

THE ROLE OF NIACIN, PANTOTHENIC ACID AND RIBOFLAVIN
IN THE NUTRITION AND HEALTH OF THE WEANLING PIG

By

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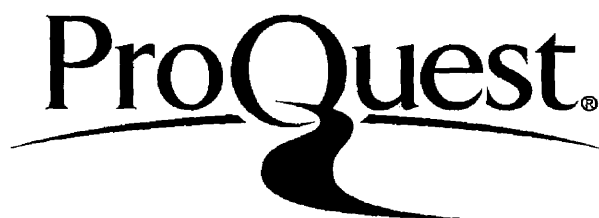
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INTRODUCTION

The first weeks after weaning are nutritionally critical. Diarrhea, post vaccination troubles, nutritional enteritis or swine pellagra, nutritional dermatitis, leg abnormalities, poor growth and high feed requirement are among the evidences of malnutrition. Swine specialists and other agricultural authorities agree that the average weaning weight is about 26 pounds.

Swine producers are reminded of the enormous baby pig losses by many press and radio releases and articles in farm and breed journals. There is a tendency, however, to accept poor doing weanling pigs as a matter of course. Many pork producers get used to their pigs making slow gains and don't realize that poor feeding is robbing them of their profit. Some mysterious "bug" is often blamed for unthriftiness and disease that result from poor feeding.

Results of many trials at experiment stations indicate that some of the feed mixtures now in use are inadequate in one or more of 3 B-vitamins for average weanling pigs. There is great variation in the B-vitamin composition of feedstuffs used for swine. For example, corn may vary 100 percent in its content of the more critical B-vitamins, Hunt et al. (1947). As reported here, the necessary B-vitamin levels appear to be higher for 20 to 30-pound pigs than for pigs weighing over 30 pounds at weaning time. This means that results of many feeding trials with pigs weighing 40 to 80 pounds initially cannot be applied to average weanling pigs.

When anything happens to throw a weanling pig off feed or decrease his appetite, deficiencies of niacin, pantothenic acid, riboflavin and possibly other B-vitamins may occur in a very short time. Deficiency trouble due to vitamin deficiencies is widespread. This is indicated by the general interest of farmers in anything that shows promise of preventing post-weaning runts. Reports from farmers all over the country, especially from the cornbelt, tell of deficiency troubles. Even good swine producers fear runts. Letters from people who consider themselves to be good hog producers tell of having about 15 percent runts each year. It would be foolish to claim that vitamin deficiencies are responsible for all this trouble or that vitamin supplementation will cure all the ills. However, there is now adequate evidence that B-vitamin supplementation is often desirable.

It is important that veterinarians, feed men and nutritionists know and be able to recognize the symptoms of vitamin deficiencies. It is also important that means of preventing and treating the common deficiencies be found and used. Optimum levels of the nutrients involved should be established. Even higher levels may be desirable for insurance against trouble.

The purpose of this thesis is to present experimental results concerning the role of niacin, pantothenic acid and riboflavin in pig growth and in efficiency of feed utilization, as well as their role in disease prevention and treatment.

REVIEW OF LITERATURE

Niacin, tryptophan, protein

August Hirsch (1885) described a noxious factor in maize. He mentioned organic disease and intestinal affection and stated that the trouble was never seen in Europe until maize was introduced.

The main symptom of niacin deficiency is necrotic large intestines. Other symptoms include poor growth, diarrhea, rough hair coats and sometimes dermatitis.

Niacin deficiency in swine has been described by Chick et al. (1938a), Madison et al. (1939), Davis et al. (1940, 1943), Hughes (1943), Powick et al. (1947), Luecke et al. (1947, 1948) and Dunne et al. (1949). Hughes (1943) estimated the requirement on a synthetic diet to be between 5 and 10 mg per 100 pounds of pig.

The occurrence of niacin deficiency is closely associated with corn diets and is related to the protein level and tryptophan content. Krehl et al. (1945, 1946) working with rats, found that the inclusion of corn grits in a niacin-low diet produced retarded growth. Growth was improved by either increasing niacin or tryptophan. Wintrobe (1945) reported that niacin deficiency was not produced when young pigs were fed a purified ration containing 26 percent casein. Powick et al. (1947a) were unable to confirm this work of Wintrobe.

Luecke et al. (1948) found that adequate amounts of tryptophan will prevent nicotinic acid deficiency and that niacin increases the utilization of dietary tryptophan. No symptoms of niacin deficiency were produced on a corn ration containing 25 percent casein. Mild symptoms of niacin deficiency were produced in pigs receiving a total of 17.4 mg of niacin daily.

Luecke et al. (1947, 1948) also established that urinary excretion of N-methylnicotinamide is a good index of niacin deficiency and agrees closely with intestinal lesions and lack of growth.

It is well established that niacin deficiency plays a big part in pig pellagra or nutritional necrotic enteritis. As early as 1934 Kinsley write, "It is usually designated as a filth-borne disease; however, it occurs in swine that are kept under the best sanitary conditions." McEwen (1937) described an outbreak of necrotic enteritis under sanitary conditions and was not able to associate the disease with a specific organism.

Birch et al. (1937) and Chick et al. (1938a) reported loss of appetite, diarrhea, growth stoppage and skin trouble (dermatitis) when a pellagra producing diet was fed. Niacin administration cured the trouble. Davis et al. (1940) presented data indicating that necrotic enteritis develops primarily as a result of nutritional deficiency. Niacin administration was effective both as a cure and as a preventative of necrotic enteritis. Madison et al. (1939) reported quick recovery from a type of necrotic enteritis on a Pennsylvania farm when niacin was fed. Luecke et al. (1949b) found that multiple vitamin supplementation, including niacin, cured B-vitamin deficiency symptoms.

Evidence presented by Powick et al. (1947b, 1948), Luecke et al. (1947, 1948) and McMillen (1949a, 1949b) indicates that practical rations containing corn may often be low in niacin for weanling pigs.

Pantothenic acid

The need for pantothenic acid in swine diets was first reported by Chick et al. (1938b). On a synthetic diet supplemented with B₁, riboflavin, niacin "eluate factor" (pyridoxine), the pigs developed paralysis of the hindquarters. The trouble was prevented when the "filtrate factor" was fed.

Hughes (1942b) associated the absence of pantothenic acid in the diet with leg abnormalities which resulted in incoordination or goose stepping. Other deficiency symptoms included loss of appetite, slow growth, diarrhea and an ulcerated condition of the large intestine.

Wintrobe et al. (1940) described ataxia and degeneration of the myelin sheath of nerve fibers in pigs fed a synthetic diet fortified with the vitamins known at that time. Later Wintrobe et al. (1942) developed this nerve degeneration in the absence of pantothenic acid and pyridoxine. Wintrobe et al. (1943) noted poor growth, loss of hair, diarrhea and small intestinal lesions among other symptoms. All of the symptoms except the abnormal gait could be corrected by the administration of calcium pantothenate.

Ellis et al. (1941) reported lameness, similar to that observed by Wintrobe (1940, 1942, 1943) and Hughes (1942b), in pigs kept in dry lot and fed a ration of corn, tankage, linseed meal, alfalfa meal and mineral. The incidence and severity of the disorder was increased by heating this diet of natural feedstuffs before feeding. In later work Ellis and Madsen (1943) found that pantothenic acid, when added alone, was effective in preventing the trouble. On this ration of natural feedstuffs, incoordination developed after three months. The extreme

symptoms of diarrhea and vomiting observed by earlier workers using a purified diet were not observed by Ellis and Madsen. Even though badly crippled, many pigs made good growth up to market weight.

Leg abnormalities identical with or similar to those described above have been observed at several cornbelt experiment stations. The occurrence of pantothenic acid deficiency on widely used types of rations, Ellis et al. (1943), Fairbanks et al. (1945) and McMillen et al. (1949a, 1949b) suggest that feed mixtures ordinarily used are often deficient in this vitamin.

Hughes et al. (1942a) placed the requirement for pantothenic acid between 179 and 268 μ g. per kg. liveweight. Ellis et al. (1943) used 515 μ g. to protect against nerve degeneration. The recommended allowance in the report of the National Research Council (1944), 18.5 mg (414 μ g. per kg.), is only slightly above the level in rations like the ones found deficient by Ellis et al. (1943). Recent evidence, Luecke et al. (1949a, 1950a) and McMillen et al. (1949a), indicates that recommended levels should be higher under practical feeding conditions than are now generally recognized.

Riboflavin

Hughes (1939) using a synthetic diet published data showing that a lack of riboflavin brought about retarded growth, diarrhea and leg abnormalities. Using a purified diet fortified with B factors other than riboflavin, Hughes (1940) found the requirement to be between 1 and 3 mg per hundred pounds of pig daily. Fence chewing and trembling were also noted as deficiency symptoms.

Patek et al. (1941) listed retarded growth, changes in the skin, hair, hoofs and in the corneal epithelium resulting in the development of lens cataract, as symptoms of clinical deficiency. These workers also noted a collapse syndrome associated with a drop in body temperature, slow and irregular pulse and respiration. Administration of riboflavin produced a rapid response and recovery. Wintrobe et al. (1944) observed swollen eyelids and lens opacities in three pigs on a diet low in riboflavin. These workers also observed rough skin caked over with heavy sebaceous exudate and a peculiar gait similar to that observed in pantothenic acid deficiency.

Riboflavin plays an important role in several enzyme systems. In recent experiments supplementation with small amounts of riboflavin greatly increased feed efficiency. Dyer et al. (1949) found that the addition of 1.5 mg of riboflavin to a corn-soybean meal diet for weanling pigs increased the daily gain from 0.39 to 0.71 pound and decreased the feed requirement from 540 to 350 pounds of feed per hundred pounds of gain. In another experiment, Krider et al. (1949b) using natural feedstuffs set the practical minimum level at 1.4 mg per pound of ration. McMillen et al. (1949a) using a ration consisting of corn, soybean oil meal, meat scraps, and mineral noted slow growth on rations containing 1.12 and 0.97 mg of riboflavin per pound of feed. The addition of 5 mg of riboflavin per pound of feed increased the efficiency of gain 25 and 29 percent in two trials. Mitchell et al. (1949) present evidence which indicates that riboflavin requirements of young pigs are higher in cold environments than at warm temperatures.

Need for B-vitamin supplementation

It is well known that a commonly used ration composed of yellow corn, tankage, soybean meal, alfalfa meal and minerals is inadequate for optimum growth and lactation performance when fed to swine in dry lot. Results of many trials especially at the Illinois, Missouri and Wisconsin Experiment Stations, prove that not only do such rations fail to promote optimum growth and lactation but various abnormalities appear in the pigs. Keith et al. (1942) observed deficiency symptoms in large growing pigs on this type of ration. Much of the earlier work along this line is reviewed by Fairbanks et al. (1944) and Krider et al. (1944). Krider et al. (1944) found that alfalfa meal and distillers solubles brought about nutritional improvement, but the weaning weights of the pigs and subsequent gains were below normal. Pigs from litters fed alfalfa and distillers solubles as well as the pigs fed the basal diets developed diarrhea, dermatitis and various leg abnormalities. Results of these studies led the authors to suggest that the growing-fattening pig may require more of the known vitamins than the literature indicates.

Luecke et al. (1947, 1948) found that the niacin requirement of pigs fed rations of natural feedstuffs is much higher than the early requirements established on a synthetic diet. The results of Powick et al. (1947a, 1947b, 1948) also indicate a high requirement for niacin. Luecke et al. (1949a) found that rations composed of natural feedstuffs may not supply adequate amounts of pantothenic acid.

Krider et al. (1948), Luecke et al. (1947, 1948) and McMillen (1949a) have shown that weanling pigs exhibit a marked response in growth and efficiency to B-vitamin supplementation when fed a corn-soybean ration in dry lot.

Dyer et al. (1949) and McMillen (1949a) presented evidence to show that supplementation with niacin, pantothenic acid and riboflavin was as effective as the addition of several other B-vitamins.

EXPERIMENTAL PROCEDURE AND RESULTS

General procedure

Several experiments have been conducted at Michigan State College from 1946 to 1950 to study niacin, pantothenic acid, and riboflavin deficiencies, supplemental rates and probable use in practical swine diets. The pigs used have been purebred pigs from the college herd and crossbred pigs from the Jackson Prison Farm. All of the pigs except those used in trial 6 were on pasture until put on experiment. The pigs used in trial 6 were raised in dry lot.

Except in trial 1 most of the pigs have averaged under 30 pounds and were about seven weeks of age when started on test. All pigs were self-fed the experimental mixtures and had access to automatic waterers. Except for the pasture trial, all groups were fed in concrete floored pens and were bedded with shavings.

In several of the trials representative pigs were autopsied at the end of the experiment. The blood levels and urinary excretion of the vitamins were studied as measures of adequacy or deficiency of the diet in some of the trials.

The breeding of the pigs is given for each experiment. The detailed composition of the rations is also presented. The pigs were vaccinated for cholera with serum and virus and treated for mange with lime sulfur or benzene hexachloride before being placed on experiment. The sodium fluoride treatment was used for worms.

The gains were tested for significance by the method of Snedecor (1946). Methods employed for the determination of vitamins in the feeds were niacin, Krehl et al. (1943); pantothenic acid, Skeggs and Wright (1944); and riboflavin, Snell and Strong (1939). Protein determinations were carried out by the usual Kjeldahl procedure. Tryptophan determinations were carried out using a modified procedure of Sauberlich and Baumann (1946).

Effect of niacin, tryptophan and
protein supplementation

Trial 1 -

Pigs used in this experiment were Duroc-Yorkshire crossbreds. The composition of the rations is shown in Table 1. Gains and feed requirements are presented in Table 2.

Pigs in lot 1 were fed the 19 percent protein ration A. They averaged 1.0 pound daily gain and required 3.09 pounds of feed per pound of gain. Three of the pigs developed diarrhea by the fourth week. On autopsy at the end of the trial, pigs from lot 1 showed thickened, necrotic large intestines characteristic of niacin deficiency.

TABLE 1

Composition of basal rations for niacin,
tryptophan, protein trials 1 and 2¹

Ingredients of rations	A	B	C	D
	%	%	%	%
Corn	80	87		68
Oats			90	
Casein (commercial)	12	5.5	4	25
Soybean oil meal	6	5.5	4	5
Complex mineral mixture ²	2	2	2	2
Composition				
Crude protein, percent	19.20 (19.10) ³	14.00 (15.10) ³	15.90	29.60
Niacin, mg per lb.	5.22 (8.70) ³	6.23 (11.20) ³	6.25	8.10
Tryptophan, percent	0.20	0.13		0.41

¹ The following amounts of B-vitamins were supplied daily to each animal: thiamine, 10 mg; riboflavin, 10 mg; calcium pantothenate, 25 mg; and pyridoxine hydrochloride, 6 mg. Supplemental vitamins A and D were added in amounts which supplied 2,000 I. U. of A and 200 I. U. of D.

² The mineral mixture contained the following (in %): bonemeal, 32.3; ground limestone, 32.3; sodium chloride, 32.3; ferrous sulfate, 2.5; copper sulfate, 0.2; manganese sulfate, 0.1; zinc oxide, 0.1; cobaltous acetate, 0.1; and potassium iodide, 0.1.

³ Data for trial 2.

TABLE 2

Trial 1 - Influence of niacin, protein level
and tryptophan on gains and feed requirements

(Five pigs in each lot, trials lasting 6 weeks)

Lot No.	Ration	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal A (19% protein)	39	81	1.00	3.09	3.09
2	Basal A $\neq$ N.A. ¹	40	99	1.40**	3.67	2.61
3	Basal B (14% protein)	27	56	0.62	2.20	3.19
4	Basal B $\neq$ N.A. ¹	28	60	0.76	2.27	2.98
5	Basal B $\neq$ tryptophan ²	27	69	1.00*	2.29	2.29
6	Basal C (15.9% protein)	28	60	0.76	2.29	3.01

¹ Pigs in lots 2 and 4 received daily supplements of 30 mg of niacin.

² Pigs in lot 5 received daily supplements of 200 mg of D-L tryptophan.

**Daily gains of lot 2 highly significant over lot 1 ($P \leq 0.01$).

*Daily gains of lot 5 significant over lot 3 ($P \leq 0.05$).

Pigs in lot 2 received the 19 percent protein ration A plus daily supplements of 30 mg of niacin. These pigs averaged 1.4 pound daily gain, a highly significant increase over the gains of the lot 1 pigs. They also required 12 percent less feed per pound of gain. On autopsy pigs from this lot showed no signs of gross pathology.

Pigs in lot 3 received the low-protein (14 percent) ration B. These pigs made an average daily gain of only 0.62 pound and required 3.10 pounds of feed per pound of gain. Four of the six pigs developed severe diarrhea. Their hair coats were rough and the skin was scaly behind the ears. Autopsy revealed severe intestinal lesions.

The lot 4 pigs were fed the 14 percent protein ration B plus 30 mg of niacin daily. The average daily gain, 0.76 pound, is not significantly greater than the lot 3 pigs. However, their feed intakes were greater, feed requirements were slightly lower and autopsy revealed normal intestines.

The pigs in lot 5 were fed the 14 percent, low-protein ration B plus daily supplements of 200 mg of D-L tryptophan. The average daily gain, 1.00 pound, is significant over lot 3. The feed requirement is 23 percent lower than for the unsupplemented lot 3. Two pigs from this lot showed a few lesions in the small intestine on autopsy.

Pigs in lot 6 were fed the oat ration containing 15.9 percent protein. This oat ration was lower in niacin but higher in tryptophan than the corn rations. The pigs made an average daily gain of only 0.76 pound and required 3.01 pounds of feed per pound of gain. This performance is very similar to the pigs in lot 4 getting the low-

protein basal B plus niacin. The pigs developed rough hair coats and did not look like thrifty, fast gaining pigs. There were no intestinal lesions on autopsy. The colons were large and distended with oat hulls.

Trial 2 -

Pigs used in this experiment were Duroc-Yorkshire crossbreds. The composition of the ration is shown in Table 1. The niacin content of the three rations decreased as the level of casein was increased. Since the lots getting a higher level of casein ate more feed, the actual intakes of niacin were quite uniform.

The gains and feed requirements are shown in Table 3. The growth curves for lots 1, 2 and 3 are presented in Fig. 1. The pigs on the basal ration B in lot 1 gained only 0.26 pound daily and required 4.04 pounds of feed per pound of gain. The pigs in lot 2, with daily supplements of 30 mg of niacin, made a highly significant larger gain of 0.61 pound daily and required only 2.25 pounds of feed per pound of gain.

No evidence of the intestinal lesions characteristic of niacin deficiency were observed in pigs autopsied at the end of the experiments from lots 2, 3 and 5. Severe lesions were present in the lot 1 pigs on the basal ration B by the fourth week of the experiment. They exhibited diarrhea, rough hair coats and poor appetites. Intestinal lesions characteristic of niacin deficiency were present on autopsy. Two of the pigs in lot 4 showed diarrhea during the fifth week. Three

TABLE 3

Trial 2 - Influence of niacin, protein level
and tryptophan on gains and feed requirements

(Five pigs in each lot, trials lasting 6 weeks)¹

Lot No.	Ration	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal B (15.1% protein)	22	33	0.26	1.05	4.04
2	Basal B $\neq$ N.A. ²	22	48	0.61**	1.37	2.25
3	Basal B $\neq$ tryptophan ³	22	57	0.84**	1.75	2.08
4	Basal A (19.4% protein) ¹	27	58	0.74	2.00	2.70
5	Basal D (29.6% protein)	22	66	1.05**	2.06	1.96

¹There were six pigs in lot 4.

²Pigs in lot 2 received 30 mg of niacin daily.

³Pigs in lot 3 received 1 gm of D-L tryptophan daily.

**Daily gains of lots 2, 3 and 5 highly significant over lot 1 ($P \leq 0.01$). Lot 3 gains highly significant over lots 1 and 2 ($P \leq 0.01$). Lot 4 not comparable for statistical treatment. Gains of lot 5 highly significant over lots 2 and 3 ($P \leq 0.01$).

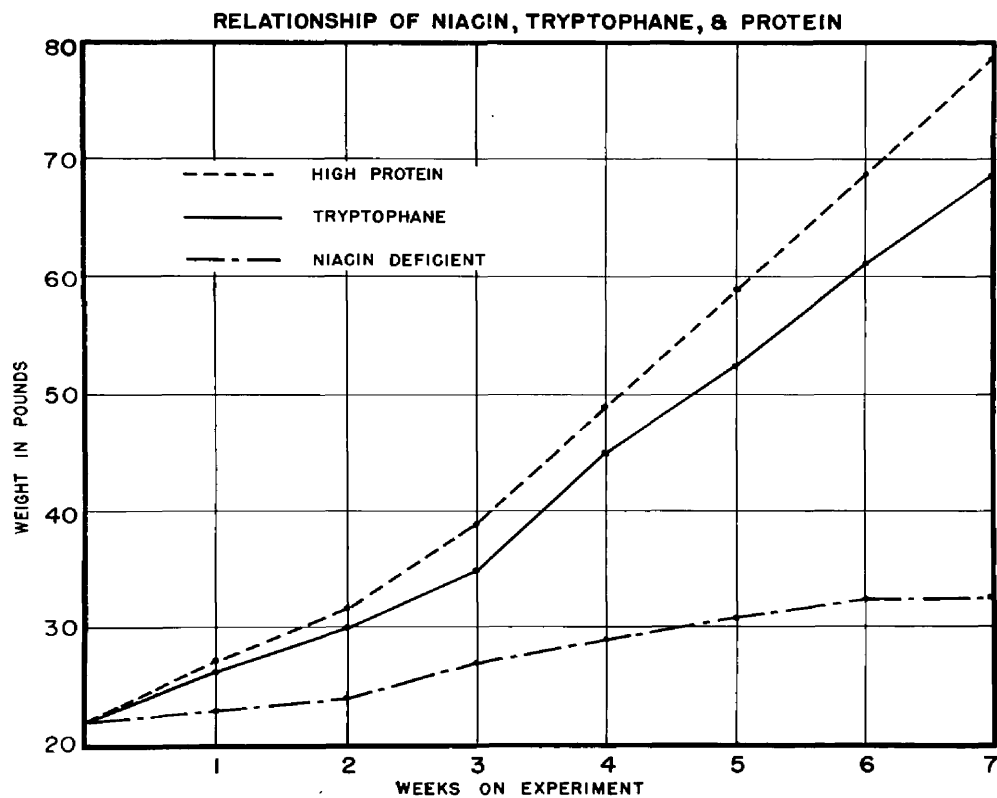


Fig. 1 Relationship of niacin, tryptophane and protein. Note the immediate effect of niacin deficiency indicating that niacin is stored for only a very short time.

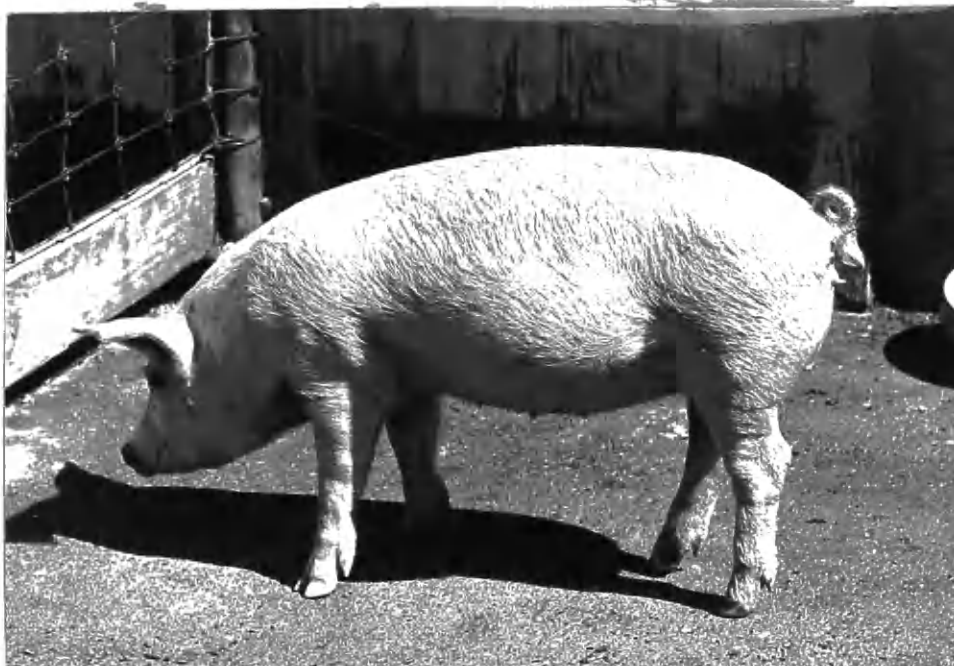


Fig. 2 Pig from niacin supplemented lot 2, trial 2. Pigs in this lot averaged 0.61 pound daily gain and weighed 48 pounds after six weeks' feeding.

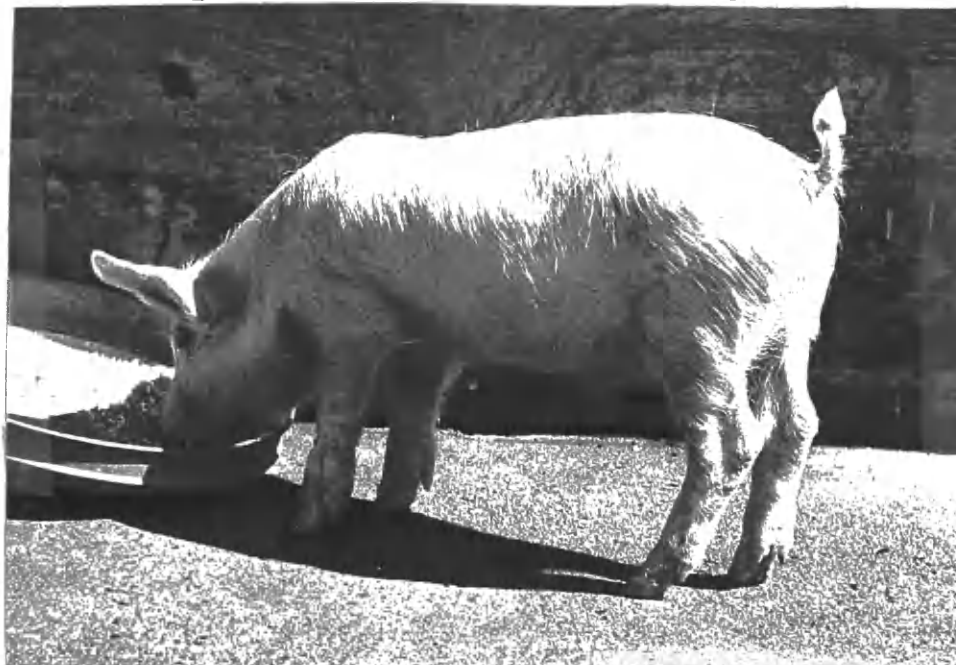


Fig. 3 Niacin deficient pig from lot 1, trial 2. Pigs in this lot averaged only 0.26 pound daily gain and weighed only 33 pounds after six weeks' feeding.

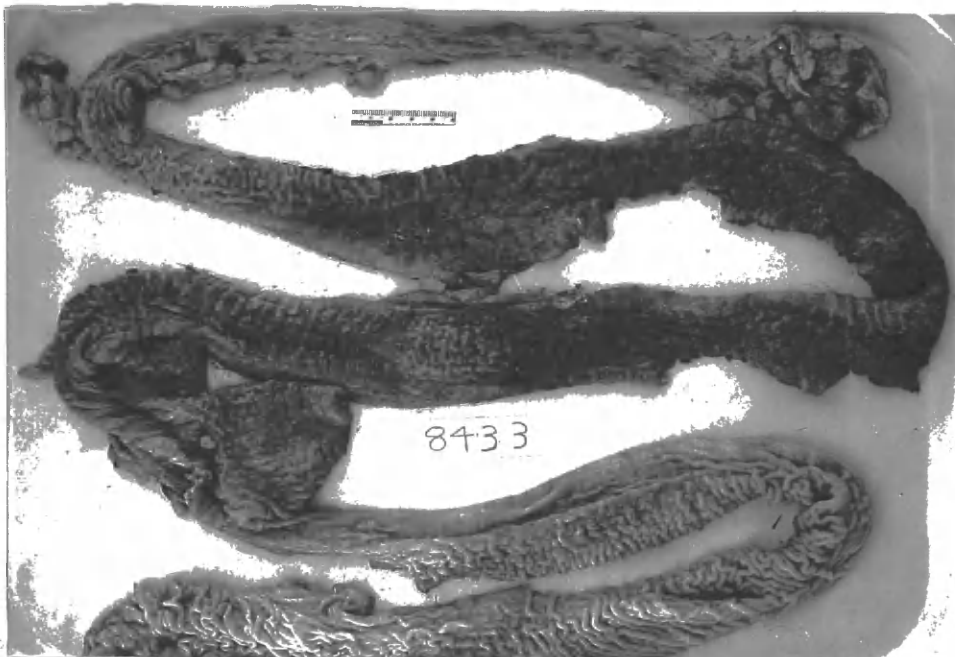


Fig. 4 Niacin deficient large intestine. Note the thickened condition with feces adhering to the inner surface. This picture was taken from a representative pig from lot 1, trial 2 at the end of the six-week trial. This condition has been corrected with niacin or multiple B-vitamin administration in from two to three weeks.



Fig. 5 Normal, healthy large intestine. This picture was taken from a representative pig from lot 2, trial 2.

of the pigs in this lot showed evidence of enteritis. This indicates that this 19.4 percent protein ration did not contain sufficient tryptophan to overcome completely the low-niacin content.

Effect of pantothenic acid supplementation

Trial 3 -

Hampshire pigs were used in lots 1 and 2 and Duroc pigs in lots 3 and 4. The composition of the basal rations is shown in Table 4. The influence of pantothenic acid supplementation on gains and feed requirements is presented in Table 5. The growth curves of lots 2 and 3 are presented in Fig. 6. In both comparisons the pigs receiving 15 mg of supplemental pantothenic acid per pound of feed (lots 2 and 4) made significantly greater gains on substantially less feed than the control pigs in lots 1 and 3.

During the seventh week, two of the pigs in lot 2 exhibited incoordination and by the end of the eighth week, four of the five animals showed abnormal gaits. Pathological examination of the sciatic nerve as described by Luecke et al. (1949a) showed degeneration of the myelin sheath. By the fourth week of the experiment, four of the six pigs in lot 4 exhibited diarrhea which cleared up in about two weeks. Their appetite decreased and the pigs became rough haired and unthrifty. By the seventh week, all of the lot 4 pigs exhibited some incoordination. The sciatic nerves from three pigs in this lot were studied pathologically. Degeneration of the myelin sheath was observed as in the lot 2 pigs.

TABLE 4

Composition of the pantothenic acid-low rations
for trials 3 and 4¹

Ingredients of rations	A	B	C
	%	%	%
Corn	86	87	77
Casein (commercial)	5.5	10	
Soybean oil meal (expeller)	5.5		20
Complex mineral mixture	3	3	3
Composition			
Crude protein, percent	15.80	16.20	16.40
Pantothenic acid, mg per lb.	3.82	3.42	4.21

¹The following vitamins were mixed in rations A and B (values expressed in mg per lb. of feed): thiamine, 5; riboflavin, 5; niacin, 15; pyridoxine, 2.5. Choline chloride was also added to both rations at a level of 0.1 percent. Supplemental vitamins A and D were added in amounts which supplied 2,000 I. U. of A and 200 I. U. of D.

The mineral mixture in rations A and B was the same as in Table 1. The mixture for ration C contained the following (in %): bonemeal, 31.6; ground limestone, 31.6; iodized salt, 31.6; ferrous sulfate, 2.1; magnesium carbonate, 2.0; copper sulfate, 0.2; potassium carbonate, 0.2; manganese sulfate, 0.5; zinc oxide, 0.1; and cobaltous acetate, 0.1.

TABLE 5

Trial 3 - Influence of pantothenic acid supplementation
on gains and feed requirements

(Trials lasting 8 weeks)

Lot No.	Ration	No. pigs per lot	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal A	5	23	66	0.68	2.12	2.76
2	Basal A $\frac{1}{4}$ P.A. ¹	5	23	74	0.91*	1.95	2.14
3	Basal B	6	25	67	0.75	2.32	3.09
4	Basal B $\frac{1}{4}$ P.A. ¹	6	24	86	1.10*	2.50	2.27

¹

Feed mixtures for lots 2 and 4 contained 15 mg supplemental calcium pantothenate per pound of feed.

*Daily gain of lot 2 significant over lot 1 ($P \leq 0.05$) and lot 4 significant over lot 3 ($P \leq 0.05$).

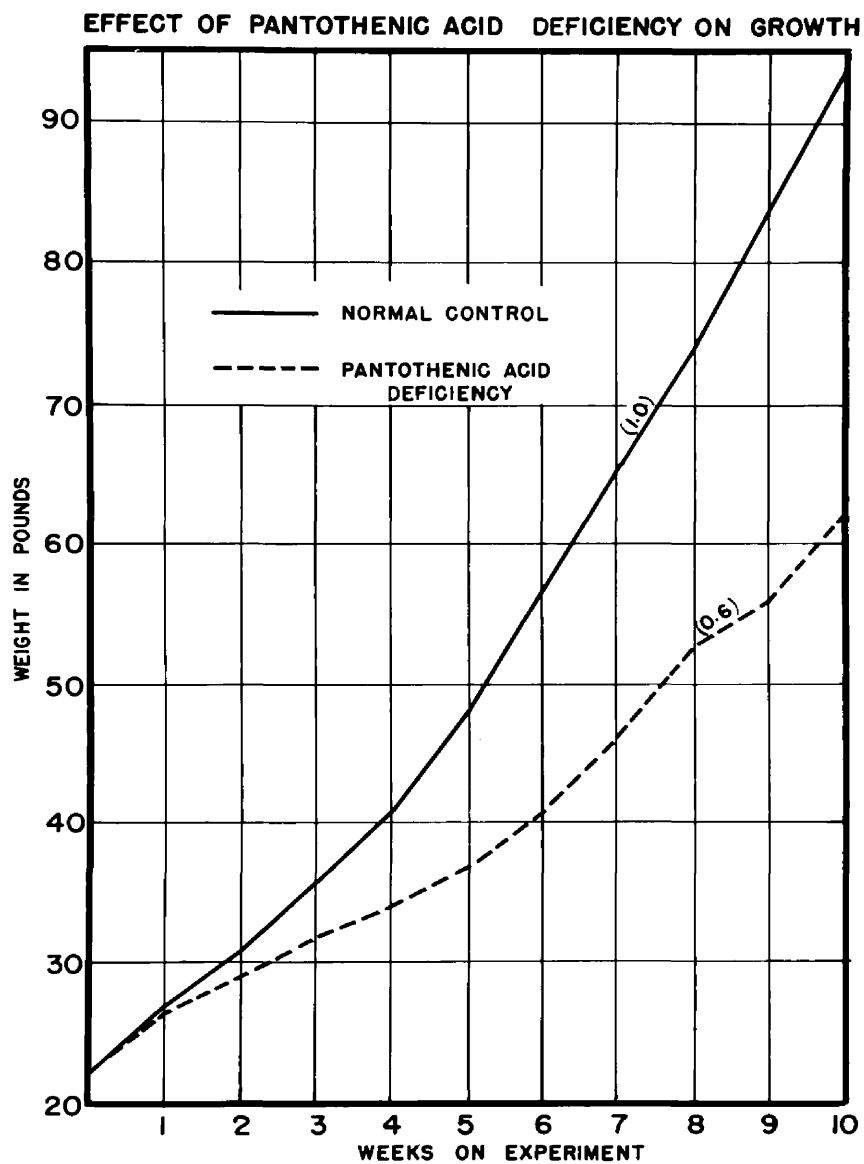


Fig. 6 Effect of pantothenic acid deficiency on growth. Note the difference in growth curves at the end of two weeks indicating that pantothenic acid is stored for only a short time.



Fig. 7 Pig from pantothenic acid supplemented lot 2, trial 4. Pigs in this lot made an average daily gain of 1.05 pounds and weighed 99 pounds at the end of the ten-week trial.



Fig. 8 Pantothenic acid deficient pig from lot 3, trial 4. Note the crooked hind legs which resulted in incoordination and goose stepping. Pigs in this lot gained only 0.60 pound daily and weighed only 66 pounds at the end of the ten-week trial.

Trial 4 -

Purebred Duroc pigs were used in this trial. The composition of the ration fed is shown in Table 4. The influence of pantothenic acid supplementation on gains and feed requirements is presented in Table 6.

The pigs in lot 1 receiving the control diet C without pantothenic acid supplementation gained only 0.4 pound daily. The daily gains were significantly increased in lot 3 by the addition of 5 B-vitamins without pantothenic acid. A similar significant increase in gain was noted in the lot 4 pigs receiving supplemental pantothenic acid only. The daily gains of the pigs in lot 2, receiving all 6 B-vitamins including pantothenic acid, were highly significant over those in the other three lots.

The pigs in lot 3 exhibited diarrhea by the fifth week. As in trial 1, all of the pigs in this pantothenic acid deficient lot showed symptoms of incoordination and degeneration of the sciatic nerve.

The pigs on the basal diet C exhibited diarrhea during the course of the experiment but no symptoms of locomotor incoordination occurred.

Effect of riboflavin level

Trial 5 -

Chester White pigs were used in this trial. The composition of the basal ration is shown in Table 7. The gains and feed requirements are presented in Table 8.

TABLE 6

Trial 4 - Influence of pantothenic acid supplementation
on gains and feed requirements

(Eight pigs in each lot, trials lasting 10 weeks)

Lot No.	Ration	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal C	24	52	0.40	1.56	3.91
2	Basal C / 6 B-vitamins ¹	22	96	1.05**	2.50	2.38
3	Basal C / 5 B-vitamins no P.A. ²	24	66	0.60*	1.83	3.05
4	Basal C / P.A. only ³	23	66	0.62*	2.16	3.48

¹ Pigs in lot 2 received supplementary B-vitamins in the following amounts (mg per lb. of feed): thiamine, 2.5; riboflavin, 5; niacin, 10; calcium pantothenate, 10; and pyridoxine, 1.5. Choline chloride was added at a level of 0.05 percent.

² Pigs in lot 3 received the same B-vitamins as lot 2 except calcium pantothenate was left out.

³ Pigs in lot 4 received only calcium pantothenate at a level of 10 mg per pound of feed.

**Daily gains of lot 2 highly significant over lots 1, 3 and 4 ($P \leq 0.01$).

*Gains of lots 3 and 4 significant over lot 1 ($P \leq 0.05$).

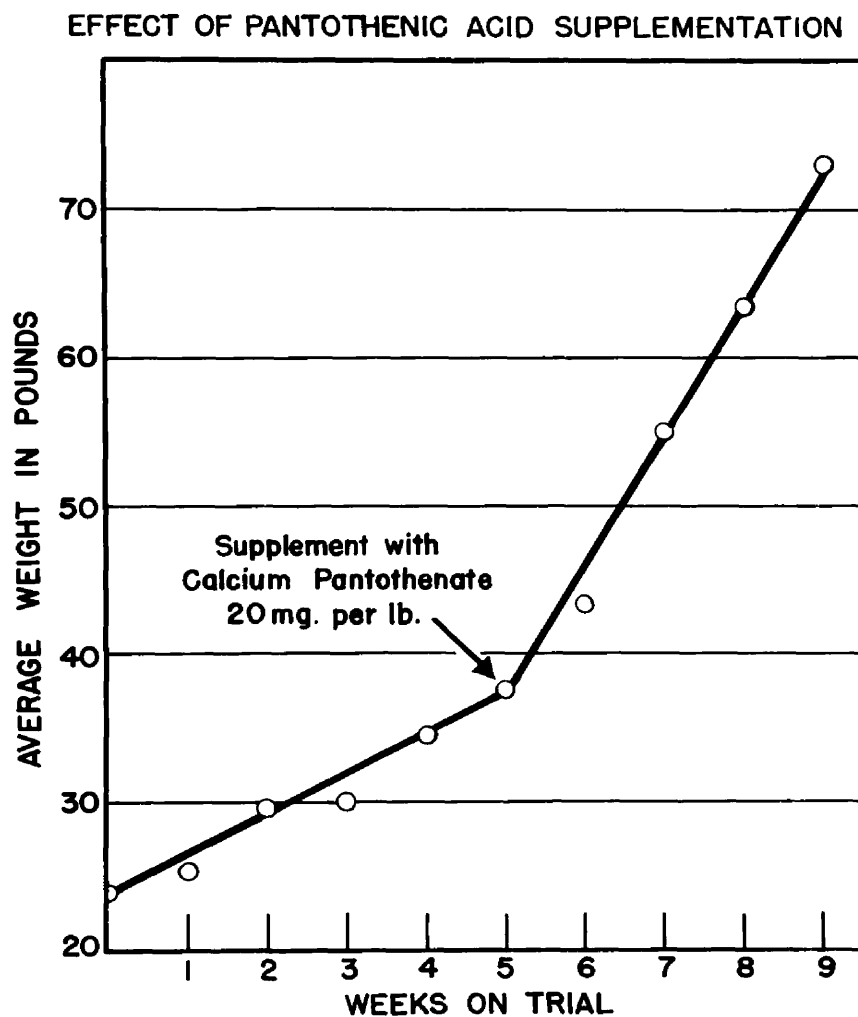


Fig. 9 Effect of pantothenic acid supplementation to a deficient ration. This marked response to supplementation can be expected only when the vitamin added is the only one deficient. In fact, the addition of the single vitamin to a multiple deficient feed mixture has been shown to aggravate the trouble. The feed mixture used was ration A, Table 9.

TABLE 7

Composition of riboflavin-low ration for trial 5¹

Ingredients of ration	Percent
Corn	77
Soybean oil meal	20
Mineral ²	3
Composition	
Crude protein, percent	16.60
Riboflavin, mg per lb.	0.84

¹The following B-vitamins were added (mg per pound of feed): thiamine, 5; niacin, 20; pantothenic acid, 20; pyridoxine, 2.5. Supplemental vitamins A and D were added in amounts which supplied 2,000 I. U. of A and 200 I. U. of D.

²The mineral mixture was the same as the one listed as a footnote to Table 1.

TABLE 8

Trial 5 - The influence of riboflavin level
on gains and feed requirements

(Nine pigs per lot, trials lasting 8 weeks)

Lot No.	Ration	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal	22	63	0.73	2.17	2.96
2	Basal + 1 mg ribo. per lb.	22	69	0.84	2.40	2.86
3	Basal + 2.5 mg ribo. per lb.	23	76	0.95*	2.62	2.77

*Differences in daily gains not statistically significant.

While the differences with increasing levels of riboflavin are not significant, there is an indication in the data that supplemental riboflavin increased the gains and lowered the feed requirement.

Effect of combined niacin, pantothenic acid
and riboflavin supplementation

Dry-lot raised purebred Duroc pigs were used in trial 6. In trial 7 pasture raised Duroc x Poland x Hampshire pigs were used. The composition of the rations used is shown in Table 9.

Trial 6 -

The results of B-vitamin supplementation in trial 6 are shown in Table 10. Growth curves of the pigs are shown in Fig. 12. Pigs in lot 1 on the basal ration gained only 0.63 pound per day and required 4.01 pounds of feed per pound of gain. There was no additional growth response in lot 2 from the addition of calcium pantothenate. In lot 3, the riboflavin supplement in addition to calcium pantothenate brought about an increase in the daily gain to 0.73 pound and decreased the feed required per pound of gain. During the fifth and sixth weeks several pigs in lot 3 exhibited diarrhea which may have been due to a borderline niacin deficiency. Two of the pigs showed typical niacin deficiency symptoms described by Dunne et al. (1949).

The pigs in lot 4 receiving supplementary calcium pantothenate, riboflavin and niacin made significantly higher daily gains (1.00 lb.)



Fig. 10 Pig with multiple B-vitamin deficiency on a corn-soybean meal diet. The pig had not gained for over two weeks. Note the rough hair and mange-like skin.



Fig. 11 Effect of multiple B-vitamin supplementation. The pig had made a gain of 0.65 pound per day and had completely recovered from the rough hair and unhealthy skin condition in two weeks.

TABLE 9
Composition of basal rations for trials 6 and 7

Ingredients of rations ¹	A	B
	%	%
Ground yellow corn	48	68
Oats	15	
Soybean oil meal (expeller)	12	12
Meat scraps	12	12
Alfalfa meal ²	10	5
Complex mineral mixture ³	3	3
Composition		
Crude protein, percent	19.50	18.20
Thiamine, mg per lb.	1.50	1.30
Riboflavin, mg per lb.	1.12	0.97
Pantothenic acid, mg per lb.	5.04	4.35
Niacin, mg per lb.	12.15	13.50

¹When synthetic vitamins were added to both rations they were added in the following amounts per lb. of feed: niacin, 20 mg; calcium pantothenate, 15 mg; riboflavin, 5 mg; thiamine, 5 mg; pyridoxine, 2 mg; B₁₂ concentrate (Merck) 0.25%; and choline chloride, 0.1%. Supplemental vitamins A and D were added in amounts which supplied 2,000 I. U. of A and 200 I. U. of D.

²The alfalfa meal in ration A was dehydrated 17% protein and in ration B was sun-cured 15% protein.

³The mineral mixture was the same as described in the footnote to Table 1.

TABLE 10

Trial 6 - Influence of B-vitamin supplements on
gains and feed requirements¹

(Seven pigs in each lot, trial lasting ten weeks)

Lot No.	Ration	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal B	24	68	0.63	2.53	4.01
2	Basal + P.A.	24	68	0.63	2.91	4.62
3	Basal + P.A. + ribo.	24	75	0.73	2.43	3.33
4	Basal + P.A. + ribo. + N.A.	23	93	1.00**	3.14	3.14
5	Basal + P.A. + ribo. + N.A. + pyridoxine + thiamine + choline	24	90	0.94**	3.06	3.26

¹ See footnote to Table 9 for levels of B-vitamins added.

**Daily gains of lots 4 and 5 highly significant over lot 1 ($P \leq 0.01$).

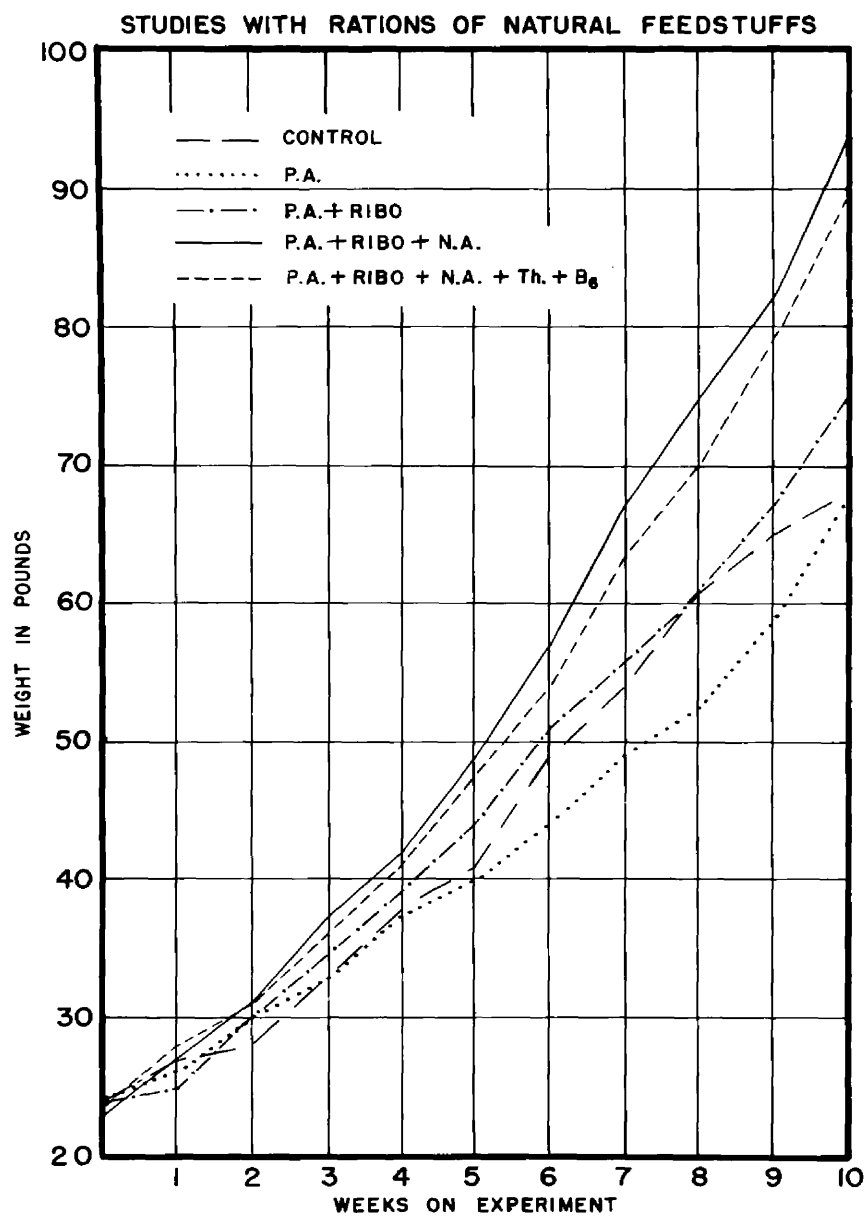


Fig. 12 Effect of B-vitamin supplementation with rations of natural feedstuffs. Growth curves for lots of pigs in trial 6. Note the significant increase in growth from the supplementation with pantothenic acid / riboflavin / niacin.

and required 22 percent less feed per unit of gain than the controls. The lot 5 pigs getting the 6 B-vitamins made an average daily gain of 0.94 pound. This gain is also highly significant over the controls and not significantly different from the gains made by lot 4. Their gains were 19 percent more efficient than the control pigs in lot 1.

Trial 7 -

The results in trial 7 are presented in Table 11. There are no significant differences between the daily gains and feed requirements of lots 1, 2, 3 and 4. It is interesting that again as in trial 6 the addition of supplementary calcium pantothenate, niacin and riboflavin (lot 5) brought about a significant increase in daily gain. The lot 5 pigs made an average daily gain of 1.01 pound daily and required 25 percent less feed than the lot 1 pigs fed the unsupplemented basal ration. The addition of vitamin B₁₂ concentrate in lot 6 had no significant effect on gains or feed requirements. Again as in trial 6, the addition of thiamine, pyridoxine and choline in lot 7 failed to further stimulate growth or increase feed efficiency. In fact, in both these trials the gains were slightly lower and the feed requirements higher when thiamine, pyridoxine and choline were added.

The lot 1 pigs getting only the basal ration in both trials exhibited diarrhea at various times during the experiments. Their hair coats were rough and they were obviously deficient. Four of the pigs in lot 1, trial 7, were goose stepping at the end of the trial.

TABLE 11

Trial 7 - Influence of B-vitamin supplements on
gains and feed requirements¹

(Eight pigs in each lot, trial lasting nine weeks)

Lot No.	Ration	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal A	27	69	0.66	2.83	4.30
2	Basal + P.A.	26	69	0.68	2.88	4.23
3	Basal + N.A.	26	70	0.70	2.85	4.07
4	Basal + P.A. + N.A.	26	76	0.79	3.17	4.02
5	Basal + P.A. + N.A. + ribo.	27	91	1.01*	3.26	3.23
6	Basal + P.A. + N.A. + ribo. + B ₁₂	27	91	1.02*	3.65	3.58
7	Basal + P.A. + N.A. + ribo. + B ₁₂ + thiamine + pyridoxine + choline	26	86	0.96*	3.27	3.41

¹ See footnote to Table 9 for levels of B-vitamins added.

*Daily gains of lots 5, 6 and 7 significant over lot 1 ($P \leq 0.05$).

These results indicate that the rations used in trials 6 and 7 were deficient in niacin, pantothenic acid and riboflavin. The levels of riboflavin, niacin and pantothenic acid in rations A and B (Table 1) should be adequate for normal growth when based on the recommendations of the National Research Council (1944). However, it appears that requirements for these vitamins on this type of feed mixture are considerably higher than those established from earlier experiments using synthetic diets.

Rape pasture as a source of B-vitamins

Trial 8 -

The pigs used in the pasture trial were purebred Chester Whites and Durocs. Each lot of pigs had access to one-quarter acre of rape pasture and green forage was always available. The composition of the basal rations is shown in Table 12. The gains and feed requirements are presented in Table 13.

There was little difference in daily gain and feed requirement between the pigs in lot 1 on the corn-soybean meal basal ration A and those in lot 2 getting supplemental B-vitamins in addition. The pigs in lot 3 on basal ration B, gained 0.61 pound daily compared to 0.39 pound daily for the pigs in lot 4 getting B-vitamins in addition to the corn-tankage ration B. This basal ration B was analyzed and found to be deficient in at least one amino acid and the B-vitamin supplementation appeared to aggravate the deficiency.

Another interesting observation was the fact that the pigs in

TABLE 12

Composition of basal rations for the pasture trial 8¹

Ingredients of rations	A	B
	%	%
Corn	77	82.5
Soybean oil meal (solvent)	20	
Digester tankage		16
Minerals ²	3	1.5
Composition		
Crude protein, percent	17.19	17.13
Niacin, mg per lb.	11.48	13.56
Pantothenic acid, mg per lb.	3.86	1.91
Riboflavin, mg per lb.	0.79	0.78

¹ Pigs in lots 2 and 4 received supplementary B-vitamins in the following amounts (mg per lb. of feed): niacin, 15; calcium pantothenate, 10; riboflavin, 2. Supplemental vitamins A and D were added in amounts which supplied 2,000 I. U. of A and 200 I. U. of D.

² The complex mineral mixture was the one outlined in the footnote to Table 1.

TABLE 13

Trial 8 - Influence of B-vitamin supplementation on gains
and feed requirements on rape pasture

(Eight pigs per lot, trials lasting 8 weeks)

Lot No.	Ration	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal A	31	93	1.11**	2.99	2.70
2	Basal A + B-vitamins	30	90	1.07**	3.03	2.83
3	Basal B	31	65	0.61	2.03	3.34
4	Basal B + B-vitamins	31	53	0.39	1.65	4.21

¹ See footnote to Table 12 for levels of B-vitamins added.

**Daily gains of lots 1 and 2 highly significant over lots 3 and 4
($P \leq 0.01$).

lots 3 and 4 consumed much less herbage than the pigs getting the more adequate basal ration A. Rape pasture proved to be an adequate source of B-vitamins under the conditions of this trial.

Alfalfa meal as a source of B-vitamins

Trial 9 -

Purebred Duroc and Chester White pigs were used in this trial. The composition of the basal rations is shown in Table 14. The gains and feed requirements are shown in Table 15. The pigs in lot 1 getting the corn-soybean meal-B-vitamin diet gained 0.86 pound daily and required 3.06 pounds of feed per pound of gain. The pigs in lot 2 getting APF in addition to the basal gained slightly faster, averaging 0.95 pound daily gain on 2.79 pounds of feed.

The pigs in lot 3 getting basal ration B with 5 percent alfalfa meal substituted for the crystalline B-vitamins gained only 0.55 pound daily, highly significant lower gains than the pigs in lots 1 and 2, getting the crystalline B-vitamins. Pigs getting the APF supplement in lot 4 gained slightly faster, 0.62 pound daily on less feed than lot 3 pigs, but the difference is not significant.

The growth rates of these lots from the beginning of the experiment until lot 1 weighed 200 pounds are shown in Fig. 13. It is interesting that the alfalfa-APF lot 4 made the same daily gain as lot 1 for the entire trial. However, the gains of lot 4 were significantly less than lot 2, receiving crystalline B-vitamins and APF, both at eight weeks and at the end of the experiment.

TABLE 14
Composition of basal rations for trial 9

Ingredients of rations	A ¹	B
	%	%
Corn	72	68
Soybean oil meal (expeller)	25	24
Dehydrated alfalfa meal		5
Complex mineral	3	3
Composition		
Crude protein, percent	17.82	18.2
Niacin, mg per lb.	25.82	11.84
Pantothenic acid, mg per lb.	14.15	4.35
Riboflavin, mg per lb.	3.17	1.11

¹ The following B-vitamins were added to ration A (mg per lb. of feed): niacin, 15; calcium pantothenate, 10; and riboflavin, 2.5. Supplemental vitamins A and D were added in amounts which supplied 2,000 I. U. of A and 200 I. U. of D. Mineral was added as given in the footnote to Table 1.

TABLE 15

Trial 9 - Alfalfa meal as a source of B-vitamins
with and without APF supplement¹

(Eight pigs per lot, trials lasting 8 weeks)

Lot No.	Ration	Initial weight lbs.	Final weight lbs.	Av. daily gain lbs.	Av. daily ration lbs.	Feed per lb. of gain lbs.
1	Basal A + B-vitamins	28	76	0.86**	2.62	3.06
2	Same as 1 + APF	28	81	0.95**	2.64	2.79
3	Basal B	27	58	0.55	2.00	3.62
4	Same as 3 + APF	28	63	0.62	2.02	3.24

¹ See footnote to Table 14 for levels of B-vitamins added.

**Daily gains of lots 1 and 2 highly significant over lots 3 and 4
($P \leq 0.01$).

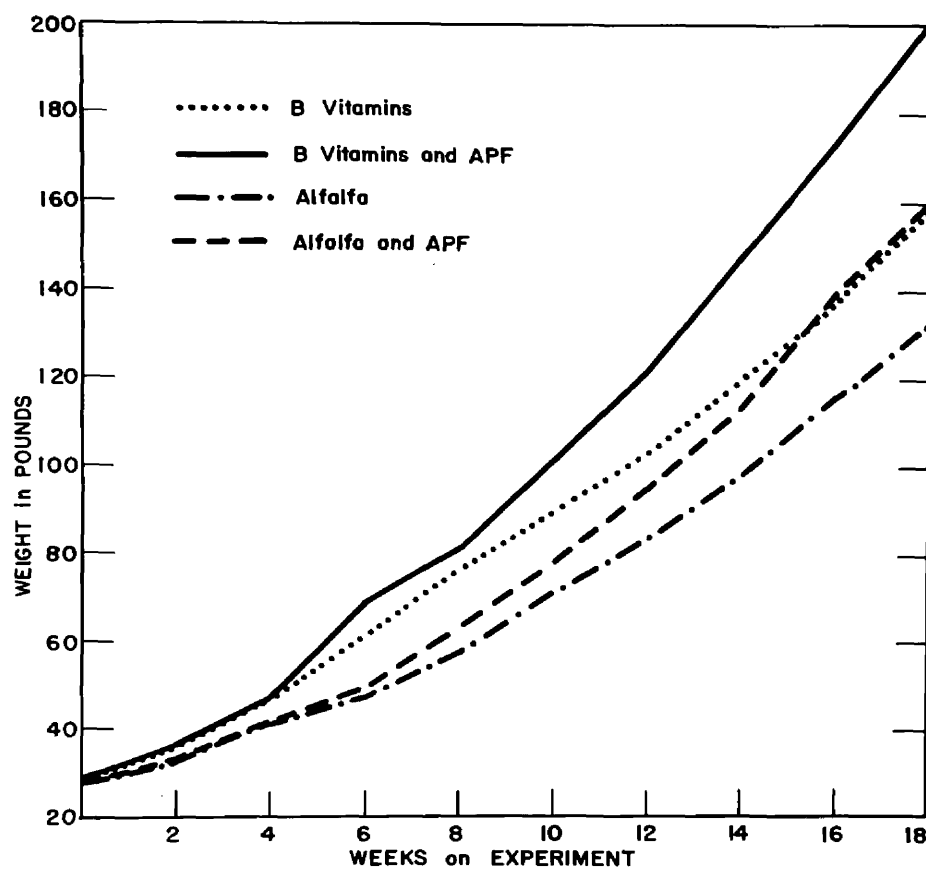


Fig. 13 Alfalfa meal as a source of B-vitamins. Note the poor growth of the alfalfa pigs, lot 3, trial 9.

All of the pigs in lot 3 receiving alfalfa meal exhibited incoordination characteristic of pantothenic acid deficiency by the thirteenth week. These lot 3 pigs also exhibited periodic diarrhea and mild dermatitis during the trial. The 5 percent alfalfa meal proved to be inadequate as a source of B-vitamins under the conditions of this experiment. The corn-soybean meal-B-vitamin ration (lot 1) became deficient in APF after 8 weeks.

Influence of initial weight and adequacy of ration
on gains and percentage of poor doing pigs

B-vitamin supplementation was found to increase the gain and decrease the percentage of the poor doing pigs. In Table 16, data on all of the pigs used in these experiments on which 8-week weights are available, has been arranged in 4 groups. Group 1 includes the pigs ranging in weight from 28-32 pounds which received all three of the vitamins. Group 2 includes 28-32 pound pigs which had one or more of the vitamins missing in the diet. Group 3 includes 22-26 pound pigs receiving all three vitamins and Group 4, 22-26 pound pigs with at least one vitamin missing.

If a pig failed to make an average daily gain of 0.80 pound for the eight-week period, he was considered to be deficient. Data in the table reveal that only 1 out of 24 of the Group 1 pigs (4.2 percent), weighing 28 to 32 pounds initially, failed to gain 0.80 pound daily when the 3 B-vitamins were fed. Eighteen out of 25 (72 percent) of the 28 to 32 pound pigs (Group 2) became deficient when one or more of these vitamins were left out of the ration.

TABLE 16

Influence of initial weight and adequacy of ration
on gains and percentage of poor doing pigs

	Group 1, 28-32 lb. pigs, ade- quate ration	Group 2, 28-32 lb. pigs, defi- cient ration	Group 3, 22-26 lb. pigs, ade- quate ration	Group 4, 22-26 lb. pigs, defi- cient ration
No. of pigs	24	25	42	55
Av. initial weight lbs.	29.5	29.8	23.9	24.1
56-day gain lbs.	57.3	36.6	55.8	34.5
Av. daily gain lbs.	1.02	0.65	1.00	0.62
Range of gains lbs.	42-76	03-68	32-78	10-61
Coefficient of variation percent	15.66	43.00	20.47	41.92
No. of poor doing pigs	12	18	9	40
Percent of poor doing pigs	4.2	72.0	21.4	72.7

Nine out of 42 (21.4 percent) of the pigs in Group 3 weighing 22 to 26 pounds initially, became deficient even though they received the 3 B-vitamins. Forty out of 55 (72.7 percent) of the pigs in Group 4 weighing 22 to 26 pounds, made poor gains when one or more of the vitamins were left out. These results indicate that higher levels of the 3 B-vitamins are more necessary for 25-pound pigs than for 30-pound pigs.

The coefficients of variation for the supplemented pigs were 15.66 and 20.47 percent respectively for the two groups. For the deficient pigs, the coefficients of variation were 41.92 and 43.00 percent. This means that variation in gain, as well as average daily gain itself, is an indication of deficiency.

DISCUSSION

The role of niacin

The data presented here along with supporting evidence establishes niacin as an essential factor in the prevention of deficiency symptoms on low-protein diets consisting largely of corn. These deficiency symptoms include loss of appetite, poor growth, rough hair coats, dermatitis and especially thickened large intestines accompanied with diarrhea.

The results reported in Tables 2 and 3 show that adequate amounts of D-L tryptophan will prevent niacin deficiency in the pig on low-protein rations, with niacin appearing to increase the utilization of dietary tryptophan. No symptoms of niacin deficiency were

observed when the pigs received either 30 mg of niacin or 1 gram of D-L tryptophan daily. These results are in agreement with those of Krehl et al. (1945, 1946a, 1946b) in that supplemental niacin and tryptophan increased the growth rate in rats on niacin-low corn diets. Powick et al. (1948) found niacin not to be completely effective as a substitute for tryptophan but tryptophan appeared to be a satisfactory substitute for niacin.

No symptoms of niacin deficiency were observed on a corn ration containing 25 percent casein (trial 2). These results confirm the work of Wintrobe et al. (1945).

Severe niacin deficiency was observed on a feed mixture containing 15.1 percent protein with 11.2 mg of niacin per pound of feed. Borderline niacin deficiency was observed on a 19.4 percent protein ration containing 8.7 mg of niacin per pound.

These results indicate that the niacin requirement estimated by Hughes (1943) through the use of purified ration is too low for corn rations. This observation agrees with that of Powick et al. (1947b) who observed severe niacin deficiency in young pigs receiving up to 0.47 mg of niacin per kg. of live weight per day.

While the gains were low and inefficient, a feed mixture containing 90 percent oats prevented the characteristic lesions and other symptoms of niacin deficiency. This observation is interesting in the light of the results reported by Davis et al. (1940) that nutritional deficiency is prevented or greatly reduced on a barley ration. Davis and coworkers also observed fewer pigs affected with

nutritional necrotic enteritis when fed wheat or oat groats instead of corn. It seems likely that the higher tryptophan content of the other grains such as oats, barley and wheat accounts for the lowered niacin requirement. The fact that there is a direct relationship between the tryptophan levels in the feed and the niacin requirement of the pig is of practical importance where corn is a major constituent of the ration. Corn is a very poor source of both tryptophan and niacin and care must be taken to insure adequate levels of both in the ration.

Another interesting observation is the fact that the disease was produced more easily in pigs weighing less than 30 pounds initially than in 40-pound pigs. Braude et al. (1946) were unable to produce niacin deficiency in heavier pigs. It is likely, however, that niacin deficiency along with a shortage of other B-vitamins is a common occurrence under farm conditions. Thorp et al. (1950) observed typical symptoms of niacin deficiency in 80-pound pigs that were on a ration of corn, soybean oil meal, meat scraps, mineral and poor pasture. Luecke et al. (1949b) found severe B-vitamin deficiencies in eleven groups of pigs on farms that averaged 17 to 40 pounds in weight. Pigs autopsied from each group indicated severe lesions characteristic of niacin deficiency. Field cases exhibiting intestinal lesions on Pennsylvania farms studied by Madison et al. (1939) responded to administration of niacin.

The role of pantothenic acid

There is ample evidence from the trials reported here and in the literature to identify pantothenic acid with degeneration of the myelin sheath of the sciatic nerve and resulting incoordination of the hind legs, or goose stepping. In every trial in which pantothenic acid was left out (trials 3, 4, 6, 7, 8 and 9) goose stepping occurred in from 7 to 13 weeks. In the trials where only a part of the pigs exhibited abnormal gaits, it appeared that practically all of the pigs were affected. Even though they did not show the definite stringhalt-like gait, they would slip down on the scales or wet places on the floor.

Goose stepping has not occurred in any of the several lots where ample pantothenic acid supplements have been added. Further evidence of the inadequacy of the pantothenic acid-low rations are the lower blood and urinary excretion levels reported by Luecke et al. (1949a, 1950a). Blood levels were found to be uniformly low in deficient pigs and to be a good criterion of the adequacy of the diet.

The incoordination resembled that described by Wintrobe et al. (1942), Hughes (1942b), Ellis et al. (1943) and Fairbanks et al. (1945). This type of leg abnormality has been observed on many corn-belt farms. Wehrbein (1916) and Doyle (1937) reported incoordination under practical feeding conditions. Goose stepping has been observed in the field in pasture-fed pigs. It has occurred under pasture feeding in trial 8 and in other experiments. Alfalfa meal cannot be depended upon to prevent entirely the trouble (trials 6, 7 and 9).

Deficiency symptoms have been observed on rations containing up to 5.04 mg of pantothenic acid per pound of feed (trial 7). There is considerable evidence that levels now generally recommended are too low for feed mixtures commonly fed in dry lot.

The role of riboflavin

The several deficiency symptoms described by Hughes (1940), Patek et al. (1941) and Wintrobe et al. (1944) have not been duplicated in experiments with pigs on diets of natural feedstuffs. In fact, no definite symptoms, like "nutritional necro" and goose stepping which characterize niacin and pantothenic acid deficiency, have been attributed to a lack of riboflavin. Some recent information, Krider et al. (1949b), Dyer et al. (1949) and McMillen et al. (1949a) identify riboflavin with efficiency of feed utilization.

The results of riboflavin supplementation in trial 5 are marred by too much variation within lots. It is interesting, however, that gains and feed efficiency increased with the addition of 1 mg and 2.5 mg of riboflavin per pound of feed to the corn-soybean meal ration. The addition of synthetic riboflavin to the commonly used type of ration in trials 6 and 7 greatly increased the efficiency of feed utilization, 25 and 29 percent respectively in the two trials. This increase in efficiency is in agreement with the findings of Krider et al. (1949b) and Dyer et al. (1949). It is reasonable to assume that riboflavin has been responsible for some of the increased efficiency noted on the addition of crystalline B-vitamin mixtures in

several trials at the Michigan and Illinois Experiment Stations.

Krider et al. (1949b) found the practical minimum level of riboflavin on mixed rations to be 1.4 mg per pound of ration. The results of trials 6 and 7 indicate that the optimum level may be higher.

The effect of combined niacin, pantothenic acid
and riboflavin supplementation

Substantial evidence has been presented which indicates that commonly used rations when fed in dry lot to weanling pigs are likely to be deficient in either niacin, pantothenic acid or riboflavin or in any two or all three of these vitamins.

In trials 6 and 7 the addition of synthetic niacin, pantothenic acid or riboflavin alone or any two of them together had little effect on gains. The same can be said for effect on feed requirement except for riboflavin. Riboflavin apparently increased feed efficiency in both trials. The significant finding is that the addition of the three vitamins together significantly increased gains and definitely lowered the feed requirement. Similar results were reported by Dyer et al. (1949) using a corn-soybean meal type of ration.

In trials 6 and 7 the addition of thiamine, pyridoxine and choline failed to increase gains and efficiency. Dyer et al. (1949) also failed to get an added growth response on addition of thiamine, pyridoxine and choline. These workers did get a substantial boost over the basal with choline alone. Krider et al. (1948) did not get an increase in gain and efficiency by the addition of biotin, pyracin,

inositol, para-aminobenzoic acid (PABA), or pteroylglutamic acid (PGA). Experimental evidence to date indicates that niacin, pantothenic acid and riboflavin are the B-vitamins most likely to be deficient in the diet of weanling pigs in dry lot. The necessity for increased levels of choline in practical swine rations is still open to question. Other B-vitamins have not been shown to be of practical significance.

The results reported here, along with those reported by Luecke et al. (1949b), identify B-vitamin supplementation with a role in the prevention and treatment of multiple B-vitamin deficiencies both under experimental and farm conditions.

Results of these experiments not only demonstrate that B-vitamin supplementation leads to more efficient gains but there is a strong indication that the use of these 3 B-vitamins exert a protein sparing action. The pigs from the B-vitamin supplemented lots in these experiments have averaged 1.0 pound daily gains (Table 16). It is interesting that these gains have been attained on corn-soybean type rations practically identical with those obtained by Dyer et al. (1949) and Krider et al. (1948, 1949) on corn-soybean oil meal rations containing 20 percent total crude protein.

These results are not surprising since it has been shown that each of these 3 vitamins have been known to exert protein sparing effect. Sure et al. (1948), working with rats, found that various components of the B complex increased the biological value of casein and the economy of feed utilization. It is well established that

niacin spares tryptophan, Krehl et al. (1945, 1946a, 1946b), Wintrobe (1945) and Luecke et al. (1947, 1948). Pantothenic acid has recently been shown to increase nitrogen retention in the pig, P. Emsbo et al. (1949). These workers found that the nitrogen retention in percent of resorbed nitrogen is appreciably lower in pantothenic acid deficient pigs than in those that received pantothenic acid.

The work of McMillen et al. (1949a), Dyer et al. (1949) and Krider et al. (1949b) suggest that riboflavin is an important factor in efficiency of feed utilization. From the evidence of a relation of these 3 vitamins individually with protein metabolism and efficiency in feed utilization, it is not surprising that supplementation with liberal quantities of niacin, pantothenic acid and riboflavin reduces the level of protein required.

This apparent protein sparing action means that the protein requirements of weanling pigs must be reevaluated in the light of B-vitamin supplementation. Early work on protein requirement was carried out with rations which may have been inadequate in B-vitamins. Fortification with these 3 B-vitamins, then, appears to be of great practical importance.

Adequate levels of B-vitamins offer insurance against the occurrence of deficiency symptoms which are common on American farms, Luecke et al. (1949). There is ample evidence that B-vitamin fortification increased the efficiency of feed utilization on both corn-soybean meal and mixed type of rations containing other ingredients. In this study,

only 4.2 percent of the 30-pound pigs that received the 3 vitamins failed to gain 0.80 pound daily, while 72 percent failed to make the gain when one or more of the vitamins was left out of the feed mixture. This means that B-vitamin supplementation offers insurance against runty pigs.

The very recent work of Luecke et al. (1950b), Cunha et al. (1950) and others, indicate that antibiotic effect plays an important part in the synthesis of B-vitamins and possible other factors in the large intestine of the pig. So far this antibiotic effect has been demonstrated only in the presence of B-vitamin supplementation. Future research may reveal that antibiotics can replace B-vitamins in the diet of the pig. The role of the B-vitamins will need to be reevaluated in experiments in which antibiotic and APF supplements are used.

SUMMARY AND CONCLUSIONS

Results are reported of the effect of niacin, pantothenic acid and riboflavin supplementation for nine experiments involving 292 weanling pigs.

Niacin was found to prevent pig pellagra on rations consisting largely of corn. The main symptom of deficiency was necrotic large intestines. Borderline pellagra was produced on rations containing up to 19 percent protein and up to 11.2 mg of niacin per pound of feed. Excellent and efficient growth was obtained on a ration containing 29.6 percent protein without added niacin. No symptoms of niacin

deficiency were noted when corn was replaced with oats. Supplemental tryptophan replaced niacin and prevented the deficiency symptoms. Supplementing a low-protein ration (15.1 percent protein) with niacin seemed to increase the utilization of dietary tryptophan, but the niacin did not replace tryptophan entirely.

The role of pantothenic acid was found to be the prevention of locomotor incoordination, goose stepping, due to degeneration of the myelin sheath of the sciatic nerve. Goose stepping has been observed on rations containing up to 19.5 percent crude protein and 5.04 mg of pantothenic acid per pound of feed.

Riboflavin was found to be an efficiency factor. When added to a commonly used mixed ration, efficiency of feed utilization was increased 25 and 29 percent in two trials.

Calcium pantothenate, riboflavin and niacin when added to the mixed basal rations, brought about a significant increase in daily gains, prevented the occurrence of deficiency symptoms, and reduced the feed required per unit of gain 22 to 25 percent.

In two trials supplements of thiamine, pyridoxine and choline failed to further increase gains or lower the feed requirements. It is concluded that the rations used were deficient in niacin, pantothenic acid and riboflavin under the conditions of these trials and that liberal supplementation of these vitamins overcame the deficiency.

The addition of synthetic niacin, pantothenic acid and riboflavin to a corn-soybean meal type ration on rape pasture failed to increase gain significantly or to increase feed efficiency significantly. It

is concluded that rape pasture furnished adequate amounts of these 3 B-vitamins when the pigs consumed enough pasture.

On a corn-tankage ration in which the pigs apparently had an amino acid deficiency, B-vitamins appeared to aggravate the trouble.

Five percent alfalfa meal failed to furnish adequate amounts of the 3 B-vitamins on the corn-soybean meal type ration and on the mixed ration. Ten percent alfalfa meal proved inadequate on the mixed ration.

Apparent protein sparing action of supplementation with these 3 B-vitamins is discussed.

Adequate levels of niacin, pantothenic acid and riboflavin are essential in maintaining vigorous and healthy pigs. Higher levels are required to prevent deficiency symptoms in 24-pound weanling pigs than in pigs weighing 30 pounds or more. Furthermore, the use of a variety of natural feed ingredients to make up a swine ration offers no guarantee that the ration will contain adequate levels of these 3 B-vitamins for weanling pigs, especially in dry lot.

LITERATURE CITED

- Birch, T. W., H. Chick and C. J. Martin
1937 Experiments with pigs on a pellagra producing diet. *Biochem. Jour.* 31:2065-2079
- Braude, R., S. K. Kon and E. G. White
1946 Observations on the nicotinic acid requirements of pigs. *Biochem. Jour.* 40:843-855
- Chick, H., T. F. Macrae, A. J. P. Martin and C. J. Martin
1938a III Curative action of nicotinic acid on pigs suffering from the effects of a diet consisting largely of maize. *Biochem. Jour.* 32:10-12
- Chick, H., T. F. Macrae, A. J. P. Martin and C. J. Martin
1938b The water-soluble B-vitamins other than aneurin (vitamin B₁), riboflavin and nicotinic acid required by the pig. *Biochem. Jour.* 32:2207-2223
- Cunha, T. J., J. E. Burnside, H. M. Edwards, G. B. Meadows, R. H. Benson, A. M. Pearson and R. S. Glasscock
1950 Affect of animal protein factor on lowering protein needs of the pig. *Arch. of Biochem.* 25:455-457
- Davis, G. K., V. A. Freeman and L. L. Madsen
1940 The relation of nutrition to the development of necrotic enteritis in swine. *Mich. Agr'l. Exp. Sta. Tech. Bul.* 170:23 pp. illus.
- Davis, G. K., E. B. Hale and V. A. Freeman
1943 Response of pigs given large doses of salmonella choleraesuis to sulfaguanidine, nicotinic acid, thiamine and pyridoxine. *Jour. An. Sci.* 2:138-145
- Doyle, L. P.
1937 Posterior paralysis in swine. *Jour. Amer. Vet. Med. Assn.* 90:656-660
- Dunne, H. W., R. W. Luecke, W. N. McMillen, M. L. Gray and F. Thorp, Jr.
1949 The pathology of niacin deficiency in swine. *Amer. Jour. Vet. Res.* 37:351-356
- Dyer, I. A., J. L. Krider and W. E. Carroll
1949 Known and unidentified factors supplement a corn-soybean meal ration for weanling pigs in dry lot. *Jour. An. Sci.* 8:541-549
- Ellis, N. R. and L. L. Madsen
1941 Relation of diet of swine to development of locomotor incoordination resulting from nerve degeneration. *Jour. Agr. Res.* 62:303-316

- Ellis, N. R., L. L. Madsen and C. O. Miller
 1943 Pantothenic acid and pyridoxine as factors in the occurrence of locomotor incoordination in swine. Jour. An. Sci. 2:365
- Emsbo, P., J. Moustgaard, A. Sjøborg Ohlsen og Grete Thorbek
 1949 Undersøgelser over B-vitaminernes betydning for svin. 243 beretning fra forsøgslaboratoriet. 1 Kommission hos August Bangs forlag, Ejvind Christensen. Vesterbrogade 60, København V.
- Fairbanks, B. W., J. L. Krider and W. E. Carroll
 1944 Distillers by-products in swine rations. 1. Creep-feeding and growing-fattening rations. Jour. An. Sci. 3:29-40
- Fairbanks, B. W., J. L. Krider and W. E. Carroll
 1945 Distillers by-products in swine rations. Jour. An. Sci. 4:420-429
- Hirsch, August
 1885 Handbook of geographical and historical pathology. 2:217 New Sydenham Society, London. From Nut. Rev. 4:191, 1946
- Hughes, E. H.
 1940b The minimum requirement of riboflavin for the growing pig. Jour. Nut. 20:233-238
- Hughes, E. H. and N. R. Ittner
 1942a The minimum requirement of pantothenic acid for the growing pig. Jour. An. Sci. 1:116-119
- Hughes, E. H.
 1942b Pantothenic acid in the nutrition of the pig. Jour. Agr. Res. 64:185-187
- Hughes, E. H.
 1943 The minimum requirement of nicotinic acid for the growing pig. Jour. An. Sci. 2:23-26
- Hunt, C. H., L. Ditzler and R. M. Bethke
 1947 Niacin and pantothenic acid content of corn hybrids. Cereal Chem. 24:355-363
- Keith, J. B., R. C. Miller, L. S. Thorp and M. A. McCarty
 1942 Nutritional deficiencies of a concentrate mixture composed of corn, tankage, soybean oil meal and alfalfa meal for growing pigs. Jour. An. Sci. 1:120-125
- Kinsley, A. T.
 1934 The infectious swine disease situation. Vet. Med. 29:24-28

- Krehl, W. A., F. M. Strong and C. A. Elvehjem
 1943 Determination of nicotinic acid. Modifications in the microbiological methods. *Ind. Eng. Chem., Anal. Ed.* 15:471-475
- Krehl, W. A., L. J. Teply, P. S. Sarma and C. A. Elvehjem
 1945 Growth retarding effect of corn in nicotinic acid-low rations and its counteraction by tryptophane. *Science* 101:489-490
- Krehl, W. A., P. S. Sarma, L. J. Teply and C. A. Elvehjem
 1946a Factors affecting the dietary niacin and tryptophane requirement of the growing rat. *Jour. Nut.* 31:85-106
- Krehl, W. A., J. De La Hueraga and C. A. Elvehjem
 1946b Tryptophane studies, I. The effect of niacin on the utilization of tryptophane. *Jour. of Bio. Chem.* 164:551-561
- Krider, J. L., B. W. Fairbanks and W. E. Carroll
 1944 Distillers by-products in swine rations, II. Lactation and growing-fattening rations. *Jour. An. Sci.* 3:107-119
- Krider, J. L., D. E. Becker, R. F. Van Poucke and M. F. James
 1948 Crystalline or crude concentrates of B-vitamins supplement a corn-soybean meal ration for weanling pigs in dry lot. *Jour. An. Sci.* 7:501-508
- Krider, J. L., D. E. Becker, L. V. Curtin and R. F. Van Poucke
 1949a Dried whey products in drylot rations for weanling pigs. *Jour. An. Sci.* 8:112-120
- Krider, J. L., S. W. Terrill and R. F. Van Poucke
 1949b Response of weanling pigs to various levels of riboflavin. *Jour. An. Sci.* 8:121-125
- Luecke, R. W., W. N. McMillen, F. Thorp, Jr. and Carolyn Tull
 1947 The relationship of nicotinic acid, tryptophane and protein in the nutrition of the pig. *Jour. Nut.* 33:251-261
- Luecke, R. W., W. N. McMillen, F. Thorp, Jr. and Carolyn Tull
 1948 Further studies on the relationship of nicotinic acid, tryptophane and protein in the nutrition of the pig. *Jour. Nut.* 36:417-424
- Luecke, R. W., F. Thorp, Jr., W. N. McMillen and H. W. Dunne
 1949a Pantothenic acid deficiency in pigs fed diets of natural feedstuffs. *Jour. An. Sci.* 8:464-469
- Luecke, R. W., F. Thorp, Jr., W. N. McMillen, H. W. Dunne and H. J. Stafseth
 1949b A study of B-vitamin deficiencies in pigs raised on farms. *Mich. Agr'l. Exp. Sta. Tech. Bul.* 211:23 pp. illus.

- Luecke, R. W., W. N. McMillen and F. Thorp, Jr.
 1950a Further studies of pantothenic acid deficiency in weanling pigs. Jour. An. Sci. 9:78-82
- Luecke, R. W., W. N. McMillen and F. Thorp, Jr.
 1950b The effect of vitamin B₁₂, animal protein factor, and streptomycin on the growth of young pigs. Arch. of Biochem. 26:326-327
- McEwen, A. D.
 1937 Necrotic enteritis of young pigs not associated with salmonella infection. Vet. Record 49:1507-1509
- Madison, L. C., R. C. Miller and T. B. Keith
 1939 Nicotinic acid in swine nutrition. Science 89:490-491
- McMillen, W. N., R. W. Luecke and F. Thorp, Jr.
 1949a The effect of liberal B-vitamin supplementation for weanling pigs on rations containing a variety of feedstuffs. Jour. An. Sci. 8:518-523
- McMillen, W. N., R. W. Luecke and Frank Thorp, Jr.
 1949b B-vitamins for weanling pigs. Mich. Agr'l. Exp. Sta. Quarterly Bul. 32:191-195
- Mitchell, H. E., B. C. Johnson and T. S. Hamilton
 1949 The riboflavin requirements of growing pigs at two environmental temperatures. Jour. An. Sci. 8:626 (Abstract)
- National Research Council
 1944 Nutrient allowances for domestic animals No. II. Recommended nutrient allowances for swine. Washington, D. C.
- Patek, A. J. Jr., J. Post and J. Victor
 1941 Riboflavin deficiency in the pig. Am. Jour. of Physio. 133:47-55
- Powick, W. C., N. R. Ellis, L. L. Madsen and C. N. Dale
 1947a Nicotinic acid deficiency and nicotinic acid requirement of young pigs on a purified diet. Jour. An. Sci. 6:310-324
- Powick, W. C., N. R. Ellis and C. N. Dale
 1947b Relationship of corn diets to nicotinic acid deficiency in growing pigs. Jour. An. Sci. 6:395-400
- Powick, W. C., N. R. Ellis and C. N. Dale
 1948 Relationship of tryptophane to nicotinic acid in the feeding of growing pigs. Jour. An. Sci. 7:228-232

- Sauberlick, H. E. and C. A. Baumann
 1946 The effect of dietary protein upon the amino acid excretion by rats and mice. Jour. of Bio. Chem. 166:417-425
- Skeggs, H. R. and L. D. Wright
 1944 The use of lactobacillus arabinosus in the microbiological determination of pantothenic acid. Jour. of Bio. Chem. 156:21-26
- Snedecor, G. W.
 1946 Statistical methods. Fourth edition. The Iowa State College Press. Ames, Iowa. 214-252
- Snell, E. E. and F. M. Strong
 1939 A microbiological assay for riboflavin. Ind. Eng. Chem. Anal. Ed. 4:346-349
- Sure, Barnett and Freeland Romans
 1948 Influence of the concentration of mixtures of various components of vitamin B complex on biological value of casein and on economy of feed utilization. Jour. Nut. 36:727-738
- Thorp, Frank Jr., W. N. McMillen and R. W. Luecke
 1950 Unpublished data. Mich. Agr'l. Exp. Sta.
- Wehrbein, Heinrich
 1916 Paralysis of pigs. Jour. Amer. Vet. Med. Assn. 49:238-244
- Wintrobe, M. M., J. L. Miller, Jr. and H. Lisco
 1940 The relation of diet to the occurrence of ataxia and degeneration in the nervous system of pigs. Bul. Johns Hopkins Hosp. 67:377-406
- Wintrobe, M. M., M. H. Miller, R. H. Follis, Jr., H. J. Stein, C. Mashatt and S. Humphreys
 1942 Sensory neuron degeneration in pigs, IV. Protection afforded by calcium pantothenate and pyridoxine. Jour. Nut. 24:345-366
- Wintrobe, M. M., R. H. Follis, Jr., R. Alcayaga, M. Paulson and S. Humphreys
 1943 Pantothenic acid deficiency in swine. With particular reference to the effects on growth and on the alimentary tract. Bul. Johns Hopkins Hosp. 73:313-341
- Wintrobe, M. M., W. Buschke, R. H. Follis and S. Humphreys
 1944 Riboflavin deficiency in swine. With special reference to the occurrence of cataracts. Bul. Johns Hopkins Hosp. 75:102
- Wintrobe, M. M., H. J. Stein, R. H. Follis, Jr. and S. Humphreys
 1945 Nicotinic acid and the level of protein intake in the nutrition of the pig. Jour. Nut. 30:395-412

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He attended Berry College at Rome, Georgia, from 1930 to 1934 receiving the B. S. degree. He attended Oklahoma A and M College from 1934 to 1936 receiving B. S. and M. S. degrees in Animal Husbandry.

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He is a member of the following organizations: Alpha Zeta, Phi Sigma, Phi Kappa Phi, Sigma Xi, American Society of Animal Production, American Genetic Association and American Association for the Advancement of Science in which he was elected a fellow in 1940.

Publications

McMillen, Warren N., Clyde H. Jamison and Wright Langham

1940 Production, handling and feeding sorghum silage by use of the trench silo. Panhandle Bulletin 66. 23 pp. illus.

McMillen, Warren N. and Wright Langham

1942 Grazing winter wheat with special reference to the mineral blood picture. Jour. An. Sci. 1:14-21

Langham, Wright, Warren N. McMillen and Lamar Walker

1943 A comparison of carotene, protein, calcium and phosphorus content of buffalo grass, buchloe dactyloides, and blue grama, bouteloua gracilis. Jour. Am. Society of Agronomy. 35:35-41

- McMillen, Warren N., Quentin Williams and Wright Langham
1943 Chemical composition, grazing value and vegetative changes of herbage in a typical plains pasture. Jour. An. Sci. 2:237-243
- McMillen, Warren N. and Quentin Williams
1944 Range and pasture studies and grazing recommendations for the Southern Great Plains (Okla.). Panhandle Agr. Exp. Sta. Panhandle Bulletin 67. 47 pp. illus.
- McMillen, Warren N.
1944 Deep well irrigation in the Oklahoma panhandle. Panhandle Bulletin 64. 21 pp. illus.
- McMillen, W. N.
1945 A useful method of appraising the adequacy of swine rations. M. S. C. Veterinarian. 5:152-158
- McMillen, W. N.
1945-46 Feeding mineral to swine in Michigan. M. S. C. Veterinarian 1 and 2:30-31
- McMillen, W. N.
1946 Swine pastures save feed and increase profit. Mich. Agr. Exp. Sta. Qua. Bulletin. 28:1-5
- McMillen, W. N., E. P. Reineke, L. J. Bratzler and M. J. Francis
1947 The effect of thiouracil on efficiency of gains and carcass quality in swine. Jour. An. Sci. 6:305-309
- McMillen, W. N.
1947 Swine fertility problems. M. S. C. Veterinarian. 7:68-71
- McMillen, W. N., G. A. Brown and R. W. Luecke
1948 Dehydrated potatoes for swine. Mich. Agr. Exp. Sta. Bulletin. 30:380-382
- Wallach, D. P., H. W. Newland and W. N. McMillen
1948 Some studies on temperature adaptation in the baby pig. Mich. Agr. Exp. Sta. Qua. Bulletin. 30:277-282
- Luecke, R. W., W. N. McMillen, F. Thorp, Jr. and Carolyn Tull
1948 Further studies on the relationship of nicotinic acid, tryptophane and protein in the nutrition of the pig. Jour. of Nutrition. 36:417-424
- Reineke, E. P., W. N. McMillen and L. J. Bratzler
1948 The effect of mild thyroprotein stimulation on growth in swine. Mich. Tech. Bulletin 209. 18 pp. illus.

- Feenstra, E. W., Frank Thorp, Jr., M. L. Gray and W. N. McMillen
1948 Transmissible gastroenteritis of baby pigs. Jour. Am. Vet. Med. Assn. 113 (861):573-575
- Luecke, R. W., W. N. McMillen, F. Thorp, Jr. and Carolyn Tull
1947 The relationship of nicotinic acid, tryptophane and protein in the nutrition of the pig. Jour. of Nutrition. 33:251-262
- McMillen, W. N., W. H. Sheldon and W. G. Peart
1948 An automatic self-cleaning water bowl for hogs. Mich. Agr. Exp. Sta. Qua. Bulletin. 31:178-181
- Luecke, R. W., F. Thorp, Jr., W. N. McMillen, H. W. Dunne and H. F. Stafseth
1949 A study of B-vitamin deficiencies in pigs raised on farms. Mich. Tech. Bulletin 211. 22 pp. illus.
- McMillen, W. N.
1949 Profitable pork production. Mich. Ext. Bulletin 299. 47 pp. illus.
- Moxley, H. F. and W. N. McMillen
1949 Four years of sow testing in Michigan. Mich. Agr. Exp. Sta. Qua. Bulletin. 31:392-394
- Luecke, R. W., W. N. McMillen, F. Thorp, Jr. and Joanna R. Boniece
1949 The effect of vitamin B-12 concentrate on the growth of weanling pigs fed corn-soybean diets. Science. 110:139-140
- Luecke, R. W., F. Thorp, Jr., W. N. McMillen and H. W. Dunne
1949 Pantothenic acid deficiency in pigs fed diets of natural feed-stuffs. Jour. An. Sci. 8:464-469
- Dunne, Howard W., R. W. Luecke, W. N. McMillen, M. L. Gray and Frank Thorp, Jr.
1949 The pathology of niacin deficiency in swine. Am. Jour. Vet. Research. 10:351-356
- McMillen, W. N., R. W. Luecke and Frank Thorp, Jr.
1949 B-vitamins for weanling pigs. Mich. Agr. Exp. Sta. Qua. Bulletin. 32:191-195
- McMillen, W. N., R. W. Luecke and F. Thorp, Jr.
1949 The effect of liberal B-vitamin supplementation on growth of weanling pigs fed rations containing a variety of feedstuffs. Jour. An. Sci. 8:518-523
- Luecke, R. W., W. N. McMillen and F. Thorp, Jr.
1950 Further studies of pantothenic acid deficiency in weanling pigs. Jour. An. Sci. 9:78-82

Luecke, R. W., W. N. McMillen and F. Thorp, Jr.

1950 The effect of vitamin B₁₂, animal protein factor and streptomycin on the growth of young pigs. Arch. of Biochem. 26:326-327