THE EFFECT OF PELLETING SWINE RATIONS ON THE PERFORMANCE OF SWINE AND RATS

Thesis for the Degree of Ph. D.

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Robert Wayne Seerley

1960

This is to certify that the

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THE EFFECT OF PELLETING SWINE RATIONS ON
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presented by

Robert Wayne Seerley

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J. A. Hoefer
Major professor

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THE EFFECT OF PELLETING SWINE RATIONS ON THE PERFORMANCE OF SWINE AND RATS

By

Robert Wayne Seerley

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies of
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Animal Husbandry

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Approved J. A. Hoefer

ABSTRACT

Nine experiments were conducted to study and evaluate the effect of pelleting three rations on growth, feed intake, feed efficiency, carcass quality, ration palatability, energy digestibility, nitrogen digestibility, and rate of food passage. The three test rations were (1) fortified corn-soybean meal, (2) 20 percent oats by weight replacing corn, and (3) 40 percent oats by weight replacing corn.

Pelleting significantly improved growth rate when the three test rations were ad libitum-fed to pigs and rats. The daily gains were the same for all pellet-fed pigs; however, in the meal form of these rations, the gains decreased as the fiber level increased. Feed consumption was generally increased with the pelleted rations. The feed required per pound of bodyweight gain increased with the higher fiber rations, but the increase was less with the pelleted rations. Carcass data showed there were no differences between the experimental rations in regard to dressing percentage, carcass length, backfat, percent lean cuts, percent primal cuts, loin area and percent fat trim.

Pelleting significantly improved daily gains and feed efficiency when the three test rations (pooled data) were equally and ad libitum-fed to paired pigs.

In both the equal and ad libitum feeding trials, the apparent energy digestibility of the high corn (low fiber) pelleted rations was significantly greater than the meal form of the same ration. On an

Robert W. Seerley

ABSTRACT Continued

equal feed intake, the apparent energy digestibility of the 40% oat (high fiber) meal and pelleted rations was not significantly different; however, digestibility of the meal form was significantly improved when ad libitum-fed. Apparent nitrogen digestibility was the same for the high corn and 40% oat rations in either meal or pellet forms.

In the rate of food passage studies, pelleted low and high fiber rations passed significantly faster through the alimentary tract than meal rations when equal and ad libitum-fed. Pooled data showed that the 5% fecal excretion time, 95% fecal excretion time, and the mean ingesta retention time were less with the pelleted rations.

A palatability study with the high corn ration in the forms of meal, pellets and reground pellets showed that pigs definitely preferred pellets.

Two feeding trials were conducted to study the effect of processed corn on the nutritive value of a rat ration. On the basis of growth, different processing methods did not improve the nutritive value of corn.

Robert W. Seerley

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Robert W. Seerley

candidate for the degree of

Doctor of Philosophy

Dissertation: The Effect of Pelleting Swine Rations on the Performance of Swine and Rats

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I. INTRODUCTION

Although pelleting was used more than a century ago to alter the physical form of formulated rations (Commissioner of Patents, U. S. Patent Office, 1860), only within the last decade has pelleting brought an important change to feeding practices. A recent survey (Wornick, 1959) indicated that over 50 percent of all commercial feed sold in the United States was in the physical form of either pellets or crumbles. The percentage of pelleted rations is increasing and will probably continue to increase in the next few years.

Fundamental research on pelleted swine rations has been extremely limited. Therefore, this study has been undertaken in an attempt to determine the effects of pelleting on the nutritive value of swine rations.

II. REVIEW OF LITERATURE

A. Effects of replacing corn with oats in swine rations.

Carroll et al. (1937) summarized that oats may make up one-half of the ration for growing-finishing swine without appreciably decreasing rate of gain; however, the feed required per pound of gain will be increased. Also, ground oats have a higher corn replacement value than whole oats. It was stated that the degree of fineness had little effect on the nutritive value. Later Crampton and Bell (1946) studied the effect of fineness of grinding on the utilization of oats when fed to pigs. They concluded the finer ground oats supported greater growth. Sorting was a problem with the coarsely ground ration with young pigs, while sorting was not a problem regardless of grind with pigs over 100 pounds bodyweight. Average feed consumption was about the same for coarsely and finely ground oats. No differences in digestibility were noted. Lloyd and Crampton (1955) fed oats at levels of 75, 52, 28 and 4 percent of the cereal grain source. Crude fiber levels were 8.6, 6.5, 4.4 and 2.3 percent, and crude protein was 8.4, 10.3, 12.3 and 14.2 percent, respectively. When the daily dry matter intake was the same, the decrease in fiber and increase in protein increased the apparent digestibility of protein. In recent years, Jensen et al. (1957, 1958, 1959b) re-evaluated oats in rations for growing-finishing swine. By feeding oat levels of 0, 29, 60 and 95 percent, they found growth rate decreased as the level of oats increased and feed required per pound gain increased as the oat level increased. They concluded the higher fiber content caused poorer performance. The

crude fiber levels were 2.8, 4.9, 6.7 and 8.1 percent for the respective oat levels of 0, 29, 60 and 95 percent. Adding 15 and 30 percent oat hulls to hulless oat rations decreased gains 18 and 35 percent, respectively. Adding corn oil to correct for total digestible nutrient reduction in 30 percent oat hull rations overcame the reduction in growth rate.

Axelsson (1948) summarized the data from several experiment stations to establish the optimum crude fiber level for growing pigs, and concluded that the optimum level was between 5.5 and 7.0 percent. In subsequent research Axelsson (1953) found optimum crude fiber levels were 6.57 percent for growth, 7.26 percent for feed efficiency and 6.64 percent for economical growth.

B. Comparisons between rations in meal and pellet forms.

1. SWINE

A summary (Table 1) of pelleting research on corn rations, for growing-finishing swine, indicates average daily gains and average daily feed consumption were increased .08 pound and .15 pound, respectively, by pelleting. Feed efficiency was improved about 6 pounds per 100 pounds bodyweight gain (Dinusson et al., 1952; Warner and Meade, 1956; Self and Chapman, 1960; Hoefer et al., 1958; Conrad and Beeson, 1958; Carlisle et al., 1959; Arkansas, 1959; Jensen et al., 1959a; Young and Wingert, 1959; Rutledge and Teague, 1959; Larson and Oldfield, 1960; Wahlstrom, 1959).

Conrad and Beeson (1958) reported a corn-and-cob ration was improved by pelleting. In fact, the corn-and-cob pelleted ration supported more growth than a ground shelled corn ration (Table 2).

Pelleting studies on oat rations for swine showed a general improvement in performance by pelleting (Lehrer and Keith, 1953; Hoefer et al.,

TABLE 1.

EXPERIMENTAL DATA ON MEAL AND PELLETED CORN RATIONS FOR SWINE

Reference	No. pigs per ration	Meal			Pellet			Percentage change due to pelleting		
		Daily gain lbs.	Daily feed lbs.	Feed efficiency lbs./cwt.	Daily gain lbs.	Daily feed lbs.	Feed efficiency lbs./cwt.	Daily gain %	Daily feed %	Feed efficiency %
Dinusson (1952)	10[a]	1.43	4.90	338	1.41	4.50	320	- 1	- 8	+ 5
Warner (1956)	10[b]	1.36	4.46	327	1.37	4.09	315	+ 1	- 8	+ 4
Self (1960)	43[c]	1.53	4.99	326	1.56	5.18	332	+ 2	+ 4	- 2
Self (1960)	39[c]	1.51	5.16	342	1.73	5.88	340	+14	+14	+ 1
Hoefer (1958)	7[c]	1.77	7.55	426	2.18	7.82	360	+23	+ 4	+15
Hoefer (1958)	10[c]	1.53	4.76	312	1.68	4.83	288	+10	+ 1	+ 8
Conrad (1958)	10[c]	1.56	5.39	345	1.78	5.74	323	+14	+ 6	+ 6
Carlisle (1959)	9[b]	1.64	6.18	378	1.72	6.23	362	+ 5	+ 1	+ 4
Carlisle (1959)	9[b]	1.67	6.11	365	1.83	6.93	378	+10	+13	- 4
Carlisle (1959)	5[c]	1.76	5.44	309	1.78	5.98	336	+ 1	+10	- 9
Carlisle (1959)	5[b]	1.80	5.67	315	1.76	5.72	325	- 2	+ 1	- 3

[a]Not reported

[b]Pasture

[c]Dry lot

TABLE 1--Continued

Reference	No. pigs per ration	Meal			Pellet			Percentage change due to pelleting		
		Daily gain lbs.	Daily feed lbs.	Feed efficiency lbs./cwt.	Daily gain lbs.	Daily feed lbs.	Feed efficiency lbs./cwt.	Daily gain %	Daily feed %	Feed efficiency %
Arkansas (1959)	NR[a]	1.61	5.76	358	1.38	4.80	348	-14	-17	+ 3
Jensen (1959)	5[c]	1.71	5.47	320	1.69	5.73	339	- 1	+ 5	- 6
Jensen (1959)	5[c]	1.84	6.44	350	1.85	6.62	358	+ 1	+ 3	- 2
Jensen (1959)	5[c]	2.02	6.11	302	1.92	6.17	321	- 5	+ 1	- 6
Young (1959	10[c]	1.67	6.24	374	1.71	5.95	349	+ 2	- 5	+ 7
Rutledge (1959)	15[c]	1.72	5.59	326	1.83	5.59	306	+ 6	0	+ 6
Larson (1960)	5[c]	1.81	6.10	337	1.61	6.00	371	-11	- 2	-10
Wahlstrom (1959)	48[c]	1.45	3.99	277	1.51	4.06	269	+ 4	+ 2	+ 3
AVERAGE		1.57	5.17	328	1.65	5.32	322	+ 5	+ 3	+ 2

[a]Not reported

[c]Dry lot

TABLE 2.

EXPERIMENTAL DATA ON MEAL AND PELLETED RATIONS FOR SWINE

Reference	No. pigs per ration	Grain source	Meal Daily gain lbs.	Meal Feed efficiency lbs./cwt.	Pellet Daily gain lbs.	Pellet Feed efficiency lbs./cwt.	Percentage change due to pelleting Daily gain %	Percentage change due to pelleting Feed efficiency %
Conrad (1958)	10	Corn, cob	1.50	407	1.62	385	+ 8	+ 5
Lehrer (1953)	5	25% oats, barley, wheat	1.73	518	1.86	372	+ 8	+28
Hoefer (1958)	10	20% oats, corn	1.47	332	1.65	292	+12	+12
Hoefer (1958)	10	40% oats, corn	1.29	361	1.65	312	+28	+14
Jensen (1959)	5	Oats	1.60	361	1.41	422	-12	-17
Jensen (1959)	5	Oats	1.64	387	1.60	419	- 2	- 8
Jensen (1959)	5	Oats	1.45	383	1.57	420	+ 8	-10
Schneider (1950)	12	Barley, peas	1.56	626	1.68	466	+ 8	+26
Thomas (1953)	90	Barley, wheat, oats	1.23	474	1.35	421	+10	+11
Thomas (1953)	24	Barley, wheat, oats	1.62	413	1.88	345	+16	+16
Dinusson (1952)	10	Barley	1.57	409	1.79	338	+14	+17
Dinusson (1952)	20	Barley	1.40	356	1.58	337	+13	+ 5

TABLE 2--Continued

Reference	No. pigs per ration	Grain source	Meal: Daily gain lbs.	Meal: Feed efficiency lbs./cwt.	Pellet: Daily gain lbs.	Pellet: Feed efficiency lbs./cwt.	Percentage change due to pelleting: Daily gain %	Percentage change due to pelleting: Feed efficiency %
Lehrer (1953)	5	Barley, wheat	1.77	476	1.89	365	+ 7	+23
Lehrer (1953)	5	Barley, wheat, 5% peas	1.66	508	1.88	388	+13	+24
Lehrer (1953)	5	Barley, wheat, 20% peas	1.74	536	1.83	376	+ 5	+30
Dinusson (1956)	NR[a]	Barley	1.39	428	1.46	369	+ 5	+14
Dinusson (1956)	NR[a]	Barley, 15% oat hulls	1.34	521	1.57	400	+17	+23
Dinusson (1958)	10	Barley	1.44	381	1.61	347	+12	+ 9
Jensen (1959)	5	Barley	.98	377	1.20	354	+22	+ 6
Jensen (1959)	5	Barley	.66	388	.97	359	+47	+ 7
Young (1959)	10	Barley	1.62	408	1.63	392	+ 1	+ 4
Larsen (1960)	5	Barley	1.73	392	1.78	343	+ 3	+12
Larsen (1960)	5	Barley, malt	1.69	382	1.78	363	+ 5	+ 5
Steffen (1953)	32	50% wheat, barley	1.68	414	1.78	382	+ 6	+ 8

[a]Not reported

TABLE 2--Continued

Reference	No. pigs per ration	Grain source	Meal		Pellet		Percentage change due to pelleting	
			Daily gain lbs.	Feed efficiency lbs./cwt.	Daily gain lbs.	Feed efficiency lbs./cwt.	Daily gain %	Feed efficiency %
Jensen (1959)	5	Wheat	1.72	338	1.78	313	+ 3	+ 7
Jensen (1959)	5	Wheat	1.76	364	1.72	355	- 2	+ 2
Jensen (1959)	5	Wheat	1.58	339	1.64	329	+ 4	+ 3
Hillier (1959)	16	Milo	1.45	306	1.51	315	+ 4	- 3
Jensen (1959)	5	Milo	1.69	332	1.82	324	+ 8	+ 2
Jensen (1959)	5	Milo	1.74	379	1.76	346	+ 1	+ 9
Jensen (1959)	5	Milo	1.73	334	2.00	322	+16	+ 4
Bohman (1953)	10	50% Alfalfa	1.50	698	1.70	558	+13	+20

1958). However, Jensen et al. (1959a) did not show any improvement in oat rations by pelleting.

Schneider and Brugman (1950), Thomas and Flower (1953), Dinusson et al. (1952, 1956, 1958), Lehrer and Keith (1953), Jensen et al. (1959a), Young and Wingert (1959) and Larson and Oldfield (1960) consistently demonstrated that pelleting improved barley rations for swine. Pelleted barley rations versus the meal form, with and without other cereal grains, increased average daily gain by .14 pound, yet feed intake was about the same. Feed efficiency was improved approximately 55 pounds per 100 pounds bodyweight gain.

Steffen (1953) reported a pelleted wheat and barley ration increased daily gains and saved 32 pounds of feed per 100 pounds gain. Jensen et al. (1959a) calculated a relative feeding value (based on corn) on four different grains in meal and pellet forms. Giving corn a value of 100 for both meal and pellet, they gave values of 97 and 101 for milo, 98 and 99 for wheat, 91 and 85 for oats, and 46 and 61 for barley in meal and pellet forms, respectively. Dinusson and Bolin (1958) and Larson and Oldfield (1960) did not find reground barley pellets to have any advantage over the original meal. Hillier and Martin (1959) did not find that pelleting improved a milo ration.

Bohman et al. (1953) found that a 50 percent alfalfa ration as a meal was unpalatable and inefficient, but pelleting improved the palatability and supported more rapid growth on 140 pounds less feed per hundredweight gain.

The effects of pelleting have been postulated by several authors. Schneider and Brugman (1950) suggested pelleting reduced feed wastage, changed the feed chemically, and that heat improved the nutritive value of the feed. Smith (1957) stated that pelleting increased certainty that pigs receive all dietary essentials by reduction of sorting and rooting out unpalatable ingredients. He also stated that feed wastage was reduced, and that in general, pigs benefit from the effects of partial cooking in the pelleting process, and the partial gelatinization of starches.

Conrad (1958) has stated that "pelleting certain swine rations appears to have some definite advantages, but these advantages are more pronounced with swine rations which contain large amounts of barley, oats or other fibrous feeds, such as alfalfa meal. Effect of pelleting swine rations is largely associated with the fiber portion of the ration. The advantages of pelleting fibrous swine rations are as follows:

1. Increased density -- pelleting the ration allows the pig to eat more, which results in faster gains and improved feed efficiency.
2. Less feed wastage -- pelleting prevents sorting and the pigs 'root' less feed out of the feeder.
3. Greater palatability -- pelleting appears to increase the palatability of fibrous rations."

Conrad continued that, "the main disadvantage of pelleting rations is the added cost incurred through pelleting, and the increased cost of transportation and handling."

In a palatability trial, Young and Wingert (1959) showed that pigs preferred pellets. On a free choice basis, pigs ate 1500 pounds of a pelleted corn ration, 348 pounds of a pelleted barley ration, 177 pounds of a ground corn ration, and 5 pounds of a ground barley ration.

2. RUMINANTS

Workers at Ralston Purina (1959) summarized the literature on meal versus pelleted roughage cattle rations and meal versus pelleted fattening cattle rations (Table 3).

Ralston Purina workers (1959) also summarized their own experiments on meal versus pelleted lamb fattening rations, which is presented in Table 4. They concluded that pelleting increased feed intake with unpalatable, high roughage rations. Feed wastage was reduced, and the animals received a balanced ration. It was suggested that less rumination helped conserve energy. There was no advantage to pelleting fattening beef cattle rations; the rumen seemed to need some coarse roughage to remain normal.

Pope (1959) reviewed the literature on pelleted sheep rations. A summary of the equal feeding trials showed that pelleting increased daily gains 0.058 pound and saved 1.5 pounds of feed per pound bodyweight gain. When data on all lamb feeding trials were compiled, pelleting increased gains 0.065 pound and improved feed efficiency 1.7 pounds per pound bodyweight gain. Feed consumption was the same for meal and pelleted rations.

Murdock and Miller (1951) reported that pelleting a finely ground sheep ration increased digestibility of crude fiber. Blaxter et al. (1956) studied the digestibility and rate of passage of dried grass as long material, medium ground and cubed, and finely ground and cubed when fed to sheep. The cubed grass passed through the digestive tract faster than the long grass. The finely ground cubed grass passed faster than the medium ground and cubed material. Also, the faster passage rates were associated with lower digestibility of the dry matter.

In a later study, Blaxter and Graham (1956) studied the digestibility of dietary cellular components and energy utilization on two levels of feeding. Coarsely chopped, medium ground and cubed, and finely ground and cubed dried grass were fed to sheep. They concluded that high feed intake and cubing medium and finely ground grass increased the rate of

TABLE 3.

PERFORMANCE OF BEEF CATTLE WHEN FED RATIONS AS MEAL AND PELLETS

Type ration	High roughage[a]		Fattening[b]	
Form of ration	Meal	Pellet	Meal	Pellet
No. of lots	17	18	21	22
No. of steers	181	195	230	230
Av. no. of days fed	127	127	122	122
Av. initial weight, lbs.	434	431	679	691
Av. daily gain, lbs.	1.26	1.88	2.50	2.35
Av. daily intake, lbs.	18.00	19.25	24.20	21.90
Av. feed per 100 lbs. gain, lbs.	1251	976	896	872

[a]Includes tests at Illinois, California, Stanford Research Institute, Oklahoma, Georgia, Oregon and Ralston Purina

[b]Includes tests at Illinois, Stanford Research Institute, Washington, Kansas, Wyoming, Purdue, California, Georgia, Oklahoma and Ralston Purina

TABLE 4.

PELLETED COMPLETE RATIONS FOR FATTENING LAMBS

	Meal	Pellet
No. of comparisons	10	10
No. of lambs	229	229
Av. initial weight, lbs.	74	75
Av. daily gain (57 days), lbs.	.48	.53
Av. daily intake, lbs.	3.86	3.95
Av. feed per 100 lbs. gain, lbs.	794	748

passage of ingesta through the digestive tract and reduced the overall digestibility of the energy of the feed. Digestibility of the cell wall constituents was depressed to a greater extent than those of the cell contents. Methane production was lower, due to a lack of extensive fermentation. Fecal losses of energy were considerably greater when the cubes were fed.

Long et al. (1955) compared a lamb ration as natural roughage-grain, ground, and ground and pelleted. Grinding lowered digestibility of dry matter, organic matter, crude protein, crude fiber and nitrogen-free extract, but pelleting the ground ration returned the digestibility to approximately the same as the natural diet.

Lindahl and Davis (1955) stated that pelleting a lamb ration increased ether extract digestibility and lowered crude fiber digestibility. The digestibility of total nutrients was about the same.

Esplin et al. (1957) fed three groups of lambs on a 47.5 percent ground corn, 47.5 percent ground alfalfa meal, and 5 percent molasses ration as meal and pellets. The first group was pair-fed on an equal intake, the second group was individually penned, but fed ad libitum, and the third group compared the meal and pellets by group feeding. The lambs fed an equal amount of feed gained the same. Gains, feed consumption, and feed efficiency were the same for the individually ad libitum-fed lambs. The pellet group-fed lambs gained .07 of a pound faster, which was significant. Apparent digestibility between pelleted and unpelleted feed for dry matter, ether extract, crude fiber and nitrogen-free extract was the same for all three groups. Nitrogen balance was not different between the two physical forms.

Smith (1958) summarized a number of pelleting experiments and concluded that the increased rate of gain associated with pelleting was

best explained on the basis of a greater intake of total feed. Net energy appeared unaffected.

Meyer et al. (1959) reported that with pair-fed lambs the digestibility of lignin and holocellulose of alfalfa hay was not greatly influenced by pelleting, but nitrogen digestibility was higher with the pelleted hay. Total digestible nutrients and digestible, metabolizable and net energy were not significantly different between the pelleted and chopped hay. They postulated that increased gains were due to increased feed intake. A faster passage of ingesta from the reticulo-rumen seemed to be responsible for this increased feed intake. This, in turn, was due to a faster rate of holocellulose digestion by the rumen microorganisms as indicated by the lignin-holocellulose ratios and in vitro fatty acid production by the rumen contents. An increase in the nitrogen content occurred in the small intestine. The abomasum nitrogen passage was calculated as 10.7 and 14.6 grams nitrogen, and the small intestine passage was 21.4 and 22.6 grams nitrogen for the chopped hay and pelleted hay, respectively. Yet only 5.3 and 5.4 grams of nitrogen were excreted in the feces of these animals. They said this increase was due to enzymes and other intestinal secretions. Also, the mixing of endogenous, microbial and food nitrogen could possibly be a large factor in the overall nitrogen and amino acid economy of the body.

Weir et al. (1959) designed a lamb digestion trial to study alfalfa in chopped and pelleted forms with and without added barley. Protein digestibility was about the same. Fiber digestibility was lowered by pelleting, particularly when barley was included in the ration. Pelleting did not affect the total digestible nutrient content of the rations.

3. POULTRY

After reviewing the literature, Smith (1957) stated that pelleting rations significantly increased growth rate and improved feed efficiency. Significant growth responses were noted in both high-energy and low-energy rations. When pellets were crumbled, the growth response was nearly as great as it was with whole pellets. He suggested the grain portion of the ration was benefited more by pelleting than other ingredients.

The importance of density as related to pelleted poultry rations is not clear. Allred et al. (1956, 1957a, 1957b) suggested that growth response was due to increased density and a chemical change in the feed ingredients. Neither steaming, autoclaving, nor water soaking improved growth response over the untreated corn.

Pepper et al. (1960) reported that pelleting, in general, resulted in significant growth improvement, but was greatest at low fat levels, and improvement declined as fat level increased.

Bearse et al. (1952) found that pelleting increased growth rate with rations containing 8, 13 and 18 percent fiber. The difference between mash and pellets became more marked as the fiber level increased. Feed efficiency was improved the most at high fiber levels by pelleting.

Dymsza et al. (1957) investigated turkey rations with reference to energy level, fiber level, meal and pellets. Pelleting increased growth with rations containing less than 639 Calories per pound and more than 10 percent fiber. As the level of fiber decreased and the energy per unit of feed increased, the advantage of pelleting was less.

Hinds and Scott (1958) found pelleting improved growth response when the corn fraction of practical-type rations was pelleted, yet no greater growth response occurred on a corn-fraction pelleted semi-purified diet. Growth response disappeared when the corn was soaked. Pelleting benefits were less as the chickens became older. They postulated the inhibitory factor effect in corn may also be in other parts of the ration and possibly pelleting improved availability of a nutrient or nutrients in corn. Pelleting the corn fraction only changed the density of corn by 10 grams per liter. Therefore, density was not considered as an important factor in pelleting poultry rations.

C. Effect of pelleting on nutrients.

Wornick (1959) surveyed the feed industry to determine the pellet mill conditions and pelleting effect upon micro-ingredients. In reply to a questionnaire, feed manufacturers stated that on an average, maximum moisture added to mash during conditioning was 4.9 percent (1.5 to 10 percent range). Minimum average was 1.3 percent (0 to 5 percent range). It was theorized that increasing the moisture content of feed products, by steaming or otherwise, will accelerate the decomposition of sensitive micro-ingredients. High production rates and rapid moisture removal from cooled pellets probably do not prevent decomposition since the moisture adsorption and dissolution of additive particles are believed to be irreversible. Pelleting temperatures were reported as:

TABLE 5.

TEMPERATURES DURING PELLETING

	Maximum		Minimum	
Location	Av. °F	Range °F	Av. °F	Range °F
Instantaneous in die, estimated	242	170-600	---	---
Steamed mash	183	120-250	113	RT[a]-160
Hot pellets	199	140-400	143	100-185

[a]Room temperature

A leading pellet mill manufacturer reported temperatures exceeded 350°F inside the die. Little was known concerning the instantaneous maximum pressures exerted in the die during feed pelleting. Pellet mill manufacturers varied widely on the subject, reporting values from 1,000 to 40,000 pounds per square inch.

Wornick stated that animal fats, seed-coatings and several micro-ingredients melt when pelleted. Data were presented to show that vitamin A was not only partly destroyed by pelleting, but retention upon storage may not be better than meal. The entire fat-soluble vitamin group was sensitive to oxidation, temperature, moisture, minerals, etc. Consequently, all fat-soluble vitamins were probably decomposed equally as much or more than vitamin A. Vitamin K as menadione and its bisulfite derivative, was known to be very easily destroyed by heat. Water-soluble vitamins vary widely in feed and pellet stability.

Reported effects of pelleting on antibiotic stability are variable. By microbiological technique, Stokstad et al. (1952) have shown that pelleting destroys commercial aureomycin, procaine penicillin and diamine penicillin by 15, 45 and 47 percent, respectively. Blakely et al. (1952) found procaine penicillin to be entirely stable to pelleting when measured by poult growth. McGinnis and Stern (1953) reported that the effect of aureomycin was improved by pelleting as measured by more poult growth response. No differences were noted with diamine penicillin or procaine penicillin. The results with aureomycin disagreed with Stokstad's findings.

Dinusson and Bolin (1958), Lindahl and Reynolds (1959), Jensen et al. (1959a) and Larson and Oldfield (1960) reported that pelleting lowered the crude fiber fraction as measured by proximate analysis. Larson and Oldfield stated further that the decrease in fiber was primarily due to a decrease in cellulose; however, it was not associated with increases in either reducing sugar or total soluble carbohydrates, except for a slight increase of reducing sugar in corn rations. The lowering of fiber was likely due to a breakdown of fibrous components of the ration, allowing for their more extensive solution during laboratory digestion. However, it was thought that these changes were small in magnitude and of doubtful nutritional significance. They found the primary benefit of pelleting a barley ration to be reduction of feed wastage. In laboratory studies Jensen et al. (1959c) found that starch in pelleted corn to be more susceptible to malt amylase digestion than starch in regular ground corn.

Smith (1957) suggested possible chemical change in the pelleting process. He stated their tests indicated that an adequate steam conditioning capacity in the pellet mill, plus the heat and pressure engendered in the pelleting process itself, did partially gelatinize the starches in grains. He thought the degree of gelatinization obtainable was significant, and that this partial gelatinization made the grain portion of the ration more easily digested than when grains were fed in a non-pelleted form.

Perkas (1959) has studied the stability of enzymes to pelleting. The losses due to pelleting ranged between 7.5 percent and 47.4 percent. The results are reported in Table 6.

D. Effects of artificial drying on the nutritive value of corn.

Several scientists have studied the effects of artificially drying corn on its nutritive value. Adams et al. (1943) found that drying temperatures of 160°F to 190°F decreased fermentable carbohydrate yield by 2 to 3 percent. Simms (1949) reported that drying temperatures as high as 190°F for 10 hours did not significantly reduce feeding value of corn. Cerniani (1951a) concluded that thermal decomposition of corn, rice, corn and potato starch started at 100°C. Weight losses became increasingly

TABLE 6.

STABILITY OF ENZYMES TO PELLETING[a]

Enzyme	Percent added to ration	Recovered by assay: Meal	Recovered by assay: Pellet	Loss during pelleting %	Assay method
Pancreatin	0.50	0.57	0.30	47.4	Disc-plate
Pabst L-297	0.25	0.26	0.21	19.2	Disc-plate
Pabst L-56-D	0.125	0.17	0.13	23.5	Disc-plate
Pepsin	0.25	0.24	0.17	29.2	Milk clot
Protease-30	0.50	0.53	0.39	26.4	Disc-plate
Protease-31	0.50	0.51	0.42	17.6	Disc-plate
Rhozyme B-6	0.50	0.52	0.33	37.0	Disc-plate
	0.50	0.40[b]	0.37	7.5	Gelatin-viscosity
		0.47	0.28	40.4	Disc-plate
	1.00	0.80	0.67	16.2	Gelatin viscosity
		1.00	0.55	45.0	Disc-plate
Rhozyme P-11	0.50	0.31	0.24	22.6	Disc-plate
	0.50	0.39	0.36	7.7	Gelatin viscosity
		0.40	0.28	30.0	Disc-plate
	1.00	0.83	0.76	8.4	Gelatin viscosity
		0.64	0.44	31.2	Disc-plate

[a]Pelleted by California Pelleting Mill, die 3/16 x 1 3/4"; temperature of pellets after coming from die to 160°C.

[b]) Indicates two values are from same sample of diet.

greater as temperatures were increased above 170°C. Weight losses up to 200°C were due to elimination of carbon dioxide. Prolonged heating at 200°C in the presence of air caused roasting and subsequent starch carbonization. Maximum dextrinization in corn and rice occurred, respectively, at 170°C (84.47 percent) and 180°C (77.34 percent).

Gausman et al. (1952) found that artificially drying excessively high moisture corn at either 180°F or 130°F reduced its niacin, pantothenic acid, riboflavin, pyridoxine, total sugar and starch content. However, if the moisture content was 40 percent or lower, there was only a small loss of these constituents.

Hathaway et al. (1952) artificially dried 27 percent corn to 14 percent by 80°, 120°, 140°, 160°, 180°, 200° and 240°F temperatures. Proximate analysis did not reveal changes in percent ash, fat, protein, nitrogen-free extract or crude fiber. Heat damage was observed at 200°F and 240°F. Rat growth tended to be reduced when corn was dried above 140°F. It was thought protein nutritive value was adversely affected at 160°F and above. David and Cabell (1957) reported drying temperatures above 135°F decreased protein nutritive value as measured by rat growth. In a subsequent report (1958) they found corn protein nutritive value was not affected if dried four hours at 198°F. One and one-half hours drying time at 240°F did not damage corn, but drying at 280°F caused a marked discoloration, parched corn odor and lowered protein nutritive value. McGuire and Earle (1958) concluded that drying temperatures from 120°F through a range to 200°F caused increased denaturation or some physical change in the protein. These conclusions were based on the solubility of proteins in water and in 0.01 N potassium hydroxide solutions at 75° ± 5°F. Solubility decreased with higher temperatures. Bonzer et al. (1958) found broilers grew equally well on 100°F,

190°F, 200°F artificially dried, and naturally dried corn. Jensen et al. (1960) studied the nutritive value of corn dried at 140°F, 180°F and 220°F. While organic solubles apparently were not affected, the starch became slightly less susceptible to malt amylase digestion. Temperature did not affect total content of riboflavin, niacin or carotene. However, pantothenic acid values were 2.58, 2.40 and 2.31 milligrams per pound, respectively, as the temperature increased. Drying at 240°F increased ether extract and crude fiber values.

E. Cooking and heat effects on nutrients.

Mitchell et al. (1949) cooked cut corn from 20 to 45 minutes at 45 to 50 pounds pressure, then toasted at 350°F to 400°F for 3 to 4 minutes. Average digestible protein of the pre-toasted corn and toasted corn was 90 and 75.8 percent, respectively. However, in another trial the protein digestibility increased from 73.8 to 79.8 percent. Average biological value dropped from 59.6 to 56.4 percent. Kurelec and Barabás (1950) reported pig gains were the same when fed either cooked or uncooked corn.

The effect of processing on breakfast cereals has been studied by Murlin and others. In 1938 Murlin found that egg replacement value of torn wheat, flaked wheat and inflated wheat, was 92.8, 82.1 and 79.8 percent, respectively. The processes used to make these three wheats were, respectively, (1) steam cooked under pressure, (2) steamed cooked at 220°F then heated 450°F for one minute, and (3) steamed cooked under pressure then heated 350°F for seven minutes. Comparisons of true digestibility proved that heat decreased the availability of nutrients for metabolism.

Ross *et al*. (1941) reported digestibility of starch by enzymes was significantly different in pablum, rolled oats, quick oats, farina and meads cereal. Finer grinding cracked wheat improved the digestibility of starch.

Stewart *et al*. (1943) studied the effect of processed oat cereals upon rat growth. Conditions for four cereals were: (1) boiling point of water for fifteen minutes, then dried fifteen seconds at 130°C, (2) same as (1) except dried one to two minutes at 200°C, (3) processed at 190°C to 232°C for 5½ to 6½ minutes at 80 to 100 pounds pressure, then released the pressure to explode, and (4) heated 122°C for five minutes, then live steam at 198°C with 200 pounds pressure for two minutes. All except the third process had equivalent growth rate to rolled oat-fed rats. Oser (1952) reported that heat processing affected most of the proteins and thiamine. A smaller effect was noted on carbohydrates, fats, inorganic salts, ascorbic acid, pantothenic acid, vitamin A and vitamin E. Other vitamins were apparently stable to heat.

Cerniani (1951b) studied the effects of heat on the decomposition of glucose, sucrose and lactose. Eleven samples of each carbohydrate were placed in a 100°C oven. At the end of 12 hours a sample was removed and weighed. Then the oven was turned up 10°C and repeated after 12 hours. This was continued for 132 hours to 200°C. Total weight losses were 21, 33.6 and 26 percent, respectively. A sharp break at 140°C was noted and indicated sudden decomposition.

Frazier *et al*. (1953) observed that dry heating of fibrin at 160°C to 210°C with cornstarch, sucrose, glucose or fructose caused considerable nutritional damage as determined by rat feeding tests. The loss in protein quality produced in dry heating fibrin at 210°C was not restored with various combinations of essential amino acids. All nine essential amino acids were necessary to restore quality.

Heintze (1955) reported 0.5 to 1 percent deamination of glycine, glutamic acid, valine, leucine, isoleucine, lysine, histidine and methionine by heating in 15 percent hydrochloric acid at 112°C to 179°C under pressure. Addition of 25 milligram percent of sucrose increased decomposition to 2 percent. Up to 47 percent of cystine, cysteine, serine and arginine was decomposed. Block et al. (1946) fed rats an experimental human diet which had been made into a cake. This diet was fed as non-toasted and toasted at 100°C to 130°C. The rats just maintained weight on the toasted, but when .63 percent of lysine was added, the rats responded normally. They concluded lysine was susceptible to heat damage. Kuether and Myers (1948) reported no effect on lysine by explosion of cereal as measured by nitrogen balance with human subjects.

Studies by Krehl et al. (1945) suggested that corn diets increased the requirement for niacin. A later study by associates of Krehl (Henderson et al., 1947) showed that the replacement of raw starch with dextrinized starch eliminated the requirement for niacin. Streightoff et al. (1949) reported losses of vitamins from corn by boiling. Corn (1) boiled 30 minutes, (2) boiled 30 minutes then held over boiling water for one hour, (3) steamed at atmospheric pressure for 30 minutes yielded, respectively, 80, 81, and 85 percent thiamine, 97, 97, and 101 percent riboflavin, 87, 87, and 103 percent niacin, and 63, 58, and 64 percent vitamin C of the uncooked corn. Boiling caused riboflavin and niacin to leach into the water, while thiamine and vitamin C were destroyed. Laguna and Carpenter (1951) have shown that lime cooked corn enhances the availability of niacin. Also, wetting a normally pellagragenic raw diet improved rat growth. By replacing certain fractions of corn, it was

found that gluten, germ, and feed meal (the non-starchy portions) produced the same benefit as lime water treatment.

Research by Pellett and Platt (1956) did not agree with some of the previous work. They reported that lime cooked corn depressed rat growth rate. Supplementation with a B complex vitamin mixture improved growth response. The addition of riboflavin produced a response which was equivalent to the B complex addition. Thiamine fortification was not beneficial. Chemical and biological assays showed a great decrease in thiamine, riboflavin and niacin content; however, the remaining niacin was thought to be more available.

It has been proposed by Kodicek (1956) that niacin of cereals may be in an alkali-labile bound form that differs from the known nicotinoyl derivatives. They found that corn has 73 percent of its total niacin in hominy and bran. Hydrolysis with 0.5 N NaOH freed the bound form of niacin.

Pearson _et al_. (1957) agreed with previous work that niacin in corn is in a bound form. Niacin improved a raw corn diet, but did not help a cooked corn diet. The authors concluded by using paper chromatographic technique that niacin was 100 percent bound in raw corn, but 100 percent free in cooked corn. Also, the cooking process may have destroyed some niacin, but the remaining niacin was available for metabolism.

Griswold (1951) reviewed the literature extensively on the effect of heat upon the nutritive value of proteins. The following reviews have been cited from Dr. Griswold's article. Hayward _et al_. (1936a) showed that soybean digestibility and biological value were improved by 3 and 12 percent, respectively, when heated by a commercial soybean meal process. Mitchell and Smuts (1932) found that raw soybeans were deficient in cystine. Hayward _et al_. (1936b) showed that cystine supplementation did not improve a cooked soybean rat diet, but did improve a raw soybean rat diet. These authors hypothesized that cystine became available when raw soybeans were cooked. Later, Johnson et al. (1939) found that while sulfur absorption was the same for raw and cooked soybeans, the retention was about 2.5 times more with the cooked beans. A similar trend was noted with nitrogen. These authors concluded a sulfur-nitrogen complex existed in the raw soybean. This complex was not available for metabolism. Hayward and Hafner (1941) stated that raw soybeans were deficient in methionine. Cooking improved the availability of methionine, but a supplemental source of methionine supported more rat growth. Ham and Sandstedt (1944), Bowman (1944, 1945, 1946, 1948) and others showed that raw soybeans contained one to several anti-tryptic factors, which lowered the biological value of raw soybeans. Heating rendered these anti-tryptic factors inactive, resulting in a higher biological value. While a proper degree of heat improved the nutritive value of soybeans, Bird and Burkhardt (1943), Parsons (1943) and Evans and McGinnis (1946) showed that excessive heat, such as autoclaving above 120°C, lowered the nutritive value. Certain amino acid deficiencies were noted with excessive heating. Methionine, cystine and lysine deficiencies have been reported by McGinnis and Evans (1947) and leucine by Klose et al. (1948). It has been suggested by Riesen et al. (1947) and Patton et al. (1948) and others that a complex occurs between the aldehyde group of sugar and a free nitrogen group of an amino acid. Lysine, arginine or tryptophan are possibly involved in these complexes.

Melnick and Oser (1949) stated in a summary of a number of papers on the effect of heat on proteins that heat had a great effect on the nutritive value of the protein without affecting the total protein content, essential amino acid composition, or protein digestibility. They showed with heat processed proteins that the rate of enzymatic liberation of the amino acids, rather than the degree of amino acid availability, was of critical importance for proper metabolism. They suggested as a hypothesis that it was important to have amino acids liberated during digestion at rates permitting mutual supplementation. Heat processing influenced the relative rate of liberation of amino acids.

Geiger (1947) has shown that incomplete amino acid mixtures which lack an essential amino acid cannot be used for protein synthesis. Experiments with lysine, methionine and tryptophan suggested that essential amino acids must be present simultaneously in order to build protein tissue from absorbed amino acids.

Callison (1948) found that addition of moisture when cooking soy grits at boiling temperature improved the biological value. With little moisture, longer cooking helped. Also, while 50 percent of thiamine was destroyed, neither riboflavin nor nicotinic acid were affected by 60 minute cooking.

Kähler (1948) reported that untreated soybeans contained a saponin which was responsible for a bitter taste. Hydrolysis, hydrothermal treatment, or infrared radiation destroyed this taste. Steaming at not more than 100°C destroyed methyl n-monyl ketone and diacetone alcohol, which were responsible for bad odors and flavors of crude soybean preparations. Steam also destroyed peroxidases and other enzymes responsible for rancidity and for destruction of fat-soluble vitamins.

Mann and Briggs (1950) showed heating soybeans altered protein peaks on electrophoretic patterns. Because several small peaks changed to one large peak, amino acid interaction and denaturation were suggested.

Carroll _et al_. (1952) discovered the site of nitrogen absorption to be different in raw and processed soybean meal. The mean digestibility coefficient of material from the terminal end of the small intestine was

32.65 ± 13.53 and 78.66 ± 3.08, but the fecal digestion coefficients were 76.96 ± 1.23 and 81.70 ± 1.23 percent for the raw and processed meals, respectively. Therefore, processing accelerated the rate of digestion and significantly increased digestibility. The pH of the intestinal contents was the same for the two groups.

In 1931 Morgan stated that she was not aware of any experiment indicating a decrease in protein digestibility due to either moist or dry heat. She tested heat treated cereal proteins and casein, and reported protein digestibility did not change. However, a nitrogen loss was noted in the urine and it was concluded that though absorbed, some nitrogen was not available for tissue metabolism.

Greaves *et al*. (1934, 1938) and Block (1934) found that casein heated above 140°C lowered the biological value and possibly altered lysine structure. Chemical analysis of heated casein detected no decrease in total lysine content, yet 0.2 percent supplemental lysine overcame the deficiency when measured by rat growth. Eldred and Rodney (1946) conducted *in vitro* digestion studies on raw and heated casein. Using combined crystalline pepsin, trypsin and chymotrypsin, the degree of digestion did not differ between the raw and heated. Available lysine, as determined by the specific enzyme lysine decarboxylase, was appreciably less in the heated casein.

Aughey and Daniel (1940), Lincoln *et al*. (1944), Eklund and Goddard (1945) and Pai *et al*. (1957) agreed that cooking of cereal and other foods had little effect on thiamine content.

Cheldelin *et al*. (1943) measured the losses of certain B vitamins after cooking thirty different foods. The degree of loss was slight for riboflavin and niacin, moderate for pantothenic acid, and extensive for inositol and folic acid.

Evans and Butts (1951) concluded that autoclaving soybean meal for 4 hours at 15 pounds steam pressure per square inch inactivated basic amino acids and tryptophan in three different ways. The types of inactivation were: (1) protein-bound amino acids react with glucose or sucrose to destroy biological activity of the amino acids, (2) protein-bound amino acids react with some other constituent of the protein to form a linkage, which was resistant to _in vitro_ digestion with trypsin and erepsin but not to acid hydrolysis, and (3) protein-bound amino acids react with sucrose or glucose to form a linkage similar to the linkage in type two. Inactivation of lysine was of types 1 and 2, arginine of types 2 and 3, histidine of types 1, 2 and 3, tryptophan of types 2 and 3. Lysine was inactivated most severely, while histidine and tryptophan were affected to a lesser extent.

Pronin and Dakh (1952) observed that B-amylase activity of flour declined as heating temperatures were increased. A 5 percent flour extract heated to 42°C, 68°C and 72°C formed 71, 51 and 16 milligrams of maltose from starch the first minute and 186, 186 and 16 milligrams during the first 15 minutes, respectively. It was postulated that a change in the B-amylase molecule occurred, thereby slowing the formation of the enzyme-substrate complex. This decreased the initial yield, but in time the enzyme became saturated with the substrate, so that the total yield remained the same. Higher heat inactivated the enzyme and resulted in poor yields.

F. <u>Effects of processing on the cellular structure of cereal grains.</u>

Wolf _et al_. (1952, 1958), Cannon _et al_. (1952), and MacMasters _et al_. (1957) reviewed the gross anatomy, microscopic structure and chemical composition of mature corn. Wolf _et al_. (1952) stated the endosperm was

surrounded by an aleurone layer, which varied in thickness from 11 to 50 microns. Since there were no intercellular spaces in this layer, water and dissolved substances must diffuse through the cell walls before reaching the starch parenchyma cells. The cells of the starchy endosperm were elongate in shape. Most of the cells were arranged roughly end-to-end, their long axes radiating in all directions from the vertical fissure under the dent in the upper part of the endosperm. Average cell thickness was 1 to 1.1 microns in the horny endosperm and 1.27 to 1.3 microns in the floury endosperm. It was stated by the authors that some structural stress was apparent, which was thought to be caused by rapid growth. Within the cells, the starch granules were embedded in a proteinaceous matrix. This matrix was loose in the floury portion of the endosperm, but dense and well developed in the outer horny endosperm.

Cannon et al. (1952) reviewed the literature on the chemical composition of the mature corn kernel. They cite the work of Porst (1912) who stated the average pentosan content of corn was 5.77 percent of the total, and of this 48.62 percent was in the hull, 1.69 percent in the endosperm and 8.38 percent in the germ.

Rothman and Polak (1941) found the structure of several cereal foods changed after cooking. Photomicrographs revealed that the endosperm was broken down, which the germ was resistant to structural change due to cooking. The cells of the kernel covering shrank and vacuolized after prolonged cooking.

Personnel at Central Soya Company, Inc. (1958) postulated that their solvent extraction process "exploded" the cellular structure inside each soybean flake, thus releasing the protein and rendering it more available. Photomicrographs illustrated the breakdown of the cellular structure.

G. Digestibility and food passage studies with pigs.

Castle and Castle (1956) studied the digestibility of a ration consisting of wheating (45%), barley meal (30%), flaked corn (14.5%), fish-meal (7.5%), lucerne meal (2.5%) and vitamin A and D (.5%), and determined the rate of passage through the alimentary tract of pigs. Using four pigs, the mean 5 percent excretion times were 20.3 and 21.5 hours (standard error ± 0.3, range 11 to 26 hours), respectively, for the A.M. and P.M. feedings. Means for the 95 percent excretion time were 52.3 and 53.5 hours (standard error ± 0.9, range 42 to 83 hours), respectively, for the A.M. and P.M. feedings. There was no marked trend with age and increasing weight.

By subtracting the 5 percent from the 95 percent excretion time, the time over which most of the ingesta was excreted was determined. These values were 32.0 and 31.5 hours (standard error ± 0.9) for the A.M. and P.M. feedings. Mean ingesta retention times were 33.1 and 35.2 hours (standard error ± 0.4) for the A.M. and P.M. feedings. Mean retention times, A.M. only, were correlated with the pig's live weight, digestibility of dry-matter of the ration, and the mean weighed dry-matter content of the feces. These correlations were ± 0.233, -0.019 and ± 0.228, respectively. None were statistically significant.

In a later report (1957) these authors used the same techniques to study the effect of (1) level of feeding, (2) amount of water, (3) fixed water and variable amounts of feed, and (4) rations with different crude fiber on the rate of food passage and percent digestibility of dry matter and crude protein.

In Experiment 1, these investigators found that a one-half normal feeding significantly slowed down food passage rate, while 1½ or 2 times normal significantly increased food passage rate. The dry matter content of the feces and the digestibility of dry matter were significantly different ($P < 0.05$) between the two extremes in feeding level. High feed intake decreased the fecal dry matter content, and increased the dry matter digestibility. Digestible protein was not altered. In this experiment water and feed were held in a constant ratio of 2¼:1 pound.

In Experiment 2, the ranges in water feeding were 2¼ (which was considered normal), 1½, 3 and 3 3/4 pounds per one pound of meal. Results of a low level feeding were the same as the normal; however, the high levels of feeding water significantly increased food passage rate. The percent dry matter in the feces, digestible dry matter and digestible protein were not altered by the various levels.

In Experiment 3, the water was held constant, and the ration fed at two levels, namely, 0.6 times normal and 1.5 times normal. Mean retention values were 35.0 hours and 23.2 hours for the low and high feeding levels, respectively. This was a difference of 11.8 hours which was significant at the $P < 0.02$ level. The fecal dry matter content, digestible dry matter and the digestible protein were the same.

In Experiment 4, normal and high fiber rations were compared. One ration had 5.6 percent crude fiber and the other ration 10.9 crude fiber. The rate of food passage for these two rations was the same. The percent dry matter in the feces was significantly higher with the high fiber-fed pigs. Dry matter, nitrogen-free extract and crude fiber digestibility coefficients were significantly lower for the high fiber-fed pigs. Digestibility coefficients for crude protein and ether extract were not significantly different between the two rations.

III. EXPERIMENTAL PROCEDURE

A. Introduction

The objectives of these experiments have been to study and evaluate the effects of pelleting on three different swine rations. The test rations were formulated to compare three fiber levels. This investigation consisted of nine experiments:

Experiment 1. Pigs ad libitum-fed three test rations in meal and pellet forms.

Experiment 2. Rats ad libitum-fed three test rations in meal and pellet forms.

Experiment 3. Palatability study -- high corn rations.

Experiment 4. Performance of paired pigs -- equally fed to 180-200 pounds bodyweight, then ad libitum fed to heavier weights.

Experiment 5. Apparent digestible energy studies with equal and ad libitum feeding.

Experiment 6. Apparent digestible nitrogen studies with equal and ad libitum feeding.

Experiment 7. Rate of food passage studies with equal and ad libitum feeding.

Experiment 8. Double reversal studies with paired pigs.

Experiment 9. Rat performance when fed processed corn.

It was hypothesized that the first ad libitum feeding experiment would provide information pertaining to the expected performance of pigs when fed with normal feed lot conditions. Subsequent experiments were conducted to provide explanations for differences observed in the ad libitum feeding experiment.

B. Experiment 1. Pigs ad libitum-fed three test rations in meal and pellet forms.

The three test rations were (1) fortified corn-soybean meal, (2) 20% oats by weight replacing corn, and (3) 40% oats by weight replacing corn. For convenience, hereafter these rations will be designated as high corn, 20% oats and 40% oats. The ingredient composition of these rations is listed in Table 7. Each ration was prepared as high protein and low protein. When pigs averaged 125 pounds bodyweight, the high protein ration was replaced by the low protein ration (based on the National Research Council's protein requirements for swine). One-half of the meal rations were made into 3/16 inch pellets by a California pelleting mill. Steam was used to condition the meal before pelleting. Proximate analysis of the six high protein rations is shown in Table 8. Analytical determinations were done in accordance with the A.O.A.C. methods (1950).

Sixty thrifty weanling Duroc, Hampshire-Chester White and Hampshire-Duroc crossbred pigs were grouped into six uniform lots. The pigs were allotted on the basis of genetic relation, weight, sex and general appearance. During the early phase of the experiment the pigs were vaccinated for hog cholera, wormed with piperazine and sprayed with lindane for external parasites. Facilities for each pen included a portable sleeping house with ajoining concrete slab, automatic waterer and a six compartment self-feeder. Feeders were checked often to insure proper plate setting. All pigs were weighed individually every two weeks. Feed placed in the self-feeders was weighed and recorded, and feed weigh backs

TABLE 7.

INGREDIENT COMPOSITION OF RATIONS[a]

Ingredient	High corn High %	High corn Low[b] %	20% oats High %	20% oats Low %	40% oats High %	40% oats Low %
Corn[c]	77.25	85.25	58.75	67.75	40.25	49.25
Oats[c]	---	---	20.00	20.00	40.00	40.00
Soybean meal (44%)	16.00	7.00	14.50	5.50	13.00	4.00
Meat and bone scraps (50%)	2.00	2.00	2.00	2.00	2.00	2.00
Fishmeal (60%)	1.00	1.00	1.00	1.00	1.00	1.00
Alfalfa meal (17%)	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	0.70	0.70	0.70	0.70	0.70	0.70
Dicalcium phosphate	0.30	0.30	0.30	0.30	0.30	0.30
Trace mineral salt (0.5% zinc)	0.50	0.50	0.50	0.50	0.50	0.50
Trace mineral (CCC - swine)	0.025	0.025	0.025	0.025	0.025	0.025
B vitamin mix (Merck 58C)	0.10	0.10	0.10	0.10	0.10	0.10
Vitamin A and D mix[d]	0.025	0.025	0.025	0.025	0.025	0.025
Vitamin B_{12} (Pfizer 9 plus)	0.05	0.05	0.05	0.05	0.05	0.05
Aurofac 10	0.05	0.05	0.05	0.05	0.05	0.05

[a]Ration cost (per cwt.): High corn - meal $2.86 pellet $3.11
20% oats - meal $2.83 pellet $3.08
40% oats - meal $2.80 pellet $3.05
Ration costs included $5.00 per ton for pelleting in addition to $2.00 per ton for grinding and mixing.

[b]High was approximately 17% crude protein. Low was approximately 13% crude protein.

[c]Corn and oats were ground through an 1/8 inch screen.

[d]Vitamin A and D supplement supplied 1000 USP units A and 300 USP units of D per pound of ration.

TABLE 8.

PROXIMATE ANALYSIS OF HIGH PROTEIN RATIONS

		H_2O %	Ether extract %	Crude fiber %	Crude protein %	Ash %	Nitrogen-free extract %
High corn[a]	Meal	13.21	3.72	3.00	18.38	4.09	57.60
	Pellet	12.98	3.77	3.07	18.13	4.07	57.98
20% oats	Meal	11.92	4.01	5.07	17.63	4.26	57.11
	Pellet	12.07	3.84	4.70	17.44	4.26	57.69
40% oats	Meal	11.10	3.79	7.71	17.38	4.66	55.36
	Pellet	10.80	4.00	7.39	17.00	4.44	56.37

[a]High corn ration analyzed 0.56 percent calcium, 0.53 percent phosphorus and 99.20 parts per million zinc.

followed the weighing of the pigs. As the pigs individually reached 210 pounds, they were sacrificed and the carcasses were evaluated by conventional methods.

C. <u>Experiment 2. Rats ad libitum-fed three test rations in meal and pellet forms.</u>

This experiment was designed to measure rat performance when the test rations were fed as meal, pellets and reground pellets. The hypothesis was that the reground pelleted rations would provide more information pertaining to the nutritive value of pelleted feed. Criteria used were: (1) growth rate, (2) feed intake, (3) feed efficiency, (4) ration palatability, and (5) ration density as related to feed intake.

Ninety individually-fed rats were fed the three high protein test rations as reported in Table 7. Five weanling male and five female rats were assigned at random to each treatment with the stipulation that a male and a female rat must be caged on each tier and on opposite sides of the rack. The rats were caged in two 60 cage racks. The rats were weighed weekly for four consecutive weeks. Water and feed were fed ad libitum.

D. Experiment 3. Palatability study -- high corn ration.

This experiment was initiated to study the palatability of the high corn ration. Smith (1957) and others stated that pigs prefer to eat the pelleted ration. Conrad (1958) observed that pelleting improved consumption of high fiber rations, and attributed the increased feed intake to improved palatability.

A group of pigs was offered the following three forms of the corn ration, each in a separate self-feeder: a meal, a pellet, and a reground pellet. The location of the feeders was alternated daily to avoid habit in feeder selection.

E. Experiment 4. Performance of paired pigs -- equally fed to 180-200 pounds bodyweight, then ad libitum fed to heavier weights.

Six replicate pairs of pigs were used in this experiment for each of the three test rations. The pigs were paired on the basis of genetic relation, weight, age, sex and general appearance. Pigs were fed individually in a 20' x 24' Doane-type house which has twelve 3' x 8' pens. Feed was provided twice daily, at 8:00 A.M. and 4:30 P.M. During the equal feed intake phase, the amount of feed provided at each feeding was based on the consumption of the pig eating the lesser amount of feed. Therefore, one pig was near maximum intake at all times while the other pig probably was receiving somewhat less than maximum desired feed intake. Feed weights were not taken at each feeding. Instead, 20 pounds of feed were weighed into a can and recorded. Each feeding was simply a volume measurement. Care was taken to insure that the cans provided for the pair emptied at a uniform rate. Single compartment feeders

with a deep cup were used in order to minimize feed wastage. Water was provided ad libitum in Jamesway steel hog pans. The pigs were weighed every two weeks, and feed consumption for the two week period was determined. This routine continued until the pigs weighed between 180 and 200 pounds; at this weight they were ad libitum fed to the end of the trial.

F. Experiment 5. Apparent digestible energy studies with equal and ad libitum feeding.

The same pair-fed pigs used for Experiment 4 were utilized in this experiment. Three weeks before the end of the equal feeding trial, these pigs were transferred to another barn where each pig was confined to an 8' x 8' pen. It was not necessary to alter feeding and management practices for this study. Accurate daily feed records were kept prior to the start of the equal feeding digestion trial in order to establish the best level of feeding. During the ad libitum feeding digestion trials, the pigs were fed twice daily, but the quantity fed always exceeded the amount the pig could consume before the next feeding.

In the initial feeding of each trial, ferric oxide was utilized for the purpose of marking the beginning of the fecal collection period. The appearance of red color in the feces marked the start of fecal collection. After five days, ferric oxide was again added to the ration; fecal collections were terminated at the appearance of the red color.

During the digestion trial, weight records were kept on feed consumed and feces excreted. Feed samples were collected at each feeding for analysis. Four fecal collections were made daily--8:00 A.M., 1:00 P.M., 5:00 P.M. and 11 P.M. After recording the weight of the fecal material, it was thoroughly mixed, and approximately a 10 percent aliquot was taken for analysis. The aliquots were put into a jar, sealed and stored at 5°C. After the five day collection period, the fecal samples were dried in a 100°C oven for the purpose of dry matter and energy determinations. Prior to the energy determinations, the dried fecal samples were finely ground in a Wiley mill, then thoroughly mixed.

Feed and fecal samples were analyzed for energy in a Paar plain jacket oxygen bomb calorimeter. Procedure followed was in accordance with the bomb calorimeter instruction manual.

The percent apparent digestible energy was calculated on the basis of the formula:

$$\text{A.D.E.}^{a}\ (\%) = \frac{(\text{Total feed energy}^{b}) - (\text{Total fecal energy}^{c})}{(\text{Total feed energy}^{b})} \times 100$$

[a]Apparent Digestible Energy

[b] [(grams of feed x % D.M. of feed) x Calories per gram of feed D.M.]

[c] [(grams of feces x % D.M. of feces) x Calories per gram of feces D.M.]

G. <u>Experiment 6. Apparent digestible nitrogen studies with equal and ad libitum feeding.</u>

This experiment was conducted simultaneously with the energy study (Experiment 5). Fecal samples for nitrogen and energy analysis were taken at the same time. The fecal samples for nitrogen analysis were placed into a jar which contained 200 milliliters of a 1 percent boric acid solution. This solution was used to avoid loss of nitrogen in the form of ammonia. The samples were sealed and stored at 5°C. At the end of the trial, the fecal solution was increased to known volume with tap water. The grams of fecal material were then calculated as grams of dry fecal material per milliliter of solution. Each sample was thoroughly mixed and a 20 milliliter aliquot was taken for macroKjeldahl determination. The macroKjeldahl determinations were done in accordance with standard A.O.A.C. methods.

Apparent digestible nitrogen was calculated using the formula:

$$A.D.N.^{a}(\%) = \frac{(\text{Total feed nitrogen}^{b}) - (\text{Total fecal nitrogen}^{c})}{(\text{Total feed nitrogen}^{b})} \times 100$$

[a] Apparent Digestible Nitrogen

[b] [(grams of feed x D.M. of feed) x % nitrogen per gram feed D.M.]

[c] [(grams of feces x % D.M. of feces) x % nitrogen per gram feces D.M.]

H. Experiment 7. Rate of food passage studies with equal and ad libitum feeding.

The method used in this experiment was a modification of the method used by Balch (1950) and Castle and Castle (1957). It was postulated that the rate of particle passage was an indication to the rate of food passage through the alimentary tract. By thoroughly mixing colored particles with a day's ration, the time the feed remained in the alimentary tract was estimated by recording the time fed and the average particle excretion time. Finely ground corn cobs were used as the reference particle. Ground corn cob particles were sized by screening and then dyed. The particles that would pass through a .156 inch (5 mesh) seive, but would not pass through a .131 inch (6 mesh) seive were selected for the passage studies. One-half of the selected particles were dyed red, and the other half dyed blue. Permanently dyed particles were prepared by soaking the particles 24 hours in either a 2 percent solution of acid fuchsin dye or methylene blue chloride dye.

These studies were conducted simultaneously with the digestion trials (Experiments 5 and 6), except the particles were fed 24 hours before the start of the digestion trials. This permitted a majority of the particles to be excreted before the start of the fecal collection period of the digestion trials. On the evening which preceded the start of the experiment, the pigs were allowed to eat only one hour. This insured a good appetite the next morning, which was important for rapid and complete consumption of the feed and particles. Approximately 400 red particles were thoroughly mixed with the 8:00 A.M. feed, and approximately the same number of blue particles were mixed with the 4:30 P.M. feed. Fecal collections were made daily at 8:00 A.M., 1:00 P.M., 5:00 P.M. and 11:00 P.M. The fecal material was washed through a .110 inch (7 mesh) sieve by water, but the particles were retained by the sieve. Particles were counted at each collection. When all particles were excreted, the total number was taken as 100 percent. Then, the percent passage at any given time could be calculated by dividing the total number of particles into the number passed up to that particular time. A particle passage curve was developed by calculating the percent excreted after each collection. This curve was developed by placing the hours after feeding on the abscissa and the percent particle passage on the ordinate, and plotting the points for percent passed at each collection. The curve was produced by drawing a line through these points. This curve was used to analyze the data statistically.

I. Experiment 8. Double reversal studies with paired pigs.

In this experiment each pig was tested twice with the meal and pelleted high corn ration; thereby each pig was his own control in comparing the two physical forms of the ration. Four pairs of uniform pigs were selected and pair-fed an equal amount of a ration. Feed consumption between pairs was not considered. This experiment required four test periods during which one pig of a pair was given the ration in the order of meal, pellet, meal, then pellet while his mate received pellet, meal, pellet, then meal. Experimental procedure was otherwise identical to Experiments 5, 6 and 7.

J. Experiment 9. Rat performance when fed processed corn.

Two trials were conducted to determine the effect of processing corn on rat growth. Smith (1957) stated that the grain portion of a poultry ration appeared to be benefited more by pelleting than other ingredients. Since most other ingredients had been previously cooked, it was unlikely that heat would have much effect on these ingredients. Rothman and Polak (1941) found the structure of several cereal foods changed after cooking. Personnel at Central Soya Company, Inc. (1958) postulated that their solvent extraction process "exploded" the cellular structure inside each soybean flake, thus releasing the protein and rendering it more available.

In this experiment, Central Soya Company, Inc. prepared corn by several different processes, which were:

Trial I -- (1) unprocessed corn, ground

(2) corn conditioned to 180°F, ground, pelleted, and reground

(3) same as (2) except conditioned to 208°F

(4) conditioned to 180°F, flaked

(5) same as (4) then toasted (20% initial moisture, 5 minutes live steam, 25 pounds jacket pressure per square inch, 25 minutes toasting time)

(6) same as (5) with 25% initial moisture

(7) same as (5) with 15 minutes toasting time

(8) same as (5) with 35 minutes toasting time

(9) same as (5) then ground

Trial II-- (1) unprocessed corn, ground

(2) same as (5) of Trial I with 50% initial moisture

(3) same as (2) with pH of the mixture adjusted to 9 before toasting

(4) unprocessed finely ground corn

(5) medium ground corn pelleted at high temperature--approximately 208°F

Ten rats were selected at random and assigned each test ration. Management of the rats was the same as reported in Experiment 2. The basic ingredients in the test rations are listed in Table 9. The rations and water were ad libitum-fed.

TABLE 9.

INGREDIENT COMPOSITION OF RAT DIET

Ingredient	Pounds
Corn	72
Crude casein (90%)	13
Fishmeal (60%)	6
Dehydrated alfalfa meal (17%)	5
Corn oil	3
Dicalcium phosphate	0.25
Trace mineral salt (98.000% NaCl, .012% Co, .013% I, .455% Mn, .045% Cu, .240% Fe, .006% Zn)	0.5
B vitamin supplement (Merck 58c)	0.1
Vitamin A and D concentrate[a]	0.05
Vitamin B_{12} supplement (Pfizer 9+)	0.25
TOTAL	100.15

[a]Vitamin A and D supplement supplied 1000 USP units A and 300 USP units of D per pound of ration.

IV. RESULTS AND DISCUSSION

A. Experiment 1. Pigs ad libitum-fed three test rations in meal and pellet forms.

Table 10 summarizes pig performance. Analysis of variance (Table 11) shows a significant difference between rations. Carcass data are reported in Table 12.

Student's range test revealed that pigs given the pelleted rations gained significantly faster than the pigs on the same ration in meal form ($P<0.05$). The daily gains were the same for all pelleted rations, but the gains were significantly ($P<0.01$) reduced with the 40% meal ration.

There were only slight differences in feed consumption with the rations containing no oats and 20% oats in either the meal or pellet forms. In the case of the 40% oat ration, the pellet-fed pigs ate 5.15 pounds per day, while the meal-fed pigs ate only 4.66 pounds per day. Surprisingly, the highest feed consumption for all lots was in the 40% oat pelleted lot. Wastage, sorting and low consumption of the 40% meal ration indicated this ration was unpalatable. It appeared the energy intake was reduced with the high fiber meal ration and resulted in poorer performance. Feed intake was increased by pelleting the 40% oat ration and was undoubtedly partially responsible for increased growth. The results were in agreement with the data from the recent evaluation of oats by Jensen et al. (1959b).

Pelleting improved feed efficiency by 0.24, 0.40 and 0.49 pounds feed per pound gain, respectively, for the high corn, 20% oats and 40% oat rations. In general, as the oat level increased, the feed efficiency

TABLE 10.

PERFORMANCE OF PIGS AD LIBITUM-FED THREE RATIONS IN MEAL AND PELLET FORMS

Ration	High corn		20% oats		40% oats	
Ration preparation	Meal	Pellet	Meal	Pellet	Meal	Pellet
Lot number	1	2	3	4	5	6
No. pigs	9[a]	10	10	10	10	10
Av. initial weight, lbs.	31.1	31.1	30.9	31.1	31.2	31.0
Av. final weight, lbs.	183.8	198.6	177.4	195.6	160.1	196.2
Av. daily gain, lbs.	1.53[b]	1.68[c]	1.47[b]	1.65[d]	1.29	1.65[d]
Av. daily feed intake, lbs.	4.76	4.83	4.87	4.81	4.66	5.15
Feed per pound gain, lbs.	3.12	2.88	3.32	2.92	3.61	3.12
Feed cost per 100 lbs. gain	$8.75	$8.80	$9.27	$8.86	$9.98	$9.35

[a]One pig died (hemorrhagic enteritis)

[b]Significantly different than Lot 5 ($P < 0.01$)

[c]Significantly different than Lots 3, 5 ($P < 0.01$); 1($P < 0.05$)

[d]Significantly different than Lots 5 ($P < 0.01$); 3($P < 0.05$)

TABLE 11.

ANALYSIS OF VARIANCE OF WEIGHT GAINS

Source of variance	df	ss	ms	f
Total	59	22,660		
Rations	5	11,056	2,211	10.47[a]
Error	55	11,604	211	

[a]Highly significant ($P < 0.01$)

TABLE 12.

CARCASS RESULTS FOR PIGS AD LIBITUM-FED
RATIONS IN MEAL AND PELLET FORMS (LOT AVERAGES)

		Slaughter weight lbs.	Dressing %	Carcass length Inches	Backfat Inches	Lean cuts Live %	Lean cuts Carcass %	Primal cuts Live %	Primal cuts Carcass %	Loin area 10th rib Sq. inches	Fat trim %
High corn	Meal	211.1	72.94	29.81	1.78	38.14	52.33	47.43	65.05	3.80	26.47
	Pellet	213.5	73.94	29.57	1.79	38.31	51.80	47.83	64.69	3.81	26.79
20% oats	Meal	210.7	72.74	30.08	1.78	38.29	52.67	47.32	63.66	3.63	25.74
	Pellet	213.7	73.06	30.26	1.76	38.04	52.06	47.87	65.50	3.79	25.90
40% oats	Meal	210.2	72.41	29.48	1.67	37.81	52.24	47.18	65.17	3.55	24.91
	Pellet	212.5	72.71	30.16	1.70	37.76	51.95	47.24	64.89	3.59	26.05

decreased, but efficiency decreased much faster with the meal rations. Feed cost per 100 pounds bodyweight gain increased with increasing levels of oats. This was primarily due to poorer feed efficiency. The cost differences were less between the pelleted rations, but followed a trend similar to that of meal rations. Although gains were more costly with oat rations, it appeared that the cost of pelleting was justified only with the higher fiber rations.

With reference to the optimum crude fiber level for growing-finishing swine, it would seem that the value (6.57 percent) reported by Axelsson (1953) is too high. On the basis of this experiment and observations by Jensen et al. (1959b) and Conrad and Beeson (1958), probably the optimum level is lower than the level suggested by Axelsson.

Carcass results showed there were no differences between the experimental rations in regard to dressing percentage, carcass length, backfat, percent lean cuts, percent primal cuts, loin area and percent fat trim. The 40% meal-fed pigs were slaughtered approximately three weeks later than the majority of the other pigs.

B. Experiment 2. Rats ad libitum-fed three test rations in meal and pellet forms.

Table 13 shows the results of this experiment. The data were analyzed by analysis of variance (three way classification, Snedecor, 1956). The daily gains and feed efficiency of the rats on various rations were generally consistent with the observations on the pig experiment (Experiment 1). Rat gains were significantly ($P<0.05$) improved by pelleting. Reground pellets were as effective in stimulating growth as the pellets. Feed consumption was reduced on the 40% meal ration, and the reground pellet-fed rats consumed more feed than the meal-fed rats,

TABLE 13.

PERFORMANCE OF RATS WHEN AD LIBITUM-FED THREE TEST RATIONS

Ration	High corn			20% oats			40% oats		
Ration preparation	Meal	Pellet	Reground pellet	Meal	Pellet	Reground pellet	Meal	Pellet	Reground pellet
Group number	1	2	3	4	5	6	7	8	9
Number rats	10	10	10	10	10	10	10	10	10
Av. initial weight, grams	38.7	36.2	39.2	38.6	38.6	40.9	38.6	38.8	38.4
Av. final weight, grams	160.6	159.6	175.6	159.4	167.0	167.2	144.9	159.6	159.6
Av. daily gain, grams	4.69	4.75	5.24[a]	4.65	4.94[b]	4.86	4.09[c]	4.65	4.66
Av. daily feed intake, grams	15.37	14.27	16.35	15.64	15.62	16.25	13.76	15.80	15.61
Feed per gram gain, grams	3.28	3.01	3.12	3.36	3.16	3.34	3.37	3.40	3.35

[a]Significantly different from group 7 ($P < 0.01$); 1, 4, 8, 9 ($P < 0.05$)

[b]Significantly different from group 7 ($P < 0.01$)

[c]Significantly different from groups 1, 2, 4, 6, 8, 9 ($P < 0.05$)

yet these differences were not significant at the 5 percent level. Palatability of the rations as measured by feed consumption appeared to be improved by the pelleting process. It was concluded that changing the physical form of the ration was not the only nutritional improvement provided by the pelleting process.

The importance of ration density is not known. Allred et al. (1956, 1957a, 1957b) reported that density was important in poultry rations for increased energy intake. Pepper et al. (1960) found that pelleting poultry rations resulted in growth improvement, but was greatest at low fat levels and improvement declined as fat level increased. This suggested density was important for adequate energy intake. In contrast, Hinds and Scott (1958) concluded that density was not an important improvement of poultry rations. Bearse et al. (1952) found the pelleting of high fiber rations improved growth; Dymsza et al. (1958) had a similar response with turkeys. Conrad and Beeson (1958) concluded that pelleting improved the palatability of a corn-and-cob swine ration.

The density of the three test rations was inversely related to the fiber level of the ration. The density of the meal rations was measured to be 1.21, 1.09 and 0.86 pounds per quart for the high corn, 20% and 40% oat rations, respectively. These same rations in pellet form measured 1.45, 1.36 and 1.25 pounds per quart, respectively. Ration density decreased as the fiber level increased, but the decrease was less with the pelleted rations. Although ration density was improved by pelleting, it cannot be concluded that an animal can consume more feed because the feed occupies less space in the alimentary tract. Visual observations of slaughtered pig and sacrificed rat stomach contents revealed that the pelleted ration appeared the same as the meal ration. These observations were made as soon as possible after pigs and rats had eaten the pelleted rations. It was believed that the pigs and rats thoroughly masticated the pellets. Therefore, it was concluded that ration density was important only to improve the palatability of the ration.

C. Experiment 3. Palatability study -- high corn ration.

In 30 days, 11 pigs ate 1220 pounds of pellets, 350 pounds of reground pellets and 325 pounds of meal. While a statistical analysis of this data was not attempted, the results clearly favored the pellets. Consumption of the meal and the reground pellets was essentially the same. These results were similar to those observed by Young and Wingert (1959).

The reasons pigs liked pellets were not definitely known. Some observations were that pelleting (1) masked unpalatable ingredients, (2) reduced dustiness, and (3) the pigs simply liked to chew on the pellet. Pigs in the equal feeding experiment (Experiment 4) developed different eating habits. The pellet-fed pigs usually consumed their feed faster than the meal-fed pigs. Many pigs on the meal ration made several trips to the water source before consuming all of the feed. On several occasions, the pigs did not appear to take a drink, but would merely blow into the water. It was possible that either dust or oat hulls were irritating the nose and membranes in the nostrils.

D. Experiment 4. Performance of paired pigs -- equally fed to 180-200 pounds bodyweight, then ad libitum fed to heavier weights.

The results of this experiment are shown in Tables 14 and 15. The data were analyzed by tests of differences as outlined in Snedecor (1959), section 2.9.

Pelleting the high corn ration significantly ($P<0.05$) improved growth rate and feed efficiency when equally fed. Trends were the same for the 20% and 40% oat rations, but the differences between meal and

TABLE 14.

PERFORMANCE OF MEAL AND PELLET-FED PIGS
WHEN ON EQUAL FEED INTAKE TO 180-200 POUNDS
THEN AD LIBITUM FED TO 230-260 POUNDS BODYWEIGHT

	No. pairs	Average daily gain, lbs.		Average daily feed, lbs.		Average feed per pound gain, lbs.	
		Meal	Pellet	Meal	Pellet	Meal	Pellet
High corn							
Equal intake[b]	6	1.47±.10[a]	1.58±.11[d]	4.96±.18	4.96±.18	3.36±.13	3.14±.16[d]
Ad libitum[c]	6	1.82±.22	2.03±.19	7.18±.30	7.46±.40	3.93±.38	3.67±.28
20% oats							
Equal intake[b]	6	1.39±.06	1.45±.07	4.71±.18	4.71±.18	3.39±.09	3.26±.13
Ad libitum[c]	6	1.50±.16	1.92±.08[d]	6.67±.69	8.38±.05	4.44±.26	4.36±.17
40% oats							
Equal intake[b]	6	1.45±.09	1.53±.08	4.99±.37	4.99±.37	3.43±.12	3.27±.14
Ad libitum[c]	4	1.88±.13	2.21±.10[d]	8.58±.36	8.52±.44	4.56±.32	3.85±.36

[a]Mean ± standard error

[b]Three pairs were started at 40-50 lbs. and three pairs started at 70-85 lbs. and equally fed to 180-210 lbs. bodyweight.

[c]After equally fed. Started at 180-200 lbs. and fed to 230-260 lbs. bodyweight.

[d]Significantly different from the meal ($P<0.05$)

TABLE 15.

COMBINED PERFORMANCE OF MEAL AND PELLET-FED PIGS WHEN ON AN EQUAL INTAKE TO 180-200 POUNDS, THEN AD LIBITUM FED TO 230-260 POUNDS BODYWEIGHT

	No. pairs	Average daily gain, lbs.	Average daily feed, lbs.	Average feed per pound gain, lbs.
Equal intake				
Meal	18	1.44 ± .05[a]	4.88 ± .20	3.39 ± .06
Pellet	18	1.51 ± .06[b]	4.88 ± .20	3.23 ± .08[c]
Ad libitum				
Meal	16	1.71 ± .11	7.28 ± .34	4.26 ± .19
Pellet	16	2.03 ± .08[b]	8.06 ± .23	3.97 ± .16[b]

[a]Mean ± standard error

[b]Significantly different from the meal ($P < 0.05$)

[c]Significantly different than the meal ($P < 0.01$)

pellets were not significant. Since analysis of variance on growth rate did not indicate any interaction among rations, the data from the three rations were pooled to measure the difference between meal and pellet when equally fed. With the pooled data, the meal and pellet average daily gains were 1.44 ± 0.05 and 1.51 ± .06, and average feed efficiency was 3.39 ± .06 and 3.23 ± .08, respectively. Pelleting improved gains significantly at the 5 percent level and feed efficiency at the 1 percent level.

When ad libitum fed, the 20% and 40% oat pellet-fed pigs gained significantly faster ($P < 0.05$) than the meal-fed pigs. Pigs fed the pelleted high corn ration followed the same trend. Feed intake and feed efficiency favored the pellet-fed pigs, but the differences were not significant. Feed consumption was the same by pigs on the 40% ration, yet the pigs receiving pellets gained significantly faster. Combining the data on ad libitum feeding made the differences in daily gains (.32 lb.) and feed efficiency (.29 lb.) significant ($P < 0.05$). Average daily feed consumption was increased by .78 pound per day, and this difference is significant at the ($P<0.20$) level of probability. While some of the observed feed intake may have been lost as wastage, it was believed that feed wastage was so minor in this experiment that the observed differences in growth could not have been due to differences in true feed intake. On the basis of this experiment, it appeared that pelleting benefits were not due entirely to increased feed intake.

Research by Lehrer and Keith (1953), Warner and Meade (1956), Dinusson and Bolin (1958), Young and Wingert (1959) and Rutledge and Teague (1959) showed that pigs fed pelleted rations gained faster than meal-fed pigs without increased feed intake. While it is logical to assume that a greater feed intake supports more growth, the results of this and other experiments suggest other factors are involved. It is hypothesized that the pelleting process causes some chemical alterations which improve the nutritive value of the ration.

E. Experiment 5. Apparent digestible energy studies with equal and ad libitum feeding.

The results of this experiment are shown in Table 16. The results on the equal feed intake trial include data from four pigs that were used on the double reversal study (Experiment 8). On an equal feed intake, the digestible energy of high corn pelleted ration was significantly greater than the same ration in meal form ($P<0.05$). The average differences between meal and pellets on the high corn ration and the 40% oat ration were 2.07 percent and 1.43 percent, respectively. The high corn ration ad libitum-fed, followed the same trend ($P<0.20$). In fact, the difference between the meal and pellet rations was greater than when the same rations were equly fed. The standard deviations were the same, but the number

TABLE 16.

AVERAGE APPARENT DIGESTIBLE ENERGY FOR PIGS FED A CORN OR 40 PERCENT OAT RATION IN MEAL AND PELLET FORMS

	No. pairs	Meal %	Pellet %
High corn			
Equal intake	12	82.54 ± .56[a]	84.61 ± .58[b]
Ad libitum	4	81.88 ± .50	84.45 ± .55
40% oats			
Equal intake	8	75.45 ± .90	76.88 ± .88
Ad libitum	4	78.80 ± .37[b]	75.82 ± .69

[a]Mean ± standard error

[b]Significantly different ($P < .05$)

of replicates was less on ad libitum feeding, thus the treatment difference must be substantially greater to be significant at the 5 percent level of probability.

When the 40% oat ration was ad libitum-fed, the digestibility of the meal ration was significantly greater ($P < 0.05$) than the same pellet ration. These results were opposite the results of equal feeding. A review of the data showed the digestibility of the pelleted ration was not particularly lowered, but the digestibility of the meal ration was greater than the other 40% oat rations. A decrease in the fecal dry matter appeared to be the main reason for the increase in digestibility. The feed intake was not different between the meal and pellet-fed pigs. The Calories per gram of fecal dry matter were greater for three of four meal-fed pigs, but when the Calories per gram of feces were multiplied by the total fecal dry matter, the total fecal energy was consistently less for the meal-fed pigs.

Analysis of the combined data showed the difference between equally fed meal and pelleted rations was highly significant ($P < 0.01$). The ad libitum data were not combined since it appeared that energy digestibility may not be the same for the two test rations under ad libitum feeding conditions.

An analysis of fecal energy revealed that the Calories per gram of fecal dry matter was significantly ($P < 0.01$) less for the pelleted rations. Average meal and pellet ration values were 4.941 and 4.625 Calories per gram of fecal matter for the high corn ration, and 4.702 and 4.590 Calories per gram of fecal matter for the 40% oat ration. The total fecal energy was significantly less ($P < 0.05$) for the high corn pellet ration. The total fecal energy was not different in the case of the meal and pelleted 40% oat ration.

The digestibility of the high corn ration was consistently greater than the 40% oat ration. Castle and Castle (1957) also found that dry matter digestibility was decreased by adding fiber to a swine ration. They concluded that a high level of feeding increased the dry matter digestibility. However, feed intake had to be quite different to make the digestibility significantly different. In this experiment the dry matter intake was always greater on the ad libitum feeding, yet the digestible energy was approximately the same. Therefore, dry matter energy digestibility did not appear to be changed when the feed consumption approximated the maximum desired intake.

F. Experiment 6. Apparent digestible nitrogen studies with equal and ad libitum feeding.

The results of this experiment showed no significant differences between either the meal and pellets, or between the two experimental rations. Replicates did not indicate any particular change in digestibility by pelleting. The variation within groups was as great as the variation between groups. Table 17 summarizes the experiment. These data include the pigs on the double reversal experiment (Experiment 8). The largest difference between meal and pellets was with the ad libitum-fed 40% oat group. Digestibility was 4.38 percent greater in the meal-fed group.

TABLE 17.

AVERAGE APPARENT DIGESTIBLE NITROGEN FOR PIGS FED A CORN OR 40 PERCENT OAT RATION IN MEAL AND PELLET FORMS

	No. pairs	Meal %	Pellet %
High corn			
Equal intake	12	78.71 ± 1.32[a]	78.09 ± 1.74
Ad libitum	4	81.02 ± 1.67	80.04 ± 2.96
40% oats			
Equal intake	8	79.11 ± 1.48	78.59 ± 1.81
Ad libitum	4	83.75 ± 1.83	79.37 ± 1.65

[a]Mean ± standard error

Morgan (1931) stated that she was not aware of any experiment indicating a decrease in protein digestibility due to either moist or dry heat. Melnick and Oser (1949) concluded that the rate of enzymatic liberation of amino acids, rather than the degree of amino acid availability, was of critical importance for proper metabolism. They thought that heat processing influenced the relative rate of liberation of amino acids. Carroll et al. (1952) reported the site of nitrogen absorption was different for raw and processed soybean meal. They concluded that processing accelerated the rate of digestion and significantly increased digestibility.

The results of this experiment and other research suggest that protein digestibility is not changed by the pelleting process. However, this is not conclusive evidence that proteins are not altered by pelleting. The effects of pelleting on protein utilization or denaturation are not known at this time. It is believed that some changes do occur, and these changes may either improve or harm the nutritive value of the protein and feed. In view of the improvement in animal performance by pelleting, the overall effects are probably good.

G. Experiment 7. Rate of food passage studies with equal and ad libitum feeding.

Table 18 summarizes the experiment. Average curves for each group of pigs are shown in Figures 1, 2, 3 and 4. The curves in Figures 5 and 6 illustrate the difference between meal and pellets when the two test ration data were combined. Five percent excretion time, 95 percent excretion time and mean retention time were used to analyze the data. These same methods of analysis were used by Castle and Castle (1956, 1957).

The excretion curves are sigmoid in shape. Usually particles appeared first in either the 11:00 P.M. fecal collection on the first day, or in the 8:00 A.M. fecal collection on the second day. The initial recovery of particles varied quite extensively in the number of particles. This was attributed to the rather voluminous defecations. The rate of recovery of particles following the initial recovery depended on the form of the ration. Generally, the pellet-fed pigs continued to excrete particles rather rapidly, but the meal-fed pigs excreted particles at a slower and more consistent rate. After approximately 95 percent of the particles had been recovered, the excretion of the last 5 percent was slow and inconsistent. It was concluded that any excretion of particles beyond 95 percent of the total was not useful for the evaluation of excretion time. Therefore, the 5 percent excretion time and 95 percent

TABLE 18.

AVERAGE RATE OF PARTICLE PASSAGE FOR PIGS FED A CORN OR 40 PERCENT OAT RATION IN MEAL AND PELLET FORMS

	No. pairs	Time of feeding	Av. 5% excretion time, hrs.		Av. 95% excretion time, hrs.		Av. retention time, hrs.	
			Meal	Pellet	Meal	Pellet	Meal	Pellet
Corn								
Equal intake	12	A.M.	20.0	17.8(±1.98)[a]	62.4	55.0(±1.55)	36.4	29.7(±2.89)[b]
	12	P.M.	20.2	17.5(±1.55)	59.8	51.8(±5.80)	35.2	28.8(±2.64)[b]
	Mean		20.1	17.7	61.1	53.4	35.8	29.3
Ad libitum	4	A.M.	26.9	19.5(±4.97)	93.0	43.4(±12.9)[b]	49.9	26.0(±8.35)
	4	P.M.	25.1	18.0(±6.06)	83.5	39.1(±13.0)[b]	45.6	24.6(±7.43)
	Mean		26.0	18.8	88.3	41.3	47.8	25.3
40% oats								
Equal intake	7	A.M.	23.8	17.4(±3.21)	59.9	61.8(±9.09)	38.2	34.0(±3.84)
	7	P.M.	24.3	17.6(±2.53)[b]	57.4	58.5(±7.01)	36.1	32.8(±3.71)
	Mean		24.1	17.5	58.7	60.2	37.2	33.4
Ad libitum	4	A.M.	21.0	19.1(±6.76)	69.9	58.6(±11.7)	39.0	28.1(±6.09)
	4	P.M.	20.9	17.5(±2.26)	71.4	58.4(±16.2)	39.8	26.3(±7.50)
	Mean		21.0	18.3	70.7	58.5	39.4	27.2

[a]Standard error of mean difference

[b]Significantly faster passage rate than the meal ($P < 0.05$)

FIGURE 1.

RATE OF PARTICLE PASSAGE: TWELVE PAIRS OF PIGS EQUALLY FED HIGH CORN RATIONS (A.M. FEEDING)

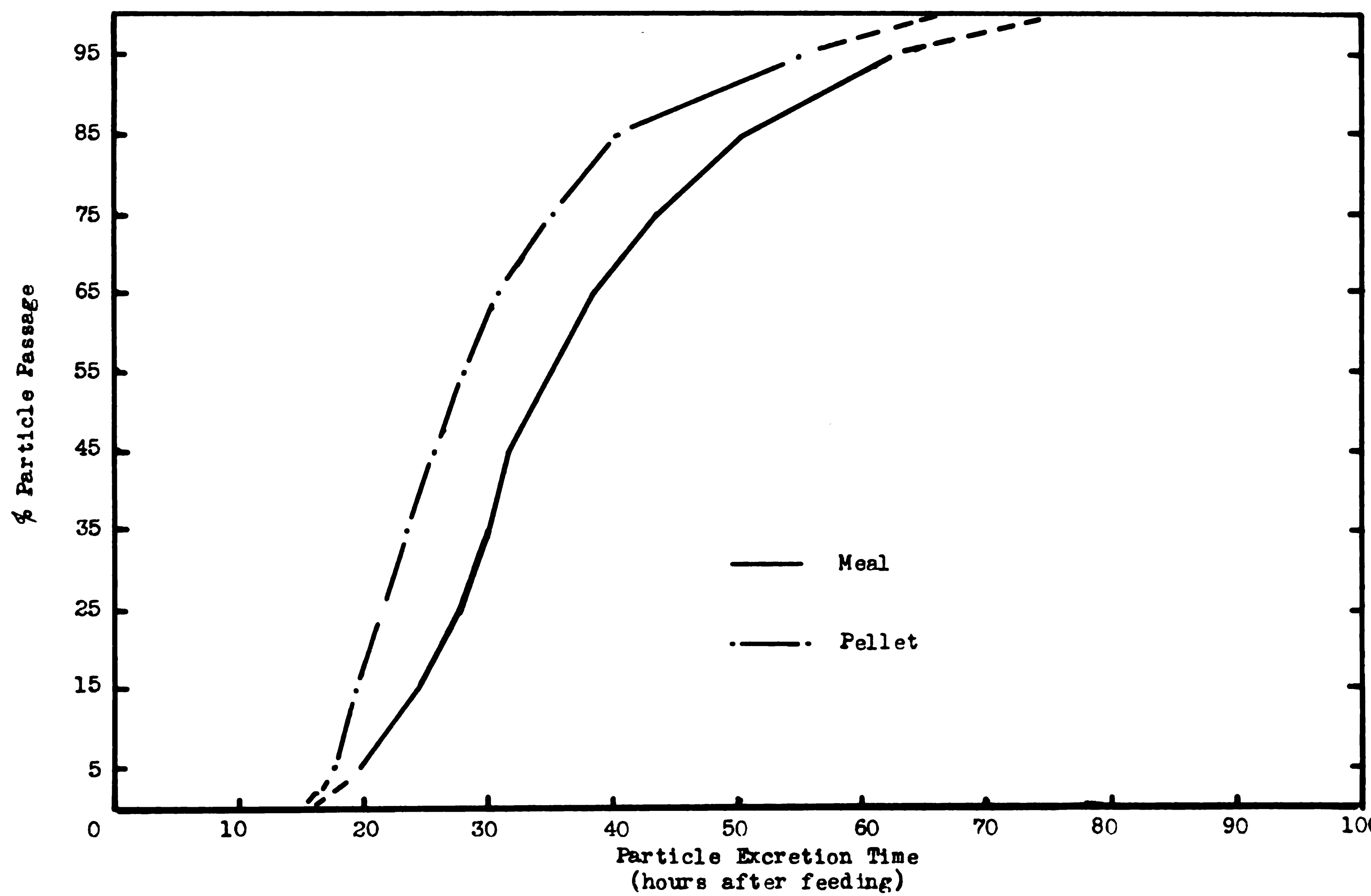


FIGURE 2.

RATE OF PARTICLE PASSAGE: FOUR PAIRS OF PIGS AD LIBITUM FED HIGH CORN RATIONS (A.M. FEEDING)

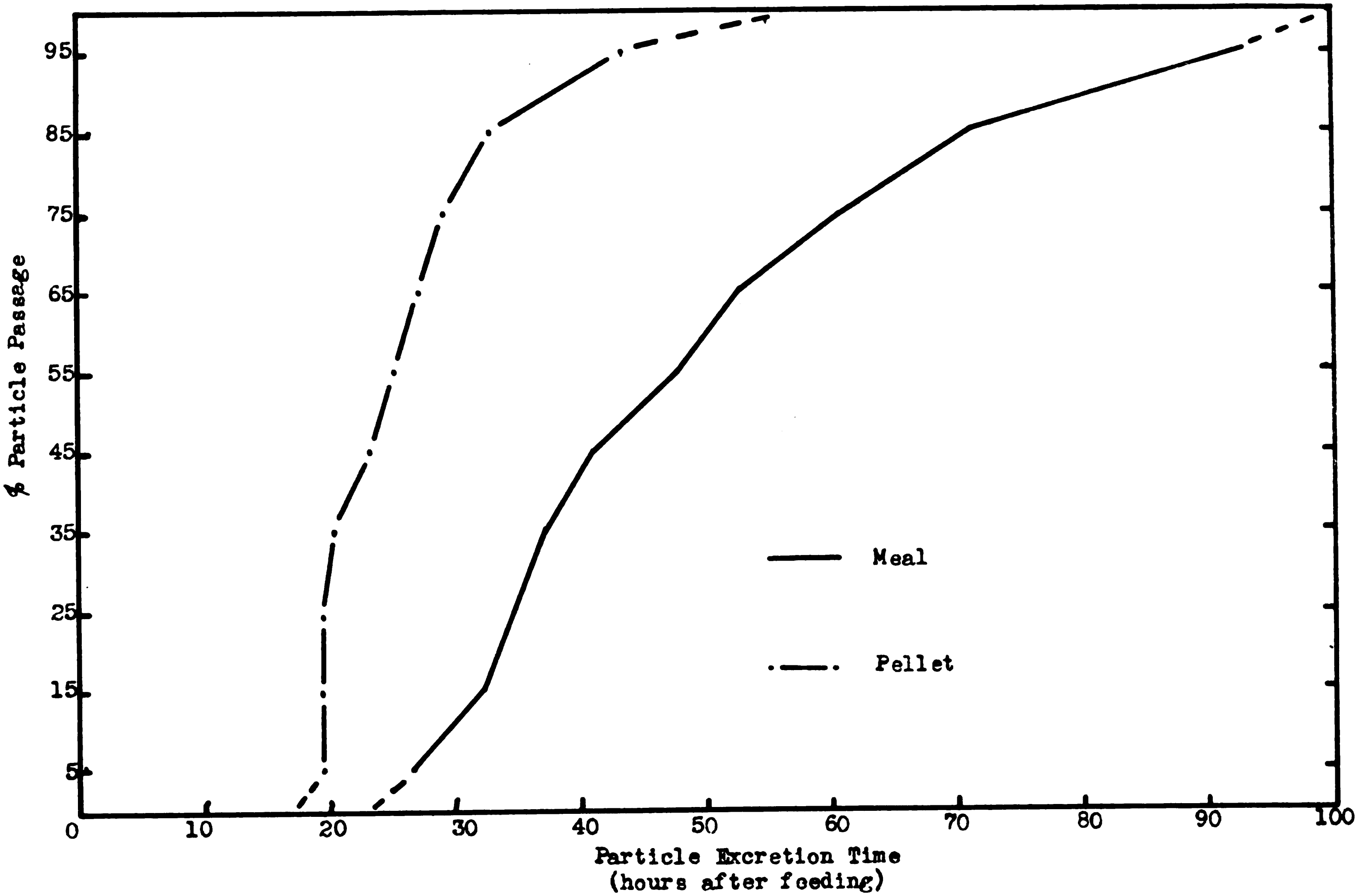


FIGURE 3.

RATE OF PARTICLE PASSAGE: SEVEN PAIRS OF PIGS
EQUALLY FED 40% OAT RATIONS (A.M. FEEDING)

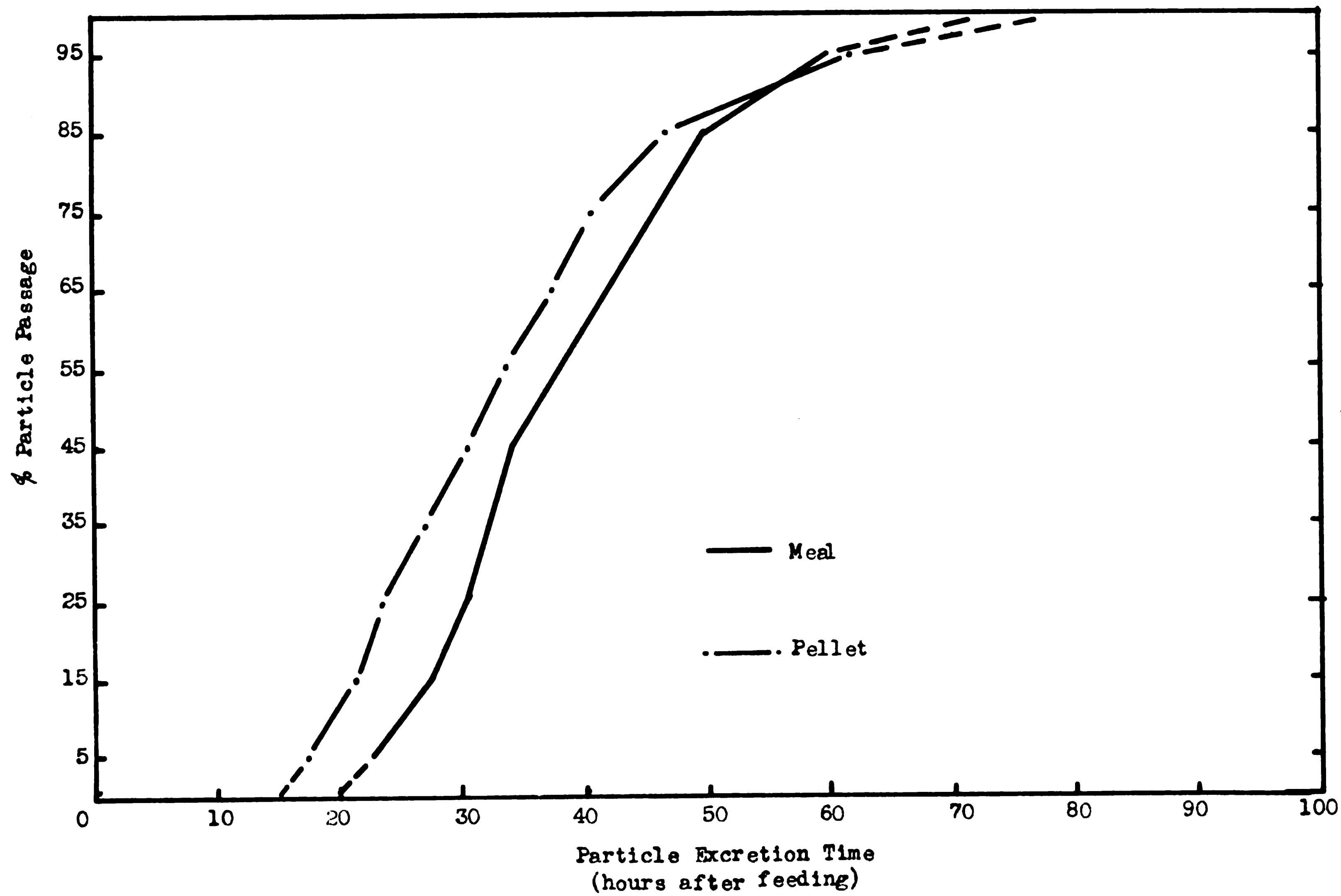


FIGURE 4.

RATE OF PARTICLE PASSAGE: FOUR PAIRS OF PIGS
AD LIBITUM FED 40% OAT RATIONS (A.M. FEEDING)

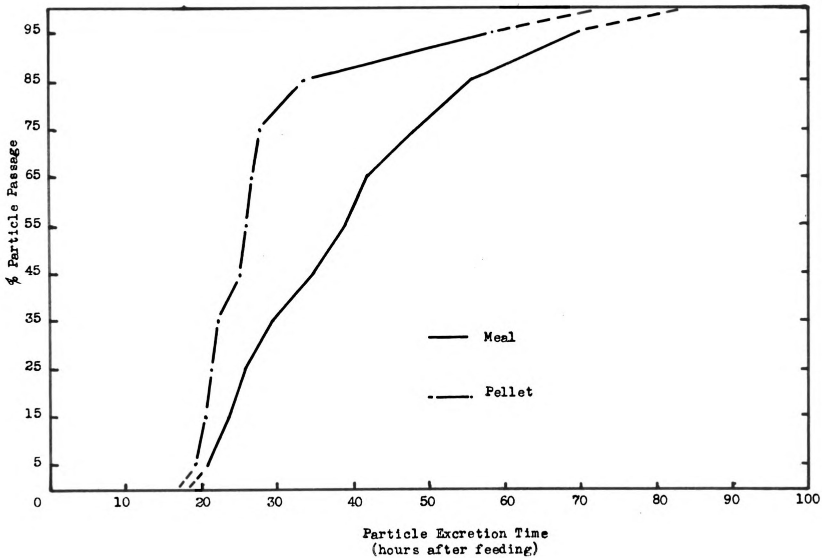


FIGURE 5.

RATE OF PARTICLE PASSAGE: NINETEEN PAIRS OF PIGS EQUALLY FED HIGH CORN AND 40% OAT RATIONS (A.M. FEEDING)

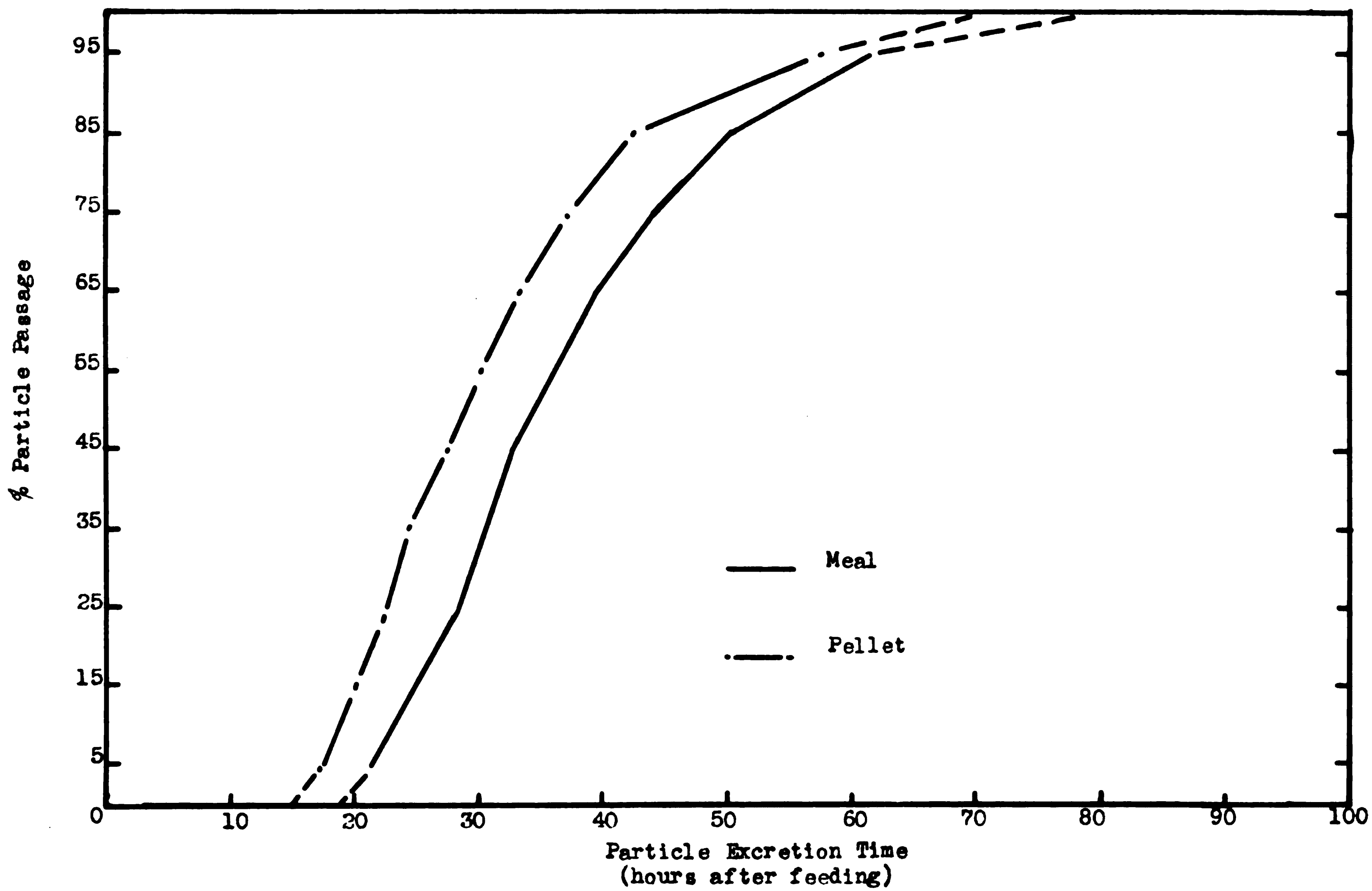
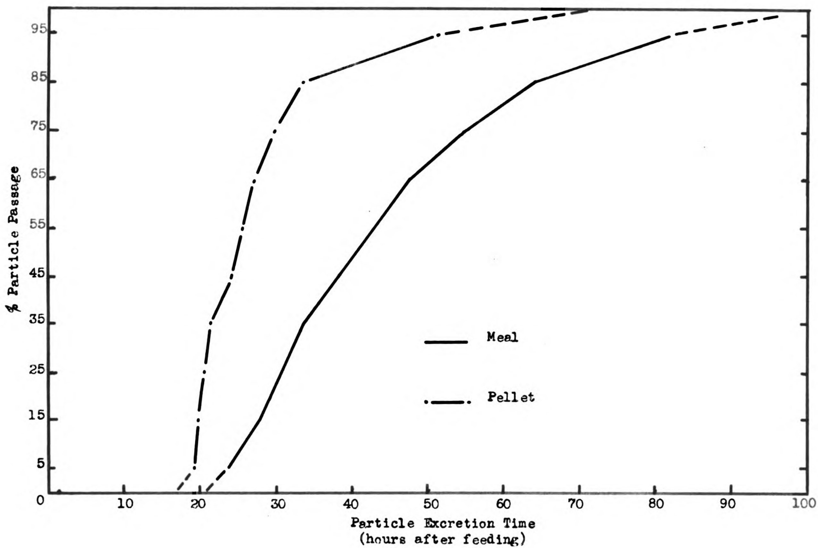


FIGURE 6.

RATE OF PARTICLE PASSAGE: EIGHT PAIRS OF PIGS
AD LIBITUM FED HIGH CORN AND 40% OAT RATIONS (A.M. FEEDING)



excretion time were selected as accurate estimates of initial and final excretion times.

The mean retention time estimated when about one-half of the particles appeared in the excreta. This value was determined by the addition of the time after feeding at 5, 15, 25, 35, 45, 55, 65, 75, 85, and 95 percent particle excretion, then dividing by 10.

The average 5 percent excretion time was significantly faster (P.M. feeding) with the pelleted 40% oat ration when equally fed. The initial excretion time was usually less for both the high corn and the 40% oat pelleted rations when fed equally or ad libitum fed. The excretion rate differences between the A.M. and P.M. feedings were slight, but generally, the P.M. feedings were excreted slightly faster.

The termination of the high corn ad libitum-fed pellet ration was significantly faster ($P < 0.05$) than the meal ration as measured by the 95 percent excretion time. The differences were 49.6 hours and 44.4 hours for the A.M. and P.M. feedings, respectively. The equally-fed high corn ration and the ad libitum-fed 40% oat ration followed the same trend, but the differences were not significant. With the equally-fed 40% oat ration, the meal-fed pigs had slightly faster 95 percent excretion times than the pellet-fed pigs.

The average mean retention time was consistently less with the pelleted rations. The differences between meal and pelleted high corn rations were significant at the 5 percent level when these rations were equally fed. Also, the mean retention times were less for the evening feeding. When data from both rations were combined into equal-fed or ad libitum-fed, the 5 percent excretion time, 95 percent excretion time, and the mean retention time indicated that particle passage was faster with pelleted rations (Table 19). On equal feeding, the differences in

TABLE 19.

COMBINED AVERAGE RATE OF PARTICLE PASSAGE FOR PIGS FED A CORN OR 40 PERCENT OAT RATION IN MEAL AND PELLET FORMS

	No. pairs	Time of feeding	Av. 5% excretion time, hrs.		Av. 95% excretion time, hrs.		Av. retention time, hrs.	
			Meal	Pellet	Meal	Pellet	Meal	Pellet
Equal intake	19	A.M.	21.4	17.6[a]	61.5	57.5	37.1	31.3[b]
	19	P.M.	21.7	17.6[b]	58.9	54.3	35.5	30.2[a]
Ad libitum	8	A.M.	23.9	19.3	81.4	51.0[a]	44.4	27.2[a]
	8	P.M.	23.0	17.8	77.4	48.8[a]	42.7	25.5[a]

[a]Significantly faster passage rate than meal ($P<0.05$)

[b]Significantly faster passage rate than meal ($P<0.01$)

A.M. 5 percent excretion time were significant ($P<0.05$), while the differences in the P.M. feeding were highly significant ($P<0.01$). Differences in the 5 percent excretion time with ad libitum feeding were as great as the equal-fed groups; however, the standard errors were larger. The 95 percent excretion time was approximately 30 hours ($P<0.05$) less when pellets were fed ad libitum. Combined average mean retention times were significantly less in the case of the pelleted rations. With equal intake both the A.M. ($P<0.01$) and the P.M. ($P<0.05$) feedings were significantly less. When ad libitum fed, the pellet mean retention time was approximately 17 hours less ($P<0.05$) than the meal-fed pigs.

Although digestive processes are different between ruminants and non-ruminants, it appears that pelleting a ration causes faster food passage through the alimentary tract of both. Blaxter and associates (1955, 1956) found the rate of food passage was faster when a lamb ration was pelleted. Later Meyer et al. (1959) reported that the faster passage of ingesta from the reticulo-rumen was possibly responsible for increased feed intake. It was thought that the faster passage from the stomach was due to faster holocellulose digestion by the rumen microorganisms.

The importance of feed intake as related to rate of food passage was not consistent between the meal and pelleted rations. When the pigs were changed to ad libitum feeding, nearly every pig consumed more feed on a daily basis than they had consumed just prior to the change. The pellet-fed pigs consumed more feed during the ad libitum feeding passage study than during the equal feeding study, and a lower mean retention time was associated with the higher feed intake. Likewise, the meal-fed pigs consumed more feed on ad libitum feeding, but mean retention time was slightly increased in this case. It appeared that higher feed intake may increase the rate of passage with pelleted rations. Castle and Castle (1957) reported that faster passage of ingesta (meal ration) was associated with a higher feed consumption.

The faster passage associated with pelleted rations was probably partially responsible for the increased feed intake. A logical conclusion was that higher feed intake due to pelleting a ration could be attributed to both increased rate of food passage and improved ration palatability.

H. Experiment 8. Double reversal studies with paired pigs.

Results of the apparent energy digestibility, apparent nitrogen digestibility and rate of food passage are shown, respectively, in Tables 20, 21 and 22. The results of this experiment provided additional evidence that pelleting increased the energy digestibility of the ration and accelerated food passage. The energy digestibility changed as the ration was changed. Nitrogen digestibility was not altered. Food passage

TABLE 20.

DOUBLE REVERSAL STUDY--APPARENT ENERGY DIGESTIBILITY OF MEAL AND PELLETS[a]

Pig number	Meal %	Pellet %	Meal %	Pellet %	Average Meal %	Average Pellet %
1	80.10	80.61	82.16	86.48	81.13	83.55
2	84.21	85.70	84.96	87.09	84.59	86.40
3	81.51	83.41	80.35	84.42	80.93	83.92
4	81.34	84.39	82.58	82.87	81.95	83.63
Average	81.79	83.53	82.51	85.22	82.15	84.38

[a]High corn ration

TABLE 21.

DOUBLE REVERSAL STUDY--APPARENT NITROGEN DIGESTIBILITY OF MEAL AND PELLETS[a]

Pig number	Meal %	Pellet %	Meal %	Pellet %	Average Meal %	Average Pellet %
1	76.37	64.78	79.79	83.36	78.08	74.07
2	82.11	83.65	82.68	83.05	82.40	83.35
3	77.08	72.37	71.97	75.47	74.54	73.92
4	70.00	79.43	77.80	71.68	73.90	75.57
Average	76.39	75.06	78.02	78.39	76.21	76.73

[a]High corn ration

TABLE 22.

DOUBLE REVERSAL STUDY--RATE OF FOOD PASSAGE, A.M. AND P.M. DATA COMBINED[a]

Pig number	Meal hrs.	Pellet hrs.	Meal hrs.	Pellet hrs.	Average Meal hrs.	Average Pellet hrs.
			5 percent excretion time			
1	10.30	13.00	18.00	17.50	14.15	15.25
2	18.75	15.00	22.00	23.50	20.38	19.25
3	19.50	15.00	16.25	15.00	17.88	15.00
4	17.00	15.00	17.50	13.00	17.25	14.00
Average	16.39	14.50	18.44	17.25	17.42	15.88
			95 percent excretion time			
1	48.50	31.75	56.50	33.50	52.50	32.63
2	60.00	57.75	57.50	66.50	58.75	62.13
3	56.50	46.00	62.75	58.00	59.63	52.00
4	55.75	46.00	41.75	92.00	48.75	69.00
Average	55.19	45.38	54.63	62.50	54.91	53.94

[a]High corn ration

TABLE 22-Continued

Pig number	Meal hrs.	Pellet hrs.	Meal hrs.	Pellet hrs.	Average Meal hrs.	Average Pellet hrs.
			Mean retention time			
1	25.94	19.20	33.77	25.98	29.86	22.59
2	33.32	32.99	32.34	37.98	32.83	35.49
3	31.28	23.16	31.66	24.82	31.47	23.99
4	31.49	26.10	29.17	39.57	30.33	32.84
Average	30.51	25.36	31.74	32.09	31.12	28.73

differences appeared small because two pellet-fed pigs in the last experiment had very slow passage.

I. Experiment 9. Rat performance when fed processed corn.

Two trials were conducted to determine the effect of processing corn on rat growth. The results of Trials 1 and 2 are reported in Tables 23 and 24. Analysis of variance (Snedecor, 1956) showed that growth rates, feed consumption and feed efficiency were not significantly different in either the first or second trial. Thus, processing the corn fraction of the diet did not change the nutritive value of the corn as measured by rat growth.

There is some reason to believe that the temperatures used in the pelleting process will have some effect upon micro-ingredients. Adams et al. (1943) found that 200°F drying temperatures caused a decrease in corn fermentable carbohydrate yield. Other scientists have observed destructive effects of drying high moisture corn (McGuire and Earle, 1958; Hathaway et al., 1952; Jensen et al., 1960). In contrast to the above results, Simms (1949) and Bonzer et al. (1958) reported that growth rate was not reduced when corn was dried at 190°F.

TABLE 23.

TRIAL I. RAT PERFORMANCE WHEN FED PROCESSED CORN

				Conditioned and flaked					
	Group unprocessed corn	Condi-tioned 180°F	Condi-tioned 208°F	Condi-tioned, flaked	Toasted 25 minutes	Toasted 25% initial moisture	Toasted 15 minutes	Toasted 35 minutes	Toasted 25 minutes, ground
Group number	1	2	3	4	5	6	7	8	9
No. rats	10	10	10	10	10	10	10	10	10
Av. initial wt., gms.	32.8	32.7	34.8	34.2	33.3	33.0	32.8	33.0	33.5
Av. final wt., gms.	156.6	153.4	165.0	154.1	153.6	164.9	158.6	156.7	155.1
Av. daily gain, gms.	4.42	4.31	4.65	4.28	4.30	4.71	4.49	4.42	4.34
Av. daily feed intake, gms.	12.64	12.50	13.26	12.32	12.53	12.97	12.40	12.57	14.21
Feed per gram gain, gms.	2.86	2.90	2.85	2.88	2.92	2.75	2.76	2.85	3.27

TABLE 24.

TRIAL II. RAT PERFORMANCE WHEN FED PROCESSED CORN

	Ground unprocessed corn	Conditioned, flaked, toasted 50% moisture	Conditioned, flaked, toasted pH 9.0	Finely ground unprocessed corn	Ground corn pelleted 208°F
Group number	1	2	3	4	5
Number rats	10	10	10	10	10
Av. initial weight, grams	52.4	52.1	53.4	53.2	52.5
Av. final weight, grams	181.1	183.8	181.1	190.3	179.0
Av. daily gain, grams	4.60	4.71	4.56	4.90	4.52
Av. daily feed intake, grams	15.87	15.93	15.96	16.30	16.10
Feed per gram gain, grams	3.45	3.39	3.50	3.33	3.56

A review of literature concerning the effect of heat and cooking on cereal grains and other ingredients revealed that high temperatures destroy, denature, and/or prevent utilization of nutrients. With quantitative analysis techniques, it has been shown that carbohydrates, proteins and vitamins may be changed or destroyed by heat (Mitchell et al., 1949; Murlin et al., 1938; Ross et al., 1941; Stewart et al., 1943; Oser, 1952; Cerniani, 1951; Frazier et al., 1953; Heintze,1955; Block et al., 1946; Streightoff et al., 1949; Pellett and Platt, 1956; Bird and Burkhardt, 1943; Parsons, 1943; Evans and McGinnis, 1946, 1947; Klose et al., 1948; Riesen et al., 1947; Patton et al., 1948; Mann and Briggs, 1950; Morgan, 1931; Greaves et al., 1934, 1938; Block et al., 1934; Eldred and Rodney, 1946; Cheldelin et al., 1943; Evans and Butts, 1951; Pronin and Dakh, 1952). Extensive losses of lysine, cysteine, serine and arginine were reported. High vitamin losses included pantothenic acid, vitamin C, riboflavin, inositol, and folic acid. Both slight and extensive thiamine losses were reported.

Research findings showed that niacin content was probably reduced, but the remaining niacin was more available. Henderson et al.(1947), Laguna and Carpenter (1951), and Pearson et al. (1957) reported that cooked corn eliminated the requirement for supplemental niacin in feed. Krehl et al. (1945) suggested that raw corn diets increased the requirement for niacin. Kodicek et al. (1956) proposed that niacin of cereal grains may be in an alkali-labile bound form. Pearson et al. (1957) agreed with Kodicek's work. They stated that niacin was 100 percent bound in raw corn, but 100 percent free in cooked corn.

The temperatures used in some of the previously cited experiments were within the range of pelleting temperatures. Wornick (1959) stated that animal fats, grain seed-coating and several microingredients will melt when pelleted. Perkas (1959) has reported that certain enzymes are destroyed by pelleting.

Research with soybeans indicated that the raw bean must be properly processed for improved nutrition value. Heat is necessary in order to destroy inhibitory factors in soybeans, yet, excessive temperatures lower the biological value of soybean protein (Griswold, 1951; Hayward et al., 1936a, 1936b; Johnson et al., 1939; Hayward and Hafner, 1941; Ham and Sandstedt, 1944; Bowman, 1944, 1945, 1946, 1948; Bird and Burkhardt, 1943; Parsons, 1943; Evans and McGinnis, 1946, 1947; Klose et al., 1948; Riesen et al., 1947; Patton et al., 1948).

It is not clear that processing of corn or any one fraction of the ration will support more growth. Perhaps the pelleting process affects all ingredients in a manner to make nutrients available simultaneously. Melnick and Oser (1949) and Geiger (1948) have clearly shown that nutrient mutual supplementation is important for growth.

V. SUMMARY

Nine experiments were conducted to study and evaluate the effect of pelleting three rations on growth, feed intake, feed efficiency, carcass quality, ration palatability, energy digestibility, nitrogen digestibility, and rate of food passage. The three test rations were (1) fortified corn-soybean meal, (2) 20 percent oats by weight replacing corn, and (3) 40 percent oats by weight replacing corn.

Pelleting significantly improved growth rate when the three test rations were ad libitum-fed to pigs and rats. The daily gains were the same for all pellet-fed pigs; however, in the meal form of these rations, the gains decreased as the fiber level increased. Feed consumption was generally increased with the pelleted rations. The feed required per pound of bodyweight gain increased with the higher fiber rations, but the increase was less with the pelleted rations. Carcass data showed there were no differences between the experimental rations in regard to dressing percentage, carcass length, backfat, percent lean cuts, percent primal cuts, loin area and percent fat trim.

Pelleting significantly improved daily gains and feed efficiency when the three test rations (pooled data) were equally and ad libitum-fed to paired pigs.

In both the equal and ad libitum feeding trials, the apparent energy digestibility of the high corn (low fiber) pelleted rations was significantly greater than the meal form of the same ration. On an

equal feed intake, the apparent energy digestibility of the 40% oat (high fiber) meal and pelleted rations was not significantly different; however, digestibility of the meal form was significantly improved when ad libitum-fed. Apparent nitrogen digestibility was the same for the high corn and 40% oat rations in either meal or pellet forms.

In the rate of food passage studies, pelleted low and high fiber rations passed significantly faster through the alimentary tract than meal rations when equal and ad libitum-fed. Pooled data showed that the 5% fecal excretion time, 95% fecal excretion time, and the mean ingesta retention time were less with the pelleted rations.

A palatability study with the high corn ration in the forms of meal, pellets and reground pellets showed that pigs definitely preferred pellets.

Two feeding trials were conducted to study the effect of processed corn on the nutritive value of a rat ration. On the basis of growth, different processing methods did not improve the nutritive value of corn.

VI. CONCLUSIONS

The results of these investigations indicated that pelleting a high corn, 20% oat or 40% oat ration resulted in (1) increased daily gains, (2) increased feed consumption, (3) improved feed efficiency, (4) reduced feed wastage, (5) improved the palatability of the rations, (6) improved energy digestibility, (7) increased food passage rate without lowering digestibility, and (8) reduced dustiness. On the basis of ad libitum and equal feeding studies and digestibility studies, it is postulated that the nutritive value of the test rations was improved by the pelleting process. Therefore, pelleting probably altered the chemical nature and/or availability of feed ingredients. Faster growth was attributed to the improvement in the nutritive value of the ration and increased feed intake.

Faster food passage rate through the alimentary tract seemed to be responsible for most of the increase in feed intake. Improved palatability probably supplemented the faster passage rate to increase feed intake. It was thought that improved ration density was important only to improve the palatability of the ration.

Better energy utilization probably had some influence on the improvement of feed efficiency. Inconsistencies in energy digestibility were noted when the low and high fiber rations were ad libitum-fed. More studies must be conducted to properly evaluate this observation. Apparent nitrogen digestibility was not changed by the pelleting process.

Studies on processed corn indicated that pelleting or heat-treating this fraction of a ration did not improve the nutritive value.

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