

PORCINE FEMUR OR PHALANX BONES AS INDICATORS
OF DIETARY PHOSPHORUS DEFICIENCY

by

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B.S., National Taiwan University, ROC, 1974

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1976

Approved by:


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ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Berl A. Koch, for his advice in this study.

I also wish to extend my appreciation to the following: Dr. Gary Allee and Dr. Ben Brent for their helpful suggestions and serving on my committee, Dr. Mark Guffey, Dr. Donald Lindley and Dr. Donald Kropf for helping to set up the experimental procedures.

My thanks are also due to Dr. Don L. Good, Department Head, Animal Science and Industry, the secretaries and other staff members in the Department who have contributed in one way or the other towards the successful completion of my graduate program.

My deepest appreciation is due to my mother, Mrs. Fong-Sheng Liu, who encouraged me throughout the whole study.

I would like to dedicate this work to my husband, Shi-Ping, who has encouraged me and endured the long separation during the period of my graduate study.

TABLE OF CONTENTS

CHAPTER	PAGE
I.	1
INTRODUCTION	1
II.	3
REVIEW OF LITERATURE	3
Phosphorus Requirement	3
Plant Sources of Phosphorus	7
Inorganic Phosphorus Sources	9
Feed Processing	10
Vitamin D and Phosphorus	11
Calcium: Phosphorus Ratio	13
Environment and Management	15
Phosphorus and Other Elements	16
Atrophic Rhinitis and Ca, P	16
III.	17
EXPERIMENTAL PROCEDURE	17
General Introduction	17
Bone Measurement and Analyses	17
IV.	25
RESULTS	25
V.	29
DISCUSSION	29
SUMMARY	32
LITERATURE CITED	33

LIST OF TABLES AND FIGURES

TABLES	PAGE
1. Composition of Diets Fed In Phosphorus Study . .	18
2. Calculated Analysis of Diets Fed In Phosphorus Study	19
3. Bone Data	27
4. Carcass Data	28

FIGURES

1. Device For Determination of Specific Gravity	21
2. Device For Determination of Breaking Strength	22

Chapter I

INTRODUCTION

A significant number of females in the swine breeding herd are lost because of bone fractures, usually the femur or the pelvic girdle. Also, recent high cost of phosphorus sources has caused a reevaluation of currently recommended phosphorus levels for swine diets and a reconsideration of the value of the plant sources of phosphorus.

The National Research Council (1973) lists the calcium and phosphorus requirements of finishing swine as 0.5% and 0.4%. Stockland et al. (1973) suggested the dietary phosphorus level of 0.45% was adequate for pigs from 27 Kg to 91 Kg. This agreed with 0.44% reported by Combs et al. (1962). It is also similar to the 0.50% reported by Allee et al. (1976), Bayley and Thomson (1969), Chaney et al. (1968), Harmon et al. (1970), Newman et al. (1976) and the 0.40% suggested by Cromwell et al. (1970, 1972) and Libal et al. (1969), Pond et al. (1975).

Data from several reports (Chapman et al., 1962; Combs et al., 1962; Cromwell et al. 1972; Libal et al., 1969; Miller et al., 1964; Rutledge, Hanson and Meade, 1961; Zimmerman et al., 1963; Stockland, 1973) have suggested that the calcium and phosphorus requirements for optimum skeletal development are greater than the requirements for maximum gain and feed efficiency of swine.

The project reported herein was concerned entirely with the effect of dietary phosphorus level on bone development. Bones examined in this study were from gilts fed varying levels of phosphorus as part of a larger and more extensive phosphorus feeding trial being conducted by Dr. Gary Allee.

Chapter II

REVIEW OF LITERATURE

Over the years many investigators have studied the calcium and phosphorus needs of swine under varying conditions. Those studies have shown that many different factors have an effect upon the phosphorus need of the pig. Some of those factors are: criteria used to determine phosphorus adequacy; ratio of calcium to phosphorus in the diet; source of dietary phosphorus; method of processing the diet; other elements in the diet and environmental factors.

PHOSPHORUS REQUIREMENT

The National Research Council (1968) listed the phosphorus requirements of growing-finishing swine, weighing from 25 to 100 Kg as 0.50% and 0.40%. Doige et al. (1975) reported that the level recommended by NRC (1968) was adequate.

Aubel et al. (1936) suggested that the minimum requirements of phosphorus in the ration of growing pigs was found to be between 0.27% and 0.30%. This represented daily intake of about 4 gms. per 100 pounds liveweight when the pig weighed about 200 pounds.

Data from several reports have suggested that the calcium and phosphorus requirements for optimum skeletal development are greater than the requirements for maximum gain and feed efficiency of swine.

Cromwell et al. (1970) used 344 SPF-Yorkshire pigs to determine the effects of dietary phosphorus and calcium level in corn-soybean meal diets on rate and efficiency of gain, carcass characteristics, and bone mineralization for growing-finishing swine from 18 to 96 Kg body weight. They reported that neither rate and efficiency of gain nor phosphorus content of the turbinates and metacarpals was improved when dietary phosphorus was greater than 0.5% and 0.4% in the growing and finishing period. Feeding less phosphorus than recommended above resulted in significantly slower and less efficient gains and carcasses with more backfat and lower ham-loin yield. This result agreed with that reported by the same group two years later (1972).

Chapman et al. (1962) investigated the calcium and phosphorus requirements of growing-finishing swine using a 6x7 factorial design, with dietary levels of calcium and phosphorus ranging from 0.2% through 0.8% and 0.2% through 0.7%, respectively. They concluded that the dietary requirements to assure maximum rate of gain and optimum skeletal development appeared to be 0.8% calcium and 0.6% phosphorus, for the pigs from 25 to 100 lb., and 0.7% calcium and 0.5% phosphorus from 100 to 200 lb., on a yellow corn-soybean basal diet.

Harmon et al. (1970) used dicalcium phosphate or soft phosphate as the phosphorus source in a corn-soybean meal diet containing 0.34% phosphorus to provide either 0.50% or 0.74% dietary phosphorus. Pigs were slaughtered at 90 Kg for serum

and bone analysis. Weight gain, serum phosphorus and turbinates and rib ash, calcium and phosphorus values increased with increases in dietary phosphorus, the responses plateauing at 0.5% phosphorus for each of these criteria.

Newman et al. (1976) reported that growing pigs (16 to 46 Kg) fed 0.6 and 0.8% P gained faster ($P < .05$) than pigs fed 0.4% phosphorus. Pigs fed 0.8% P gained faster ($P < .05$) than those fed 0.4% P during the finishing period (46 to 101 Kg) when fed barley-soybean meal diets. This level was a little higher than that suggested by NRC requirement.

Plumlee et al. (1958) suggested that, for growing-fattening pigs, adding 0.15% phosphorus from either dicalcium phosphate or phosphoric acid to a practical corn-soybean oil meal ration (0.30% phosphorus) resulted in a highly significant increase in rate of gain and serum phosphorus values and also a marked improvement in feed efficiency.

In 1973, the National Research Council recommended the phosphorus requirement for growing-finishing swine as 0.4%. The requirement for growing pigs was lower than that recommended in 1968. Pond et al. (1975) showed that the NRC recommended phosphorus requirement (1973) for growing-finishing pigs did maintain normal growth and bone development.

Stockland and Blaylock (1973) tried to determine the calcium and phosphorus requirement for growing and finishing pigs by using limestone and phosphoric acid as Ca, P supplements, respectively. The calcium requirement of growing-finishing swine

from 27 to 91 Kg was approximately 0.3% of the diet for maximum gain and feed efficiency. On the other hand, the level of dietary calcium required to maximize skeletal development was 0.6% of the diet. The phosphorus requirement of swine from 27 to 91 Kg was 0.45% or less for maximum gain and feed efficiency as well as for maximum skeletal development. Dietary calcium levels did not influence the incidence of lameness in pigs from 20 to 91 Kg live weight, but lameness tended to be slightly greater in pigs fed diets containing 0.45% phosphorus compared to pigs fed the diets containing 0.65% phosphorus.

Libal et al. (1969) used 190 Yorkshire X Hampshire cross-bred pigs to determine the effect of dietary levels of calcium and phosphorus on gain, feed intake, feed conversion, bone weight, bone breaking strength (BKS), percent bone ash and incidence of Atrophic Rhinitis (AR) in growing-finishing swine. Increasing phosphorus in equal increments from 0.30% to 0.70% of the diet improved average daily gain in a linear manner. Also, the linear effect of levels of dietary phosphorus on feed intake was significant ($P < .005$) with the highest intake at the 0.60% level. The linear effect of phosphorus levels on BKS approached significance. The results of these experiments showed that calcium and phosphorus levels can vary considerably without significantly affecting daily gain and feed conversion of pigs. Levels of the two elements did affect bone formation as shown by BKS and bone weight data.

Bayley and Thomson (1969) evaluated the effect of feeding corn-soybean diets containing 0.9% calcium and one of the

following levels of total phosphorus, 0.34, 0.44, 0.50, or 0.56% in the form of meal or as pellets using gain and bone development as criteria. Calcium and phosphorus balances for the diets containing the lowest and highest levels of phosphorus were also carried out. Gain and bone development were improved by phosphate addition to provide 0.5% phosphorus in the diet, but increasing the level beyond this caused no further response in growing pigs.

Allee et al. (1976) used ninety pigs to determine the minimal level of supplemental phosphorus required by growing-finishing pigs. Graded levels of supplemental phosphorus (0, .05, .10, .15 and .20% of the diet) from dicalcium phosphate were added to a 16% protein milo-soybean meal basal diet containing .36% phosphorus. Calcium level was maintained at .6% in all diets. They suggested that growing and finishing pigs should be supplied at least .15% supplemental inorganic phosphorus for maximum daily gain and feed efficiency.

PLANT SOURCES OF PHOSPHORUS

At the end of last century, it was generally thought that only organic forms of phosphorus could be assimilated by the body and used for synthesis of many phosphorus-containing compounds in the body tissue.

Hart et al. (1909) designed a study with pigs to determine "what percent of the ash ingredients must be in organic combination to be of nutritive value", the results convinced them that "phytin as the source of phosphorus gave no better results

than inorganic phosphates", contrary to the common view. Forbes and Keith (1914) reviewed the research on phosphorus up to that date and confirmed that inorganic forms of phosphorus were at least equal to organic phosphorus. Some 70-90% of the phosphorus in cereal grains was shown to be in the form of phytin. Since that time many studies have been carried out to evaluate the utilization of phytin phosphorus.

Chapman et al. (1955) suggested that growing-finishing swine did not utilize plant phosphorus as efficiently as inorganic phosphorus, as evidenced by a significantly poorer feed efficiency and decreased average daily intake.

Moore and Tyler (1955) studied the utilization of phytin phosphorus in the digestive tract of the pig and found that it was utilized to a greater extent in diets containing added calcium phosphate.

Bayley and Thomson (1969) indicated that only 20-30% of the phosphorus in corn and soybean meal can be utilized by the pig. Noland et al. (1968) used growing swine to evaluate the availability of the phosphorus in a corn-soybean meal basal diet. Four diets were formulated assuming availabilities of either 30, 40, 50 or 60%. No significant differences in either rate or efficiency of gain were obtained in this trial either to 45 Kg or to 90 Kg. Results of this trial indicated that the phosphorus in a corn-soybean meal diet was 30 to 60% available for growing swine.

Tonroy et al. (1970) used corn grit phosphorus as a control to evaluate the availability of phosphorus in sorghum

grain. He reported that the phosphorus retention values were 4.49 and 1.86% for the 0.3% and 0.5% phosphorus levels, respectively.

Besecker et al. (1967) reported that the apparent digestibility of the phosphorus in barley was calculated to be 17.68 and 24.29%, respectively, from diets containing 0.3 and 0.5% total phosphorus. Woodman and Evans (1948) showed that pigs 50 to 90 Kg in weight absorbed 30 to 40 percent of the phosphorus in a barley-wheat bran diet with no added inorganic phosphorus.

INORGANIC PHOSPHORUS SOURCES

Many supplements are being used as sources of phosphorus. Most reports are concerned with corn-soybean meal type diets supplemented with dicalcium phosphate as the primary source of inorganic phosphorus.

Plumlee et al. (1958) studied the utilization of phosphorus supplements by swine. They gave top rank to dicalcium phosphate, monocalcium phosphate, and phosphoric acid, which they found to be equal. These were followed, in the order named, by steamed bone meal, defluorinated phosphate, Curacoa Island phosphate, and soft phosphate with colloidal clay.

Dicalcium phosphate supported more rapid gains than soft phosphate at a level of 0.5% dietary phosphorus, although rib and turbinate ash values were similar (Harmon et al. 1968).

Several studies have indicated that the phosphorus in soft phosphate with colloidal clay were poorly available to farm

animals and poultry. Such results were reported for the chick by Grau and Zweigert (1953), Johnson and Phillips (1956), Miller and Joukovsky (1953) and Motzok and Branion (1956); for turkey by Wilcox et al. (1954); for cattle by Long et al. (1976), Plumlee et al. (1958), Van Zante et al. (1967).

Miller et al. (1953), Chamberlain et al. (1963) suggested that the phosphorus from dicalcium phosphate, Curacao Island phosphate, bone meal, and defluorinated phosphate were all good sources of readily available inorganic phosphate. Newman et al. (1976) reported that defluorinated rock phosphorus appeared to be equal to sodium salt of phosphate and dicalcium phosphate as a source of supplemented phosphorus for pigs fed barley-soybean meal as growing and finishing diets judging by rate and efficiency of gain.

FEED PROCESSING

Some methods of feed processing appear to increase the availability of phytin phosphorus.

Hart et al. (1909) observed that soaking wheat bran overnight allowed the enzyme phytase to act with the result that some of the phytin phosphorus in the bran was hydrolyzed to inositol and inorganic phosphorus.

O'Dell (1962) found a marked increase in the inorganic phosphorus content of isolated soybean meal after autoclaving for various lengths of time. Lease (1966) reported a similar but less dramatic change in the inorganic phosphorus content of sesame meal with autoclaving. McCance and Widdowson (1944)

demonstrated that wet heat quickly destroyed phytase, whereas dry heat did not. Thus the increase in inorganic or available phosphorus might be due to the hydrolysis of phytin instead of the enzyme reaction.

Bayley et al. (1969) showed that phosphorus absorption from the diet containing no added phosphorus (0.35% P, 0.90% Ca) was increased from 19 to 29% by steam pelleting, but steam pelleting did not have this effect on the diet containing the highest level (0.56% P, 0.90% Ca) of phosphorus. The increased absorbability of the phosphorus in the low-phosphorus diet as a result of steam-pelleting was manifested in greater gains and improved bone development. Steam pelleting the diets with adequate phosphorus improved gain and feed efficiency, but this effect could not be explained on the basis of either increased phosphorus availability or increased digestibility of the energy or nitrogen in the diet.

Summers et al. (1967) reported that steam-pelleting appeared to render more than 25% of the remaining phosphorus available to the chick when using wheat in the basal diet. Pelleting wheat without sufficient steam did not have the same effect on phosphorus availability.

VITAMIN D AND PHOSPHORUS

Harris and Innes (1931) postulated that the vitamin D increased the net absorption of Ca and P, but much of the work done since then has indicated that its action is on Ca absorption only.

Boutweel et al. (1946), Krieger et al. (1941) and Spitzer et al. (1948) all demonstrated that in the absence of vitamin D, phytic acid phosphorus was not available to the rat, but when vitamin D was fed, more of the phosphorus was utilized. In studies with chicks, McGinnis et al. (1944) showed that phytin phosphorus was poorly available in the absence of vitamin D, but that it was nearly as available as inorganic phosphorus when adequate vitamin D was fed.

Those studies indicated that the phytin phosphorus was made available by the action of an intestinal enzyme, phytase, capable of splitting the phytin molecule. It appeared that vitamin D might be necessary either for phytase formation or for its proper function. Spitzer et al. (1948) reported that the phytase content of the small intestines of rats fed phytin phosphorus and vitamin D showed no difference in phytase concentration. They suggested that the vitamin D function was not in phytase formation, but a secondary effect on its proper function.

Schneider and Steenbock (1939) proposed that vitamin D was acting in rachitic rats, deprived the soft tissues of P which entered bone, this deprivation being responsible for the observed cessation of growth of the animals. In later experiments, Cramer and Steenbock (1956) put rats on a low P diet containing vitamin D; on increasing the Ca content, the blood and bone ash Ca increased, but growth was decreased. They interpreted this as showing that vitamin D could cause a differential shunt of P from soft tissues to bone. In the absence of vitamin D such a transfer does not apparently occur.

Conversely, Steenbock and Bundfeldt (1951) found that if growth was increased in rachitic rats, the percentage of bone ash fell because the demand of the soft tissues for P were greater than those of bone. Feaster et al. (1953) put animals on a low P, vitamin D free diet; when they were given P^{32} , they deposited more of the isotope in their soft tissues and less in the femurs, compared to the controls. From all the studies mentioned above, Irving (1963) suggested that vitamin D could enhance pool turnover of phosphorus thus increased phosphorus entry from soft tissue into bone.

DeLuca (1974) proposed that the active form of vitamin D was $1,25-(OH)_2-D_3$. He also found that the $1,25-(OH)_2-D_3$ acted independently of its Ca transport function to stimulate the elevation of serum inorganic phosphate. Although all of the systems responsible for this elevation had not been elucidated, he still thought $1,25-(OH)_2-D_3$ might be regarded as a phosphate transport hormonal substance.

CALCIUM : PHOSPHORUS RATIO

The ratio of calcium to phosphorus will vary depending on the weight and age of the pig and the level of calcium and phosphorus in the diet. If the calcium intake is too high, for example, and the phosphorus level is just about adequate, then the excess calcium could cause a deficiency of phosphorus to occur, by tying up a certain amount of phosphorus in the intestinal tract, causing it to be excreted in the feces rather than being absorbed. These two mineral elements are more

efficiently utilized when they are present in a certain ratio to each other (Irvin, 1964).

Chapman et al. (1962) and Cromwell et al. (1970) found the calcium-phosphorus ratio was more important when minimal dietary levels of phosphorus were fed. Stockland et al. (1973) reported that there were no significant interactions between Ca and P as levels increased from 0.15 through 0.90 and 0.45 through 0.65, respectively.

Doige et al. (1975) used a factorial design with three levels of calcium and three levels of phosphorus to study calcium and phosphorus deficiencies and imbalances in swine fed from 22 Kg to 90 Kg. All changes were minimal if low levels of either element were accompanied by a Ca:P ratio near 1.25:

1. Low calcium-high phosphorus rations resulted in parathyroid enlargement, reduced bone mass, increased numbers of osteoclasts and fibrous replacement of bone. In animals fed high calcium-low phosphorus rations, hypophosphatemia, reduced bone ash and overgrowth of epiphyseal plate were observed.

Today, the exactness of the ratio between calcium and phosphorus is less emphasized than it was in early research work. The most favorable ratio appears to be between 1:1 and 1.5:1. In the NRC, the ratio will average about 1.3 to 1 with all weights of growing and finishing swine, while the average recommended calcium:phosphorus ratio for breeding swine is 1.5:1 (Gielsen, 1974).

ENVIRONMENT AND MANAGEMENT

Brown et al. (1974) reported that in the animals maintained at 2°C, there was a marked increase in phosphorus excretions from day 1 to day 60 of the experimental period followed by a precipitous decline during the 60-80 interval. Phosphorus excretion by the control (20°C) animal increased slowly to a peak at day 50 followed by a decline. At all time intervals the phosphorus excretion by the animals kept at 2°C was greater than that of controls ($P < .05$). This would suggest that either the cold-stressed pigs did not utilize phosphorus and therefore excreted it or there was some alteration at the site of reabsorption in the distal tubule of the kidney. The calciuria occasioned by treatment was less pronounced than the phosphouria. There were no significant differences in the mineral concentration of the bones.

Kornegay et al. (1973) used 109 crossbred gilts which had been raised in total confinement on concrete for five gestation-lactation cycles in a 2X2X2 factorial experiment of the following treatments: 10.3 and 11.0 vs. 15.5 and 15.0 g daily of Ca and P, respectively (analyzed), total confinement on concrete vs. dirt lots during breeding and gestation; group vs. individual feeding during breeding and gestation. Farrowing and weaning performance was not significantly different between sows fed the high or low Ca and P level or between sows housed in total confinement on concrete or in dirt lots. Femur breaking strength, tibia ash, rib specific gravity were not significantly different between the individual and group fed sows.

PHOSPHORUS AND OTHER ELEMENTS

High levels of Ca, Fe, Al, Zn in the diet tie to P, and make the phosphorus less available (NRC, 1973). On the other hand, a high dietary P level will also increase the Zn and Mg requirement (O'Dell et al. 1960).

Gillis (1950) found in chicks and rats that K was a factor influencing calcification, since on diets deficient in K the bone ash and blood inorganic P were reduced. Harrison and Harrison (1961) reported the K enhanced the P absorption from the gut in rats.

ATROPHIC RHINITIS AND Ca, P

Brown, Krook and Pond (1966) reported that high levels of calcium and phosphorus were required to prevent excessive resorption of the osseous frame of the turbinate bone. Cromwell et al. (1970, 1972), Libal et al. (1969), Lindley (1967), Liptrap et al. (1970), and Peo et al. (1969) did not agree with the conclusion. But they all suggested the turbinate bones were more sensitive to phosphorus and calcium deficiencies than other skeletal tissues.

Chapter III

EXPERIMENTAL PROCEDURE

General Introduction

Bones used in this study were collected from gilts that were part of a long-time dietary phosphorus study being conducted by Dr. Gary Allee.

Sixty cross-bred gilts weighing about 52.4 Kg, were randomly assigned, according to initial weight and litter, to 15 slotted-floor pens representing 5 replications of the 3 dietary treatments. Dicalcium phosphate was added at 3 different levels to a 14% protein sorghum-soybean meal diet containing 0.30% phosphorus to give a total phosphorus level of either 0.40%, 0.50% or 0.60%. Dietary calcium level was maintained at 0.65% in all treatments. The pigs were group fed with feed and water provided ad libitum. Composition of the diets is shown in Table 1 and calculated analysis of each diet is shown in Table 2. Before this trial, all the pigs had been on a ration containing 0.80% Ca and 0.60% P which met all nutrient requirements recommended by NRC (1973).

After 70 days of feeding, five pigs from each treatment were slaughtered in the Animal Science and Industry Department meat laboratory.

Bone measurements and analyses

Routine carcass data was collected when carcasses were broken down to wholesale and retail cuts. Also, the outside

Table 1. Composition of diets^a fed in phosphorus study

Ingredient	0.4% Dietary P	0.5% Dietary P	0.6% Dietary P
Sorghum grain %	81.8	81.88	81.30
SBM, %	15.3	15.3	15.3
Dicalcium phosphate ^b	0.5	0.95	1.43
Limestone	1.3	1.10	0.87
Salt	0.4	0.4	0.4
Vitamin premix ^c	0.5	0.5	0.5
Trace mineral ^d	0.1	0.1	0.1
Antibiotic premix ^e	0.1	0.1	0.1

^aDiets were in meal form.

^bDicalcium phosphate: 21% P, 18% Ca

^cAmounts per lb.: 400,000 USP units of vitamin A, 30,000 USP units of vitamin D₃, 450 mgs. of riboflavin, 1,200 mgs. of d-pantothenic acid, 29.9886 mgs. of choline, 2,500 mgs. of niacin, 2,000 I.U. of vitamin E, 2.2 mgs. of vitamin B₁₂, 250 mgs. of vitamin K, 2.850 mgs. of antioxidant.

^dContaining 5.5% manganese, 10% iron, 1.1% copper, 10% zinc, 0.15% iodine, 0.1% cobalt.

^eTylan 10

Table 2. Calculated analysis of diets fed in phosphorus study

Item	0.4% Dietary P	0.5% Dietary P	0.6% Dietary P
Crude protein	14.08	14.08	14.05
Lysine	.62	.62	.62
Calcium	.64	.65	.65
Phosphorus	.40	.50	.60

phalanx was collected from the right front foot and the femur was removed from the right hindquarter.

The bones were autoclaved for 5 minutes at 100°C and the remaining adhering tissue was manually removed. The cleaned bones were then placed individually in plastic bags and stored in a freezer between analyses until the study was completed.

A radiograph was made of each femur, with the help of Dr. Mark Guffey of the Department of Surgery and Medicine, using Litton X-ray machine.

Specific gravity was determined in the Animal Science and Industry Department meats laboratory. Each femur was thawed to room temperature, dried and weighed. It was then immersed in a tank of water in which temperature had been adjusted to 80°F, and its weight in water was taken again. The specific gravity was then calculated using the equation by Brown et al. (1951).

$$\text{SpG} = \frac{\text{Wt. in the air}}{\text{Wt. in the air} - \text{Wt. in the water}}$$

The device used is shown in Fig. 1.

The breaking strength was measured in the Department of Civil Engineering with the help of Dr. Donald Lindley. The bone was placed on two supports (as shown in Fig. 2). The supports were 2.5 cm in diameter and 10.1 cm apart. A third rod, 2.5 cm in diameter, was focused upon the center of the

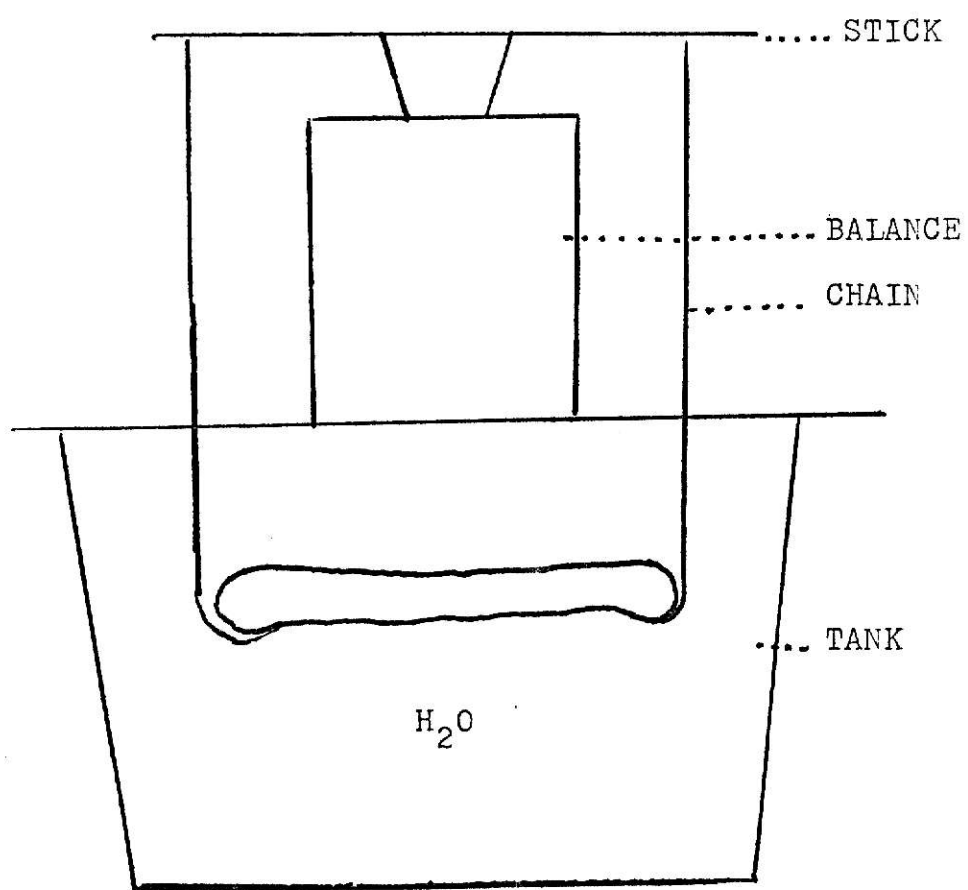


Fig. 1. Device for determination of specific gravity

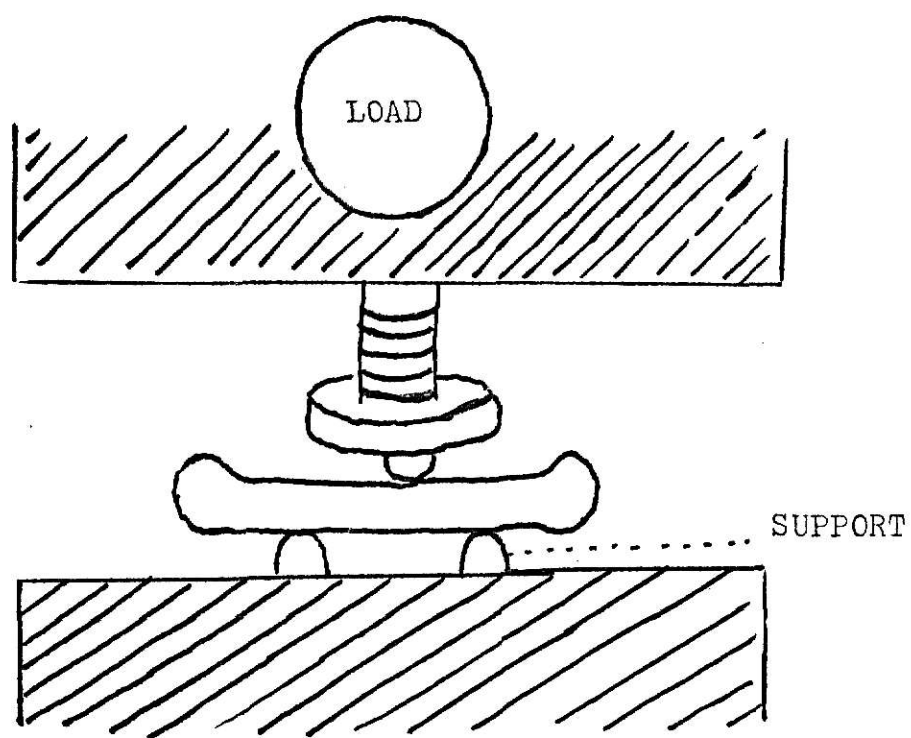


Fig. 2. Device for determination of breaking strength.

bone and driven down by a press until the bone was broken. The force (Kg) required to break the bone was recorded automatically. The stress was calculated as

$$\begin{aligned}
 S \text{ (psi, lb/in}^2\text{)} &= MC/I \\
 &= \frac{F(do/2)}{\pi/64(do^4-di^4)} \\
 &= \frac{F(64)do}{2\pi(do^4-di^4)} \\
 &= \frac{32Fdo}{\pi(do^4-di^4)}
 \end{aligned}$$

where, M is moment

C is distance from the neutral axis to the
point of maximum stress

F is force required to break the bone

I is inertia of moment

do is outside diameter of femur at the breaking
point

di is inside diameter of femur at the breaking
point, calculated by:

$$di = do - 2(\text{thickness of bone})$$

Approximately 4 cm. of the shaft near the breaking point was sawed off from the femur and bone marrow removed. The clean femur and a portion of the phalanx were then used for the ash, calcium and phosphorus determinations at the Animal Science and Industry Department analytical laboratory on a dry, fat-free basis. Three replicates were taken from the femur shaft

and head of the phalanx. The phosphorus was analyzed by the method of Fiske and Subba Row (1925). In order to get rid of the P interference in Ca determination, the sample was diluted by SrCl before the atomic absorption analysis.

The analysis of variance, multiple range test and correlation were conducted according to the method outlined by Snedecor and Cochran (1971).

Chapter IV

RESULTS

Bone measurements are summarized in Table 3. An analysis of variance, multiple range test and correlation were conducted on the measured parameters according to the methods outlined by Snedecor and Cochran (1971). The breaking strength (Kg/cm^2) of the femur from gilts fed 0.6% phosphorus was significantly higher than that of those from the 0.4% level (Table 3). However, the breaking strength expressed in "Kg" did not show any significant difference between the 3 treatments.

The P and total ash content of the femur and phalanx increased slightly, but not significantly in bones from gilts receiving 0.6% dietary phosphorus. Values (dry, fat-free basis) ranged from 13.06% to 13.38% and 69.79% to 70.57%, respectively for the femurs and 9.58% to 9.96% and 59.40% to 60.85%, respectively for the phalanges. The Ca content of phalanges from gilts receiving 0.4% dietary phosphorus was significantly higher than Ca content of those from the two other treatments. However, correlation ($r = .24$) of Ca content between femur and phalanx showed that there was no consistent relationship in Ca content between femur and phalanx. The Ca:P ratio in the femur was close to 2:1 for each treatment.

No consistent trends or significant differences were found in specific gravity and thickness or femur measurements.

Chemical analyses of femur and phalanx from the same animal showed no consistent relationships.

The X-ray examination of the femurs failed to show any differences between dietary treatment groups.

Carcass data is summarized in Table 4. Differences in backfat and carcass length were not significantly different. Dietary P apparently had no significant effect on the carcass.

No adverse effect of low phosphorus level on bone development or growth was observed throughout the whole feeding trial. It appears that 0.4% total dietary phosphorus is adequate for growth of gilts from 52.4 Kg to 101.9 Kg on a sorghum-soybean meal diet, but higher level is needed for maximum bone strength.

Table 3. Bone data.

Dietary P, %	.4	.5	.6
No. of bones	5	5	5
Femur			
Avg. specific gravity	1.189 \pm .030	1.212 \pm .036	1.200 \pm .020
Avg. wall thickness, cm.	1.090 \pm .074	1.136 \pm .028	1.110 \pm .038
Avg. breaking strength			
Kgs.	394 \pm 42	437 \pm 82	431 \pm 65
KG/cm ²	455.2 \pm 102.0 ^a	539.6 \pm 110.3 ^{a,b}	623.1 \pm 206.7 ^b
Avg. ash, % ¹	70.13 \pm .47	69.79 \pm 1.13	70.57 \pm 1.32
Avg. Ca., % ¹	26.74 \pm 1.44	26.20 \pm 1.43	26.50 \pm 1.78
Avg. P, % ¹	13.08 \pm .26	13.06 \pm .43	13.38 \pm .33
Phalanx			
Avg. ash, % ¹	59.40 \pm 1.26	59.84 \pm 1.69	60.85 \pm 2.13
Avg. Ca, % ¹	23.79 \pm .34 ^a	20.63 \pm 1.64 ^b	20.61 \pm 2.03 ^b
Avg. P, % ¹	9.61 \pm .36	9.58 \pm .32	9.96 \pm 0.76

¹ On dry fat-free basis; Each value is the mean \pm standard deviation of 5 observations.

a,b Significant difference (P<.05)

Table 4. Carcass data^a

Dietary P, %	0.4	0.5	0.6
Average Backfat, cm.	2.87	2.95	3.20
Avg. LEA, cm. ²	30.13	25.81	26.98
Carcass length, cm.	81.3	83.1	83.6

^aAverage slaughtered wt: 101.9 Kg^bData from 4 pigs

Chapter V

Discussion

Two ways to express breaking strength are

- 1) Force, expressed in "pounds" or "Kg"
- 2) Stress, expressed in "lb/in²" or "Kg/cm²"

The force used to break the bone will depend on both the thickness and strength of the bone (Miller et al. 1964). Stress was selected as the most appropriate way to express strength of bone in this study.

The breaking stress of femurs, expressed in Kg/cm², from pigs fed 0.6% dietary P was significantly higher ($P < .05$) than that of those from the 0.4% level. Force (Kg) values also increased as dietary phosphorus increased, but differences were not significant.

The correlation ($r = .28$) between breaking strength and ash content of femur was just approaching significance. Libal et al. (1970), Cromwell et al. (1972) also reported that the increased breaking strength was not accompanied by an increase in bone ash. The increasing breaking strength might be attributed to the structural or physical change of the bone, but that can not be ascertained in this study.

The percent ash, Ca and P of femurs did not increase as the dietary phosphorus level increased from 0.4 to 0.6%.

Cromwell et al. (1970) also suggested that bone density was not improved by feeding phosphorus levels higher than 0.5% and 0.4% during the growing and finishing stages, respectively.

Libal et al. (1969) also found that bone density of growing-finishing pigs was not improved by raising the phosphorus level from 0.40 to 0.70% in 0.10% increments. Results with baby pigs have indicated, however, that bone development was improved by feeding levels of calcium and phosphorus higher than those levels required for maximum gains and feed efficiency (Miller et al., 1962, 1964; Combs et al., 1962; Rutledge et al., 1961). Thus, for the growing-finishing pig, it appears that the margin of difference between the levels of calcium and phosphorus needed for maximum growth and maximum skeletal development is less than for the baby pig.

The ash, Ca and P content of femurs reported in this study are higher than results reported by other studies. That might be attributed to the removal of the bone marrow before analysis.

The Ca:P ratio in the femur is close to 2:1 for every treatment group. Blair et al. (1963) also found a ratio of 2 gm. of calcium to 1 gm. of phosphorus in the bones of 20 Kg pigs. Nielsen (1972) reported that the calcium : phosphorus ratio in bone was very uniform and varied from 2.0 to 2.2. Brown et al. (1972) reported that Ca:P ratio in femurs changed with age. For pigs of 24 weeks of age, the Ca:P ratios were 1.60, 1.61, and 1.68 from proximal, shaft, distal segment of femur, respectively.

The X-ray examination of the femurs failed to show any difference between dietary treatment groups. This agreed with the result reported by Bayley and Thomson (1969). They did not find any abnormality on radiographs from pigs fed 0.35%

and 0.65% dietary phosphorus level, although some of the pigs showed lameness. Chapman et al. (1962) showed radiographic changes in the femurs of many animals expressing outward symptoms of skeletal abnormalities. It appears that X-ray would be a good assay method only when a very low dietary phosphorus level was fed.

The carcass data did not show any significant difference between three dietary treatments. Cromwell et al. (1972) also reported that increase of dietary phosphorus from 0.35 to 0.80% did not significantly influence carcass length, backfat thickness or loin eye area. But the results of previous work by Cromwell et al. (1970) indicated that feeding less phosphorus than that recommended by the NRC (1968) resulted in a carcass with more backfat.

The breaking strength of the femurs from gilts fed 0.60% phosphorus was significantly higher than that of those from the 0.40% level. However, those gilts receiving the 0.40% phosphorus diet showed no outward signs of phosphorus deficiency. It appears that the requirement of 0.4% P recommended by NRC (1973) is adequate for pigs weighing from 56.8 Kg to 99.5 Kg for normal growth, but higher level is needed for maximum bone strength. Other workers have reported the same level of dietary P is adequate for finishing pigs (Cromwell et al., 1970, 1972; Libal et al., 1969; Pond et al., 1975). However, Allee et al. (1976), Bayley and Thomson (1969), Chaney et al. (1968), Harmon et al. (1970) and Newman et al. (1976) reported a slightly higher level of 0.50% P for finishing pigs.

SUMMARY

The phosphorus requirement of finishing pigs was determined by the studies of femur and phalanx. Fifteen crossbred gilts (initial average weight 52.4 Kg) were slaughtered after 70 days on trial (final average weight 101.9 Kg). Each group of five gilts had received either 0.40%, 0.50% or 0.60% total dietary phosphorus and 0.65% dietary calcium during the feeding period. The basal sorghum-soybean meal diet supplied 0.30% of plant phosphorus.

Specific gravity, X-ray or chemical analysis of femurs showed no significant differences between dietary treatments, but the breaking strength of the femurs from those receiving 0.6% phosphorus was significantly higher than that of those receiving 0.4% phosphorus. Comparisons between femur and phalanx from the same animal were inconsistent. The carcass data did not show any significant effect of dietary P.

Breaking strength was greater in bones from gilts receiving 0.60% P diet, but no outward signs of phosphorus deficiency or any adverse effects of low P diet on growth were observed in any treatment. It appears that 0.4% total dietary P is adequate for the normal growth of finishing gilts on a sorghum-soybean meal diet, but higher level is needed for maximum bone strength.

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PORCINE FEMUR OR PHALANX BONES AS INDICATORS
OF DIETARY PHOSPHORUS DEFICIENCY

by

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B.S., National Taiwan University, ROC, 1974

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1976

ABSTRACT

Fifteen crossbred gilts (average initial weight 52.4 Kg) were slaughtered after 70 days on feed (average final weight 101.9 Kg) in a dietary phosphorus study. Each group of five gilts had received either 0.40%, 0.50% or 0.60% total dietary phosphorus and 0.65% dietary calcium during the feeding period. The basal sorghum-soybean meal diet supplied 0.30% of plant phosphorus.

Specific gravity, X-ray or chemical analysis of femurs showed no significant differences between 3 treatments, but the breaking strength of femurs from gilts fed the 0.40% level. The increasing breaking strength could not be related to the change of ash content. The Ca:P ratio in the femurs was close to 2:1 in all treatments. Comparisons between femur and phalanx from the same animal were inconsistent. The carcass data did not show any significant effect of dietary P.

Breaking strength was greater in the bones of gilts receiving 0.60% P diet, but no outward signs of phosphorus deficiency or any adverse effects of low P diet on growth were observed in any treatment. It appears that 0.4% total dietary P is adequate for the normal growth of finishing gilts on a sorghum-soybean meal diet, but higher level is needed for maximum bone strength.