkness. Outside light was shut out in order to have complete control of effect of light.
At about 12 weeks of age, or even earlier, as soon as it was possible to tell the sex, the chicks were identified for sex and particular sex of each bird recorded accordingly. Before transferring the birds to the laying house the males were dubbed which involved trimming the combs and wattles to prevent injury when they were placed in cages.

Laying Facilities And Care

At the age of 16 weeks, they were transferred to a 32' X 25' X 6' laying room, provided with forced draft ventilation and artificial light. The birds continued to be housed under 12 hours of artificial light from about 8:00 a.m. to 8:00 p.m., every day, followed by 12 hours of darkness. Outside light was also shut out. The temperature was regulated by thermostat.

There were four and one half banks of cages in the laying house. Each bank was made up of fifty-two 8" X 16" individual cages arranged in two rows of 26 cages per row.

The males were separated from the females and each chicken was put in a separate cage. The floor under the cages was covered with wood shavings to act as absorbent for the fecal excretion and the waste matter, removed about once each week.

Shelter and lighting were the same during summer and winter.

Rations

Water was offered ad libitum at all stages. The quantity and kind of feed provided for the chickens varied according to the stage of
growth and their requirements for a particular purpose including brooding, rearing and laying (Table 1). Each ration, nutritionally adequate according to NRC recommendation was mixed in feed mixing plant at the Agricultural Experiment Station in Bozeman.

**Brooding Ration**

Up to 8 weeks of age, the chicks were fed chicken starter containing about 240 lbs. of 50% soybean oil meal, providing the highest protein level of all the rations, bearing in mind that the growing chicks required high energy level for their proper development.

**Grower Ration**

The grower ration for rearing the chicks was fed from 8 to 16 weeks during which time the birds remained in the brooder house. The protein level at this growing stage was about 16½%.

**Laying Ration**

Laying ration was given as soon as the chickens were transferred to the laying house at the age of 16 weeks. The amount of calcium needed was more than that required both at the starting and growing stages for the formation of egg shells. Amount of carbohydrates was reduced and the protein level fed was about 16½%, the same as in grower ration.

Overfeeding was carefully avoided to prevent waste. At the time of laying the first egg the chicken concerned was given 1000 grams of the laying ration at a single feeding, after the already existing feed
in the feed trough had been discarded. At each subsequent feeding of that same laying hen, 500 grams of feed was given her and this amount of feed was represented by "0" marked on the individual card bearing the cage and bird number of the chicken. Thus, two zeroes represented 1000 grams of ration fed.

At the end of the experimental period, the number of zeroes appearing on the individual card were multiplied by 500 to give the total amount of feed in grams fed to each hen, including any leftover still existing in the trough at the time. The leftover in each trough was reweighed and the weight subtracted from the total amount fed. The result was the amount of feed actually consumed by the particular hen. The total amount consumed by individual bird was utilized in calculating feed conversion.

Each day, all the eggs laid by all hens were marked on the individual cards, numbered, collected and weighed.

**SIZE:**

**Measurements Of Size**

In addition to obtaining the weight of each bird at hatching time, other regular measurements were also taken. The body weights and shank length and width measurements of the birds were obtained at 4, 8, 16, 20 and 24 weeks of age and also at the time of laying the first egg. When a bird laid an egg or eggs for the first time, the body weight and shank measurements of the bird were recorded on the individual card,
along with the date on which the egg was laid, as follows: Date of laying the first egg, body weight at first egg lay, i.e., initial body weight, shank length, and shank width. At the end of the experimental period, when the pullets were 58 weeks of age, the final body weights were recorded.

The shank measurements consisted of the shank length, shank width and shank depth in some cases. Some forms of shank indexes were obtained. One form of these indexes was derived from multiplying the shank length by the shank width (shank length \( \times \) width), while another index among them resulted from the multiplication of the following 3 shank measurements: shank length, shank width and shank depth (shank length \( \times \) width \( \times \) depth).

**Reliability Of Measurements**

Repeatability of characters in random sample body weight and shank measurements was used to test the reliability of these measurements. A random sample of 48 chickens, made up of 24 males and 24 females, equally representing all breeding types, were all weighed and their shank length, shank width and shank depth for both left and right feet, respectively, measured by two different persons, in 2 weeks, which were separated by a 4-week interval. Each person made these measurements on 2 consecutive days in each of the 2 weeks.

The intraclass correlation method introduced by Snedecor (1946) was used in calculating the repeatability, \( r = \frac{\text{between animal variance}}{\text{within animal variance}} \).
This repeatability was calculated for body weight, shank depth, shank length, shank width, shank index (shank length × shank width), shank index (shank length × shank width × shank depth), and shank index (shank length × shank depth) (Table 4).

**Relationship Of Measurements**

The measurements were correlated with one another to find out the intensity of association existing among them as explained by Steel and Torrie (1960). Phenotypic correlations were calculated for the body weight versus shank index and for the body weight versus shank length, measured at 16 and 24 weeks of age, respectively.

Correlations were also calculated for all of the above characters (body weight, shank index and shank length) and weight gain, egg mass, egg number, average egg weight and feed conversion.

**FEED CONVERSION:**

*How Measured*

Feed conversion, in this experiment, meant the unit of egg produced by one unit of feed. This amount was obtained by dividing the egg mass (total weight of all eggs) by the total amount of feed consumed.

**Phenotypic Correlations**

In order to determine the relationship between egg numbers, egg size (average egg weight), egg mass, and measurements of size—weights, shank length and shank index with regards to feed conversion, Multiple
Regression was used to calculate the $R^2$, since the study involved more than two variables exerting individual effects on another variable.

The Multiple Correlation Coefficient $R^2$ is always less than unity and was used in this work to measure the proportion of the variation that was accounted for by the relationship among the factors involved. Par R (Partial Regression), Beta (Standard Regression), and $r$ values, were also utilized for the evaluation in addition to $R$ Squares.

How Selection For Feed Conversion Affects Other Characteristics

Measures of the correlated responses to selection for feed conversion were made by calculating the selection differential for the selected 50 percent of the population regarded as 42 birds. These 42 birds were then used in the calculation of selection differential for body weight (initial), body weight (final), shank index, egg laid, maturity age and egg weight to find out how selection for feed conversion affected the other characteristics.
STATISTICAL ANALYSIS

Correlation Coefficient was used to determine the relationship between the body weight and shank index on the one hand and the relationship between the body weight and shank length on the other hand. It provided a simplified method of comparing the use of shank index and shank length for measuring size and might suggest which of these shank measurements would be more reliable for use in assessment of body size in chickens.

Linear regressions of body weight on shank measurements, as well as their repeatability, were calculated in accordance with procedures shown by Snedecor (1946).
RESULTS AND DISCUSSION

Reliability Of Measurements

Each of the characteristics had a very high repeatability but the repeatability for the body weight was unexpectedly high, almost a perfect correlation (.993) (Table 4). The reason for this high value of repeatability in the body weight might have been due to the effects of the body weight of the parental types at both extremes.

This value exceeded the repeatability of .85, .85 and .70 for both sexes, males and females respectively, with all birds in different groups (types, not specified) as observed by Gyles, Kan and Smith (1957). They concluded that the numerator in the ratio of variance components used for estimating repeatability, consists of all genetic variances in addition to variances due to the permanent influence of environment. They also added that the denominator consists of all the above plus the variance from temporary or random environmental effects.

Since all the birds used for measuring the repeatabilities of body size measurements in this experiment were reared on the same rations and under the same uniform environmental condition, it would appear that any existing difference among them must be due to genetic rather than environmental factors. Therefore, it seems that the best method of achieving meaningful results in measuring the repeatabilities in measurements of body size is by using only the crosses which are intermediate in size.

One of the shank indexes (shank length X width X depth) was found
to be unreliable to be used for measuring size because, among all the traits studied, the shank depth involved in calculating this shank index had the lowest repeatability and of all the shank indexes calculated, the shank index incorporating the shank depth had the lowest repeatability (.971).

Shank index incorporating shank length X shank width also had a high repeatability (.991).

**Correlations Between Shank Index Or Shank Length And Body Weight**

The high positive correlation between shank index or shank length and the body weight of birds at 16 and 24 weeks of age demonstrated a strong phenotypic relationship between the body weight and either of these two shank measurements of the birds. For the body weight versus shank index of all breeders at 16 weeks of age, the positive correlation coefficient, r (.94), suggested that the body weight increased as the shank grew larger, too. The variation due to this relationship accounted for was $r^2 = .88$ or 88% of the variance accounted for. The correlation was significant at 1 percent level of probability.

The relationship between the shank length and the body weight was also a strong one as the $r$ was .89 and $r^2$ was .79. Correlation was significant at the 1 percent probability level. Shank index or shank length and the body weight at 24 weeks of age were also positively correlated.

For shank index versus body weight at 24 weeks, $r$ was .93 and $r^2$
was .86. Correlation was significant at 1 percent level of probability. Body weight versus shank length had positive correlation of \( r = .90, \)
\( r^2 = .81. \) Correlation was significant at 1 percent level of probability. (Figures 1, 6, 11 and 16).

The coefficient of correlation between body weight and shank length was higher at the age of 24 weeks than at 16 weeks of age, indicating, on the one hand, that among the birds used for this study the body weight and shank length were not necessarily more highly correlated at an earlier age than they were correlated at a later age.

On the other hand, the shank index and the body weight were more closely correlated at an earlier age than they were correlated at a later age in the birds that were studied (Table 3).

Although the study revealed, on the whole, that the shank index (shank length \( \times \) shank width) is a reliable measure for body size, the difference between this shank index and the shank length in the values of their respective correlations with the body weight, was too small to justify the method involved in obtaining the shank index for use in place of shank length. The latter was just slightly lower than the former.

For all the breeding types there is similarity between the regression of body weight on shank length and on shank index, indicating that whatever the size of the birds the relationships between these characters are almost constant.
The correlations $r (.94)$ for the body weight versus shank index at 16 weeks of age, $r (.93)$ for body weight versus shank index at 24 weeks, $r (.88)$ for body weight versus shank length at 16 weeks, and $r (.90)$ for body weight versus shank length at 24 weeks of age, show a natural inclination of the dots in the scatter diagram to lie in a band stretching in a regular pattern from left to right. This means that there is a common inherent factor for size among all these breeding types.

With reference to a scatter diagram he used for a study of the stature (in inches) of brother and sister, Snedecor (1946) stated that $r (.558)$ was a reflection of the propensity of the dots to lie in a band extending from the lower left to the upper right, not scattered in a random manner along the entire area. He said, "Biologically, $r=0.558$ measures the common inheritance of stature by these siblings."

Also, the slopes of the regression lines being closer to one another at 16 than they were at 24 weeks of age indicate the similarity between the body weight and shank measurements as measures of body size at an early stage as compared to a later stage of development of the birds.

In a study of the distribution of egg weight and body weight for dwarfs and their big sisters and half-sisters, Hutt (1959) stated that similar slopes of the lines fitted to these data show that the relationship between the egg size and the body size in dwarfs does not
differ much from that in the larger birds.

Comparisons between the body weights and the shank measurements among all type of breeders combined at various stages of development showed the average values of these measures of size as follows: at 16 weeks of age the body weight of the Leghorn X Leghorn was 1340.3 g, shank index and shank length were 977.8 and 1114 mm, respectively. The Bantam X Leghorn weighed 953.9 g, while the shank index and shank length, respectively, measured 687 and 938 mm. The body weight of the Leghorn X Bantam was 793.5 g, shank index was 616.5 and shank length was 894 mm. Bantam X Bantam weighed 409 g, shank index was 381 and the shank length was 685 mm.

Average of similar measurements of the same birds taken at the age of 24 weeks were as follows: body weight of the Leghorn X Leghorn was 1795.3 g, the shank index was 1035.5 and the shank length was 1132 mm. The Bantam X Leghorn weighed 1239.5 g, shank index was 711.6 while shank length measured 951 mm. Body weight of the Leghorn X Bantam was 1039 g, their shank index was 647.8 and shank length was 906 mm. Bantam X Bantam weighed 573.1 g, shank index was 389.2 and shank length measured 685 mm.

The Bantams, as compared to the other type of breeders, had the smallest body size measurements, shank length, shank index and body weight. Hence, the dots representing these birds on the scatter diagrams (Figures 1-20) representing the shank measurements and body
weights of these Bantams were located at the lower left of the regression line, indicating that their small body size might have the effect of causing the degree of relation of shank measurements to body weights in all the mating types combined to drop far below the average, on the one hand.

On the other hand, the Leghorns having the largest body size measurements were represented, on the scatter diagram referred to above, by dots located at the extreme upper right of the regression line. The location of these dots so high up the regression line indicates that the effects of the large size measurements in the Leghorns might raise the degree of relation of shank measurements to body weights in all the mating types combined far beyond the average.

Similar slopes of the lines fitted to the above data in various mating types involved indicated that the relation of shank length and shank index to the body weight in all types of breeders differs little between groups.

Several researchers and poultry breeders had tried and are still trying hard to control the effects of body size by breeding in order to develop an optimum body size that is neither too large nor too small; some size intermediate enough to enhance economic progress.

For all the situations involving all type of breeders as described above, it was noted that correlations between the body weight and shank length or shank index were highly positive and their regression, linear
at all ages.

Measurements of Feed Conversion

The measurement of feed conversion (unit egg mass per unit feed consumed) revealed that the efficiency of the crosses (Bantam X Leghorn and Leghorn X Bantam) was more than that of the parental types. Feed conversion for the Bantam X Leghorn was .334 while that of the Leghorn X Bantam was .356 compared to .327 for the Leghorn X Leghorn and .306 for the Bantam X Bantam types.

These results appear to emphasize the importance of an optimum size for efficiency in feed conversion and to indicate that the intermediate size, the size of the crosses, might be the optimum size.

Since it is time consuming to measure feed, all the birds must be given feed that had been weighed ahead of time, and unconsumed feed weighed at the end of the experiment, it was necessary to investigate the possibility of measuring feed conversion indirectly by using multiple regression technique.

The factors used in the regression technique were the body size measurements (initial body weight, final body weight, weight gain, shank length and shank index) and egg measurements (egg mass, rate of egg production and average egg weight). The following is an example of the application of a calculated regression for bird number 110.
\[ \hat{Y} = 0.1042 - 0.00017 X_1 + 0.3529 X_2 + 0.005691 X_3 \]

\[ = 0.1042 - 0.00017 (570) + 0.3529 (0.593) + 0.005691 (25.8) \]

\[ = 0.1042 - 0.097 + 0.209 + 0.147 = 0.361 \]

Where \( X_1 = \) Final body weight

\( X_2 = \) Rate of egg production

\( X_3 = \) Average egg weight

The measured conversion for hen number 110 was 0.344. She also had a final body weight of 570 g, her rate of production was 0.593 eggs per day, and egg weight averaged 25.8 g and by the application of the regression equation her estimated feed conversion was:

\[ \hat{Y} = 0.1042 - 0.00017 (570) + 0.3529 (0.593) + 0.005691 (25.8) \]

as given in details above.

Multiple Regression results of the effects of other traits on feed conversion had indicated that egg number and average egg weight, when used independently with final body weight, would yield a result more than twice as much as the result from a combination of egg mass with the final body weight (initial body weight plus weight gain). The final body weight obtained when the birds were 58 weeks of age would appear to yield a higher result with regards to feed conversion than would do the initial body weight and weight gain used independently because both of these factors make up the final body weight.

However, the regression equation must be used with caution in calculating the feed conversion because if this technique satisfies the
condition in one population it may not necessarily satisfy that of a different population.

Phenotypic Correlations

In using the Multiple Regression method, the measure of the effects of the following characters, at the initial statistical analysis, gave the $R^2 = .36$ for feed conversion versus initial body weight, weight gain and mass/day while $R^2 = .39$ was yielded by feed conversion versus final body weight and mass/day. The result of feed conversion versus shank index, weight gain and mass/day was $R^2 = .37$. Feed conversion versus shank length, weight gain, and egg mass had $R^2 = .35$ as compared to $R^2 = .39$ for feed conversion versus weight gain, final body weight and mass/day.

With reference to the above results, the largest amount of feed consumed by the birds involved in this experiment was utilized to maintain the final body weight as it contributed the largest $R^2$ value = .39.

Since the problem in connection with this observation of feed conversion was to determine, as much as possible, the particular factors of major importance in promoting the highest results in the ability of the chickens to convert feed to eggs, it was necessary to evaluate, independent of each other, the two egg factors, namely, egg/day (i.e. egg number) and egg size (i.e. average egg weight), that make up the egg mass (egg number X average egg weight).

Further evaluation showed that feed conversion versus initial body
weight, weight gain, rate of egg production (egg number) and average egg weight (egg size) yielded $R^2 = 0.82$ in comparison to feed conversion versus shank index, weight gain, rate of egg production and average egg weight resulting in $R^2 = 0.84$. Also, feed conversion versus final body weight, rate of egg production, average egg weight, contributed $R^2 = 0.84$. Feed conversion versus shank length, weight gain, rate of egg production, average egg weight, produced $R^2 = 0.83$ while 0.84 was the value of $R^2$ yielded by feed conversion versus weight gain, final body weight, rate of egg production, average egg weight.

Upon using the egg number and egg size independent of each other, the resulting $R^2$ values rose above 0.80, indicating, even by the associated BETA (Standard Regression) values, that the biggest contribution in the group of variables shown on Table 5 was made as a result of egg number and egg size exerting their effects as factors that are independent of each other. The only difference between these two methods of calculating effects of independent variables on feed conversion is that one method used the egg number and egg size (average egg weight) independently while the other used the products which is egg mass (egg number X egg size).

Results of the calculation of feed conversion above also revealed that the combination of shank index or shank length with egg number (egg production rate) and egg size would also yield $R^2$ values above 0.80.
Correlation of shank index or shank length to the final body weight of these birds being studied showed strong relationship between each factor of the shank and the final body weight; in each case the correlation was highly positive.

However, any of the following major factors of body size, namely, the final body weight, shank index, plus the two major egg factors, consisting of the egg number and egg size, must be taken into consideration in making any genetic selection based on feed conversion in order to achieve a successful result as indicated by standard partial regression coefficients.

Effects Of Selection For Feed Conversion On Other Traits

The effects that selection for feed conversion would have on the other traits included in the analysis was determined by calculating the selection differential for each of those traits.

Lush (1945) described selection differential as a measure of intensity of selection. It shows the breeder the direction to which selection is going by revealing whether other traits increase or decrease as selection is made for one of the traits. For example, poultrymen have long known that the association between body weight and the egg weight demonstrates a positively correlated response, where selection for egg production (egg number) results often in reduced growth or no change at all.

In this experiment, selection differential was also used as a measure of correlated response in order to find out the changes in the
following characters brought about by selection for feed conversion as one of the characters involved in the birds being selected (Table 2):

(a) Initial Body Weight (body weight at time of laying first egg)
(b) Final Body Weight (body weight at 58 weeks of age)
(c) Shank Index (shank length X shank width)
(d) Egg Number/Day (number of eggs laid per day)
(e) Average Egg Weight
(f) Egg Mass (average weight of eggs laid X egg number)
(g) Maturity Age (age at time of laying first egg).

The result on Table 2 showed that selection of the 50% most efficient layers for feed conversion caused an increase of about 14.8% in the number of eggs produced per day. There was a very slight increase of egg weight by about 1.5% which might be interpreted to mean that the feed consumed was utilized more for increasing the egg number than was used for increasing the average egg weight. Maturity age remained almost unchanged as the percentage increase of 0.60% was negligible. That result suggested that selection for feed conversion could have very little or no delaying effect on the sexual maturity age of the birds involved.

Both the initial body weight and the shank index decreased by 1.36% and 1.64%, respectively, showing that selection for feed conversion would not appear to reduce these aspects of body size substantially. This may be due to the fact that this selection differential
was based on data collected with regards to the final body weight which contains the initial body weight and at the time, 58 weeks of age, when the shank had stopped growing. The final body weight is made up of the initial body weight and the weight gain. So, final body weight yields a higher result than do these other two factors of body size in the evaluation of feed conversion, as had been previously explained under measurements of feed conversion.

The substantial reduction of the final body weight by about 15.16% appeared to confirm the existence of a negative correlation between feed conversion and the final body weight and that the smaller bird rather than the larger one utilizes the feed it consumes more for conversion to eggs than for maintenance of body size.

The result seemed to point out that a poultryman who raises birds for a profitable egg production must select small rather than large birds for breeding. The larger the bird the more the feed it requires for maintenance of body weight and the more the cost of production for the breeder - the less the profit. However, genetic correlation is better than selection differential, which is strictly phenotypic, because the genetic correlation measures the effects of genes that are common to both characters.

**Egg Mass Versus Egg Number**

From the economic point of view, it would appear that egg mass is more important than egg number. For example, to get 1000 grams of egg
(egg mass) it may either take 15 eggs, or it may take 25 eggs, to get the same grams of egg, depending on the weight of eggs involved.

Another example of common occurrence is that in most countries eggs are at present being sold by the weight and not by the number.

The larger the egg the higher the price. Hence, one dozen of grade A (large) eggs would cost more than the same number (one dozen) of the medium-sized eggs, which in turn costs more than the same number of the small-sized eggs.

From the above standpoint, it would seem to be more profitable for the poultrymen if the small type of birds were developed to lay large eggs. The result is expected to be fruitful and the cost of production low, if body size was used as a criterion for selecting the breeders.

The shank length would provide adequate measure for optimum body size as a criterion for purpose of selecting birds towards development of increased egg mass in the small-sized layers since the shank index, though a reliable measure of body size, may be more time-consuming to obtain.

However, final body weight at the end of the experiment must be taken into consideration as this is a very important factor affecting feed conversion and the best measurement of body size so far acceptable in this experiment.
Figure 1. Scatter Diagram and Regression of Body Weight on Shank Index Of All Mating Types at 16 Weeks of Age.
Figure 2. Scatter Diagram and Regression of Body Weight on Shank Index of BL (Bantam X Leghorn) at 16 Weeks of Age.
Figure 3. Scatter Diagram and Regression of Body Weight on Shank Index of LB (Leghorn X Bantam) at 16 Weeks of Age.
Figure 4. Scatter Diagram and Regression of Body Weight on Shank Index of LL (Leghorn X Leghorn) at 16 Weeks of Age.

\[ a = 24.0669 \]
\[ \hat{y} = 24.0669 + 1.1246X \]
Figure 5. Scatter Diagram and Regression of Body Weight on Shank Index of BB (Bantam X Bantam) at 16 Weeks of Age.

Males (X)
Females (o)

\[ a = 3.4027 \]
\[ y = -3.4027 + 1.1628X \]
Figure 6. Scatter Diagram and Regression of Body Weight on Shank Index of All Mating Types at 24 Weeks of Age.
Figure 7. Scatter Diagram and Regression of Body Weight on Shank Index of BL (Bantam X Leghorn) at 24 Weeks of Age.
Figure 8. Scatter Diagram and Regression of Body Weight on Shank Index of LB (Leghorn X Bantam) at 24 Weeks of Age.
Figure 9. Scatter Diagram and Regression of Body Weight on Shank Index of LL (Leghorn X Leghorn) at 24 Weeks of Age.

Males (X)
Females (o)

\[ a = 81.5345 \]
\[ \hat{y} = 81.5345 + 0.9463X \]
Figure 10. Scatter Diagram and Regression of Body Weight on Shank Index of BB (Bantam X Bantam) at 24 Weeks of Age.

\[ a = 29.3142 \]
\[ y = 29.3142 + 0.7192x \]
Figure 11. Scatter Diagram and Regression of Body Weight on Shank Length of All Mating Types at 16 Weeks of Age.
Figure 12. Scatter Diagram and Regression of Body Weight and Shank Length of BL (Bantam X Leghorn at 16 Weeks of Age.)
Figure 13. Scatter Diagram and Regression of Body Weight on Shank Length of LB (Leghorn X Bantam) at 16 Weeks of Age.

Males (X)
Females (o)

\[ a = -74.8096 \]
\[ \hat{y} = -74.8096 + 17.2438X \]
Figure 14. Scatter Diagram and Regression of Body Weight on Shank Length of LL (Leghorn X Leghorn) at 16 Weeks of Age.

Males (X)
Females (o)

\[ a = -105.4475 \]
\[ \hat{y} = -105.4475 + 21.4216X \]
Figure 15. Scatter Diagram and Regression of Body Weight on Shank Length of BB (Bantam X Bantam) at 16 Weeks of Age.

Males (X)
Females (o)

\[ a = -47.6225 \]
\[ \hat{y} = -47.6225 + 12.2923X \]
Figure 16. Scatter Diagram and Regression of Body Weight and Shank Length of All Mating Types at 24 Weeks of Age.
Males (X)
Females (o)

\[ a = -75.2727 \]
\[ \hat{y} = -75.2727 + 20.9693X \]

Figure 17. Scatter Diagram and Regression of Body Weight on Shank Length of BL (Bantam X Leghorn) at 24 Weeks of Age.
Figure 18. Scatter Diagram and Regression of Body Weight on Shank Length of LB (Leghorn X Bantam) at 24 Weeks of Age.
Figure 19. Scatter Diagram and Regression of Body Weight on Shank Length of LL (Leghorn X Leghorn) at 24 Weeks of Age.
Males (X)
Females (o)

\[ a = 0.26 \]
\[ \hat{y} = 0.26 + 8.3284X \]

Figure 20. Scatter Diagram and Regression of Body Weight on Shank Length of BB (Bantam X Bantam) at 24 Weeks of Age.
TABLE I. Chicken Rations.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Brooding Ration (0-8 weeks)</th>
<th>Growing Ration (8-18 weeks)</th>
<th>Laying Ration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Wheat</td>
<td>720.5</td>
<td>825.0</td>
<td>769.5</td>
</tr>
<tr>
<td>50% Soybean Oil Meal</td>
<td>240.0</td>
<td>130.0</td>
<td>140.0</td>
</tr>
<tr>
<td>Feed Phosphorous</td>
<td>15.0</td>
<td>17.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Limestone</td>
<td>12.5</td>
<td>16.0</td>
<td>64.0</td>
</tr>
<tr>
<td>Salt</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Trace Minerals</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Vitamin Mix*</td>
<td>5.0</td>
<td>5.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

* Vitamin Mix + D is contained in the laying ration.

TABLE II. Selection Differential For Correlated Characters In Chickens Selected For Feed Conversion.

<table>
<thead>
<tr>
<th>Traits</th>
<th>Average of Population</th>
<th>Average of Top Half</th>
<th>Difference</th>
<th>Percentage Increase or Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed conversion</td>
<td>.3388</td>
<td>.3969</td>
<td>+ .058</td>
<td>+ 17.12</td>
</tr>
<tr>
<td>Body weight:</td>
<td>980.59</td>
<td>967.26</td>
<td>- 13.33</td>
<td>- 1.36</td>
</tr>
<tr>
<td>(initial)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight:</td>
<td>1152.529</td>
<td>1093.095</td>
<td>- 59.434</td>
<td>- 5.16</td>
</tr>
<tr>
<td>(final)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shank index</td>
<td>565.918</td>
<td>556.649</td>
<td>- 9.269</td>
<td>- 1.64</td>
</tr>
<tr>
<td>Eggs laid:</td>
<td>159.635</td>
<td>183.262</td>
<td>+23.627</td>
<td>+ 14.80</td>
</tr>
<tr>
<td>(egg number)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maturity age</td>
<td>148.141</td>
<td>149.024</td>
<td>+ 0.883</td>
<td>+ 0.60</td>
</tr>
<tr>
<td>Egg weight</td>
<td>37.856</td>
<td>38.428</td>
<td>+ 0.572</td>
<td>+ 1.51</td>
</tr>
<tr>
<td>(egg size)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE III. Correlation Coefficients (r) Computed For Shank Index And Shank Length Measurements, Respectively, Versus Body Weight At Different Growth Stages.

<table>
<thead>
<tr>
<th>Shank Measurements versus Body Weight</th>
<th>Number of Birds Measured</th>
<th>Age of Birds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shank index versus body weight</td>
<td>221</td>
<td>16 Weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.94**</td>
</tr>
<tr>
<td>Shank length versus body weight</td>
<td>221</td>
<td>24 Weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.89**</td>
</tr>
</tbody>
</table>

**Significant at 1 percent level.

TABLE IV. Repeatability Of Body Weight And Shank Measurements.

| Body Weight | .993 |
| Shank depth | .786 |
| Shank length| .979 |
| Shank width | .979 |
| Shank index (length x width) | .991 |
| Shank index (length x width x depth) | .991 |
| Shank index (length x depth) | .971 |
TABLE V, Correlations Computed For The Measurements Of The Effects Of Independent Variables On Feed Conversion.

<table>
<thead>
<tr>
<th></th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
<th>X6</th>
<th>X7</th>
<th>X8</th>
<th>X9</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>X2</td>
<td>-.076</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>X3</td>
<td>-.216</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>X4</td>
<td>-.354**</td>
<td>.381**</td>
<td>.669*</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>X5</td>
<td>-.070</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>X6</td>
<td>.108</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>X7</td>
<td>.389**</td>
<td>.579**</td>
<td>.522**</td>
<td>.094</td>
<td>.620**</td>
<td>.604**</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>X8</td>
<td>.784**</td>
<td>.254**</td>
<td>.188**</td>
<td>-.009</td>
<td>.311**</td>
<td>.279**</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>X9</td>
<td>.139*</td>
<td>.892**</td>
<td>.832**</td>
<td>.346**</td>
<td>.887**</td>
<td>.885**</td>
<td>---</td>
<td>---</td>
<td>.354**</td>
</tr>
</tbody>
</table>

* Significant at 5 percent level.
** Significant at 1 percent level.

X1 Feed conversion
X2 Initial body weight
X3 Final body weight
X4 Weight gain
X5 Shank length
X6 Shank index
X7 Mass/day (egg mass)
X8 Egg/day (egg number)
X9 Egg size (average egg weight)
SUMMARY

Size is a general name for volume, bulk and mass. The body weight in chickens is too variable to be used as a reliable measure for body size. Hence, shank length is used as a representative of body size. But, shank length alone is one dimensional measurement and would be a partial measure of the body size as the shank width and shank depth are left out of the picture.

An attempt was made to find out if shank index (shank length x shank width) was really more satisfactory than shank length or body weight for use as a measure for body size in White Leghorns and White Leghorn Bantams and their crosses.

Effects of body weight, shank index, egg mass, egg number and other independent variables on feed conversion (egg mass + feed consumed) were also measured.

The body weight, shank length and shank index were obtained at 4, 8, 16, 20, 24 and 58 weeks of age (final body weight measured at 58 weeks). Initial body weight was measured at the time of first egg lay. Repeatabilities for body weight, shank length, shank depth, shank width and shank index were calculated. Repeatability of body weight was unexpectedly too high, probably due to effects of the body weight of the parental types at the extremes.

The shank index (shank length x width x depth) was too unreliable to be used as a measure of body size while the shank index (length x width) was reliable. But, the difference between the latter shank
-70-

index and shank length was too small to justify the additional work involved in obtaining this shank index in place of shank length.

For feed conversion the intermediate-sized birds, the crosses which might be termed the optimum-sized birds, were more efficient than the parental types.

Combination of shank index or shank length or final body weight with egg number and egg size yielded \( R^2 \) values above .80. Therefore, these factors must be considered when making any meaningful genetic selection based on feed conversion.

Effects of selection for feed conversion on other characteristics indicated that the selection of the 50% most efficient layers for feed conversion caused an increase in the egg production per day, a slight increase in the egg weight and very little or no delay on the sexual maturity age of the birds involved in this study. There was a slight decrease of the initial body weight and shank index as well as a substantial decrease in the final body weight.

The result seemed to show that the smaller bird, rather than the larger one, utilizes the feed it consumes more for conversion to eggs than for the maintenance of body size, that the largest amount of feed consumed by the birds studied in this work was utilized to maintain the final body weight, and that the smaller rather than the larger birds should be selected in breeding for profitable egg production.

Genetic correlation, however, is better than selection
differential which is strictly phenotypic because the genetic correlation measures the effects of genes that are common to both characters.

From the economic point of view, it seems that the egg mass is more important than the egg number; the larger the eggs the higher the price, in spite of the number of the eggs concerned.

Since the shank index, though a reliable measure of body size, may be more time-consuming to obtain, the shank length would appear to provide adequate measure for the optimum body size as a criterion for selecting birds for purpose of developing increased egg mass in the small-sized layers. However, final body weight must also be considered.
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       white leghorns and
       white leghorn bantams