EVALUATION OF NOVEL DIETARY FEED ADDITIVES FOR NURSERY AND GROWING/FINISHING PIGS

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ABSTRACT

The objectives of this research were: 1) to compare the effect of source and level of inclusion of dried whey permeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs, 2) to evaluate the effect of a fortified nutrient pack (FNP) on growth performance and total tract nutrient digestibility in growing/finishing pigs, and 3) to compare chromic oxide (Cr_2O_3) and acid insoluble ash (AIA) as digestibility markers for total tract digestibility determination in growing/finishing pigs. Three experiments were conducted to compare the feeding value of DWP (80% lactose) and CHO (40% lactose, 30% sucrose, and 10% glucose) in diets for nursery pigs. Results from these experiments indicate that the inclusion of DWP and CHO improved ADG and ADFI compared with pigs fed a diet without lactose. However, the importance of including a highly digestible carbohydrate source in diets for nursery pigs is more evident as pigs are weaned lighter and younger. Two experiments were conducted to evaluate the effect of FNP (fumaric, malic, citric, phosphoric, and lactic acids, L-carnitine, chromium picolinate, inulin, d-pantothenic acid, and niacin) on growth performance and total tract nutrient digestibility in growing/finishing pigs. Results from these experiments indicate that the addition of 0.25 or 0.50% FNP to the diets did not improve ADG, ADFI, or G/F of growing/finishing pigs. Dry matter, CP, and GE digestibility were not improved ($P > 0.1$) with the addition of FNP in 50-kg pigs. However, the addition of 0.25% FNP to the diets of 85-kg pigs during the last 14 d of growth, improved CP and GE digestibility. Two experiments were conducted to compare Cr_2O_3 and AIA as digestibility markers for total tract digestibility determination in growing/finishing pigs fed *ad libitum*. Results from these experiments indicate that Cr_2O_3 and AIA offer a rapid and reliable technique for digestibility determination in

growing/finishing pigs. However, AIA showed superior characteristics compared with Cr_2O_3 as its analyzed values are more consistent, produce less environmental impact, and is more cost effective.

CHAPTER 1

INTRODUCTION

The cost of feed ingredients commonly used in swine diets has greatly increased in the last decade. This trend of higher feed costs has affected the profitability of swine operations, and it has become imperative to search for new feed alternatives and substances that may improve feed efficiency of pigs. Researchers have conducted numerous studies to evaluate new feed additives that may enhance growth performance, health status, and nutrient digestibility of nursery and growing/finishing pigs.

Early weaning continues to be a common practice in swine production systems in order to improve the number of pigs produced per sow per year. As pigs are weaned earlier, an adequate feeding program becomes more critical. Research has demonstrated that the use of milk-based products such as whey, whey permeate, deproteinized whey, or crystalline lactose improve growth performance (Mahan, 1993; Owen et al., 1993; Nessmith et al., 1997) and are essential for a successful nursery program. The lactose fraction of dried whey was identified as the main fraction that enhanced growth performance (Mahan, 1992), and it has been suggested (Mavromichalis et al., 2001) that alternative simple sugars such as sucrose can effectively replace the lactose fraction in diets for nursery pigs. Therefore, high sucrose containing products (carbohydrate product, CHO) may be an effective replacement for high lactose containing products (dried whey permeate, DWP).

In a farrow-to-finish operation, growing and finishing diets represent the greatest volume of feed and make up approximately 75% of the total feed costs. Therefore, the use of novel products that may enhance feed utilization and nutrient digestibility is an opportunity to reduce feed costs and increase profitability. A fortified nutrient pack product (FNP), which consists of a mixture of fumaric, malic, citric, phosphoric, and lactic acids, L-carnitine, chromium picolinate, inulin, d-pantothenic acid, and niacin, has been suggested to increase growth performance, carcass characteristics, and nutrient digestibility of late finishing pigs.

New feed additives for pigs are routinely evaluated using growth and digestibility studies. To conduct digestibility studies with pigs during the time they are on a comparative feeding test, a digestibility marker at a known concentration must be added to the diet (Schurch et al., 1952). This marker method heavily relies on accurate chemical analyses of the marker in feed and feces (Adeola, 2001). Chromic oxide and acid insoluble ash were evaluated as digestibility markers for total tract digestibility studies in growing/finishing pigs fed *ad libitum*.

The objectives of this research were: 1) to compare the effect of source and level of inclusion of DWP and CHO on growth performance of nursery pigs, 2) to evaluate the effect of FNP on growth performance and total tract digestibility in growing/finishing pigs, and 3) to compare chromic oxide and acid insoluble ash as digestibility markers for total tract digestibility determination in growing/finishing pigs.

CHAPTER 2

REVIEW OF LITERATURE

INTRODUCTION

New feed additives are constantly being evaluated as costs of feed ingredients used in swine diets continue to increase. Feed additives are intended to increase growth rate, feed utilization, and improve health status of pigs. In order to maximize the profitability of any swine operation, diets should be formulated to maximize growth at the lowest cost. Therefore, it is imperative to continuously evaluate novel products and feed alternatives that may decrease feed costs and improve growth performance of nursery and growing/finishing pigs.

CARBOHYDRATE SOURCES IN DIETS FOR NURSERY PIGS

Feeding a diet containing milk products such as dried whey, whey permeate, and deproteinized whey has been shown to improve feed intake and growth performance of weanling pigs (Mahan, 1993; Owen et al., 1993; Nessmith et al., 1997). Mahan (1992) evaluated the efficacy of the lactoalbumin and lactose component of dried whey and reported that the lactose component was the primary component responsible for enhanced gain and feed intake of nursery pigs. Several studies have evaluated the effect of different levels of lactose in diets for nursery pigs. Nessmith et al. (1997) reported linear improvements in ADG and ADFI with increasing lactose levels up to 40% in pigs weaned between 10 and 19 d of age. Mahan (1993) reported similar results in pigs weaned at 23 d of age and fed up to 35% dried whey or 25% lactose. However, Mahan et al. (2004) reported that the dietary lactose level necessary to maximize growth performance of nursery pigs decreases as pigs become older and heavier. Lactase activity is high at birth and gradually starts to decrease at week 2 (Bird et al., 1995), whereas α-amylase activity is low at birth and rapidly increases after 4 weeks of age (Corring et al., 1978). Therefore, as pigs become older, the digestive tract matures and there is an increased secretion of digestive enzymes necessary to hydrolyze more complex components found in cereal grains.

Research has also shown that health status and intestinal environment is greatly influenced by lactose inclusion (Wells et al., 2005). Similarly, Miguel and Pettigrew (2005) reported that the inclusion of lactose reduced pathogenic bacteria as the formation of lactic acid increased thus, lowering *Escherichia coli* and Enterobacteria coliforms present in the stomach and intestinal tract of the pig. This improvement in gut environment may become even more relevant as pigs are weaned early at less than 3 weeks of age and exposed to increased health challenges.

Despite the strong evidence that lactose improves growth performance and health status of early weaned pigs, other simple sugars such as sucrose have been suggested to be an effective replacement for lactose. Research has demonstrated that dextrose (Mahan and Newton, 1993; Richert et al., 1996), a high sucrose containing product (de Rodas et al., 1998), and sucrose (Mavromichalis et al., 2001) can effectively replace all or a portion of the lactose fraction in nursery diets. Diaz et al., (1956) reported that sucrose increased sweetness, palatability, and therefore encouraged nursery pigs to eat more. Furthermore, Mavromichalis et al. (2001) reported that sucrose or molasses could be used to replace lactose in diets for nursery pigs with no negative effects on growth performance or nutrient digestibility.

A FORTIFIED NUTRIENT PACK FOR GROWING/FINISHING PIGS

Several feed additives have been evaluated in growing/finishing diets aimed to improve growth performance and nutrient digestibility of pigs. A novel fortified nutrient pack product (FNP), which consists of a mixture of fumaric, malic, citric, phosphoric, lactic acids, L-carnitine, chromium picolinate, inulin, d-pantothenic acid, and niacin, has been suggested to increase daily gain, feed conversion, digestibility of the diet, and carcass characteristics of late finishing pigs. However, little research has been published determining the effect of FNP on growth performance of finishing pigs. Bergstrom et al. (2007) evaluated the effect of FNP, ractopamine, and its combination in 100-kg finishing pigs. The addition of FNP and its combination with ractopamine did not affect ADG, ADFI, or G/F; however, loin depth was increased. Similar results were reported by Frank et al. (2008) when adding FNP in combination with ractopamine in 100-kg finishing pigs. No effects on ADG and ADFI were observed with the addition of FNP; however, G/F and loin depth were increased in pigs fed diets with FNP compared with pigs fed diets without FNP.

CHROMIC OXIDE AND ACID INSOLUBLE ASH AS DIGESTIBITILITY MARKERS

The marker method in digestibility studies with pigs has been demonstrated to have similar results as the conventional total collection method (Schurch et al., 1952). However, the marker method heavily relies on the characteristics of the marker. Adeola (2001) described that an appropriate digestibility marker should be chemically easy to analyze, nonabsorbable, nonessential, nontoxic, completely inert, and uniformly mixed within the feed and feces. Chromic oxide (Cr_2O_3) has been shown to be a reliable marker for digestibility studies with adequate recovery rates (Jongbloed et al., 1991; Bakker and Jongbloed, 1994). Although strong evidence supports that chromic oxide is a reliable marker, several problems have been reported with its use. Several researchers have reported low recovery rates of Cr_2O_3 (McCarthy et al., 1974; Moughan et al., 1991; Jagger et al., 1992), interference with other minerals (Saha and Gilbreath, 1991), and environmental concerns with high Cr content in feces. Naturally occurring markers such as acid insoluble ash (AIA) have been suggested as digestibility markers for pigs. McCarthy et al. (1974) reported that AIA was a superior marker over Cr_2O_3 and that no additional source of AIA was required. Acid insoluble ash naturally occurs at variable levels in feeds and is commonly found at low levels in cereal-based diets. However, more accurate results have been reported when an additional source of AIA was added to the diet to complement the low levels of natural AIA (Scott and Hall, 1998).

CHAPTER 3

COMPARISON OF DRIED WHEY PERMEATE (DWP) AND A CARBOHYDRATE PRODUCT (CHO) IN DIETS FOR NURSERY PIGS

INTRODUCTION

Research has shown that the use of milk products such as whey, whey permeate, deproteinized whey, or crystalline lactose improve growth performance (Mahan, 1993; Owen et al., 1993; Nessmith et al., 1997) and enhance the intestinal environment (Miguel and Pettigrew, 2005) of early-weaned pigs. Mahan (1992) demonstrated that the carbohydrate and not the protein component of dried whey was the main component responsible for the enhanced growth performance of nursery pigs. Although lactose from either dried whey or crystalline lactose has been demonstrated to enhance growth performance of nursery pigs, other simple carbohydrates also may be beneficial. Further research has indicated that the inclusion of a highly available carbohydrate source, such as dextrose (Mahan and Newton, 1993), a high containing sucrose product (de Rodas et al., 1998), or sucrose (Mavromichalis et al., 2001) can effectively replace the lactose portion of nursery diets. Alternative simple sugars for the replacement of lactose have been investigated as changes in milk supply may decrease the availability and increase the cost of lactose.

Some researchers (Brooks, 1972; Mavromichalis et al., 2001) reported that sucrose can effectively replace lactose in diets for nursery pigs. Under conditions where sucrose is highly available, accessible, and at competitive prices, products containing high sucrose may be an alternative to high lactose containing products such as dried whey permeate (DWP), which is 80% lactose. Carbohydrate product (CHO) is a blend of 40% lactose, 30% sucrose, and 10% glucose and may be an alternative carbohydrate source for nursery pig diets. Therefore, the objective of this research was to compare the effect of source (DWP or CHO) and level of inclusion of these carbohydrate products on growth performance of nursery pigs.

MATERIALS AND METHODS

General

All experimental protocols used in these studies were approved by the Louisiana State University (LSU) Agricultural Center Animal Care and Use Committee. Pigs (Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc) were obtained from the LSU Agricultural Center Swine Unit and housed in an environmentally controlled nursery building containing 34 pens. Each pen (0.97 x 1.47 m in size) had hard plastic slotted flooring, one nipple waterer, and a four-hole self-feeder to provide *ad libitum* access to water and feed. Weanling pigs were blocked by initial BW in a randomized complete block design, and littermates and sex were balanced across treatments. Pigs were fed in a 3 phase feeding program that lasted from d 0 to 7 (phase 1), d 7 to 21 (phase 2), and d 21 to 28 (phase 3). All pigs and feeders were weighed at the beginning and end of each growth phase to determine ADG, ADFI, and feed efficiency (G/F).

In all experiments, dietary treatments were formulated based on the amino acid and nutrient concentrations provided by International Ingredients (St. Louis, MO) for DWP and CHO, and on the nutrient values reported by NRC (1998) for all the other ingredients. Diets were formulated to contain 1.60, 1.40, and 1.20% total Lys for phase 1, 2, and 3 respectively, and to meet or exceed the amino acid ratios suggested by Baker (1997) for 10-to 20-kg pigs. Soybean meal was held constant within each phase, and salt levels fluctuated among diets in order to hold the Na and Cl% constant. The phase 1 and 2 diets were calculated to contain 0.90% Ca and 0.80% P, whereas phase 3 diets were calculated to contain 0.80% Ca and 0.70% P. Feed was provided in mash form in all phases of the experiment.

Experiment 1

A total of 80 weanling pigs with an average initial BW of 7.3 ± 1.2 kg and average age of 23 ± 3 d were allotted to 5 dietary treatments. Each treatment was replicated with 4 pens of 4 pigs per pen. Dietary treatments (Tables 3.1 to 3.3) followed the same design in each of the phases and included: 1) control diet with no lactose added; 2 to 3) 2 levels of DWP; 4 to 5) 2 levels of CHO. The levels of each source for each phase were: phase 1 (12.5 and 25%), phase 2 (10 and 20%), and phase 3 (6 and 12%).

Experiment 2

A total of 150 weanling pigs with an average initial BW of 7.6 ± 1.1 kg and average age of 26 ± 3 d were allotted to 5 dietary treatments. Each treatment was replicated with 6 pens of 5 pigs per pen. Experiment 2 was similar to Experiment 1, except that the inclusion levels for each carbohydrate source were reduced during phase 1 and 2, and during phase 3, all pigs were fed a common diet with no lactose added (Tables 3.4 and 3.5). The levels of each source for each phase were: phase 1 (6 and 12%), phase 2 (3 and 6%), and phase 3 (none, common diet for all pigs).

Experiment 3

Experiment 3 included the same dietary treatments (Table 3.2 to 3.5) and design as Experiment 2, but pigs were weaned earlier. In this experiment, a total of 80 weanling pigs with an average initial BW of 5.7 ± 0.7 kg and average age of 21 ± 2 d were used. Each treatment was replicated with 4 pens of 4 pigs per pen.

Statistical Analysis

Data from all 3 experiments were analyzed as a randomized complete block design using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). Block and dietary treatment were used as sources of variation and each pen served as the experimental unit. Orthogonal contrast statements were used to determine the followig effects: 1) source, which was 2 levels of DWP versus 2 levels of CHO, 2) level, which was the low levels versus the high levels of DWP and CHO, 3) source x level, 4) control versus DWP, and 5) control versus CHO.

RESULTS

Experiment 1

The results of Experiment 1 are shown in Tables 3.6 and 3.7. During phase 1, pigs fed diets with either DWP or CHO had increased ($P < 0.1$) ADG and ADFI compared with pigs fed the control diet (no lactose). Gain:feed was not affected for pigs fed diets with DWP ($P > 0.1$), but it was reduced ($P < 0.1$) for pigs fed diets with CHO compared with pigs fed the control diet. During phase 2, 3, and overall, ADG, ADFI, and G/F were not affected in pigs fed diets with either DWP or CHO compared with pigs fed the control diet. During phase 3, there was a source by level effect in G/F ($P = 0.05$) for pigs fed diets with CHO. The high level of CHO improved G/F compared with pigs fed the low level of CHO. However, there was no source or level effect in ADG, ADFI, or G/F in any other phase of the experiment.

Experiment 2

The results of Experiment 2 are shown in Tables 3.8 and 3.9. During phases 1 and 2, pigs fed diets with CHO had increased ($P < 0.1$) ADG and ADFI compared with pigs fed the control diet, but G/F was not affected.

Table 3.1. Composition of experimental diets used in Phase 1 (Experiment 1, as fed basis)[a]

Item, %	Control	DWP		CHO	
Inclusion levels,%	0	12.5	25	12.5	25
Lactose,%	0	10	20	5	10
Corn	57.61	45.64	33.69	45.24	32.89
Soybean meal (48% CP)	22.27	22.27	22.27	22.27	22.27
Fishmeal menhaden	6.97	7.00	7.00	7.00	7.00
SDPP[b]	4.00	4.00	4.00	4.00	4.00
Dry fat	3.00	3.00	3.00	3.00	3.00
Red blood cells[c]	2.00	2.00	2.00	2.00	2.00
Dried whey permeate	---	12.50	25.00	---	---
Carbohydrate product	---	---	---	12.50	25.00
Monocalcium phosphate	0.94	0.59	0.25	0.92	0.90
Limestone	0.71	0.71	0.72	0.64	0.57
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[d]	0.50	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Salt	0.75	0.42	0.10	0.57	0.39
Trace mineral premix[e]	0.10	0.10	0.10	0.10	0.10
Antibiotic[f]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
DL-met	0.07	0.10	0.14	0.10	0.14
L-thr	0.02	0.05	0.08	0.05	0.08
Biolys	---	0.04	0.08	0.04	0.09
Calculated composition					
ME, kcal/kg	3,437	3,460	3,483	3,474	3,510
Lys, %	1.60	1.60	1.60	1.60	1.60
TSAA, %	0.91	0.91	0.91	0.91	0.91
Thr, %	1.04	1.04	1.04	1.04	1.04
Trp, %	0.31	0.30	0.30	0.30	0.30
Ca, %	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80
Na, %	0.48	0.48	0.48	0.48	0.48
Cl, %	0.62	0.62	0.62	0.62	0.62

[a]Diets calculated to contain 1.60% total lysine, 0.90% Ca, and 0.80% P.
[b]Blood plasma (AP-920) was obtained from American Protein Corp., Ames, IA.
[c]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[d]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[e]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[f]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO.

Table 3.2. Composition of experimental diets used in Phase 2 (Experiment 1, as fed basis)[a]

	Control	DWP		CHO	
Inclusion levels,%	0	10	20	10	20
Item, % Lactose,%	0	8	16	4	8
Corn	60.22	50.67	41.11	50.34	40.46
Soybean meal (48% CP)	25.00	25.00	25.00	25.00	25.00
Fishmeal menhaden	5.00	5.00	5.00	5.00	5.00
Dry fat	3.00	3.00	3.00	3.00	3.00
Red blood cells[b]	2.00	2.00	2.00	2.00	2.00
Dried whey permeate	---	10.00	20.00	---	---
Carbohydrate product	---	---	---	10.00	20.00
Monocalcium phosphate	1.43	1.15	0.88	1.41	1.39
Limestone	0.74	0.74	0.75	0.68	0.63
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[c]	0.50	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Salt	0.63	0.36	0.10	0.48	0.34
Trace mineral premix[d]	0.10	0.10	0.10	0.10	0.10
Antibiotic[e]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
DL-met	0.08	0.11	0.15	0.11	0.15
L-thr	0.07	0.10	0.12	0.10	0.12
Biolys	0.15	0.19	0.22	0.19	0.23
Calculated composition					
ME, kcal/kg	3,403	3,422	3,440	3,433	3,462
Lys, %	1.40	1.40	1.40	1.40	1.40
TSAA, %	0.80	0.80	0.80	0.80	0.80
Thr, %	0.91	0.91	0.91	0.91	0.91
Trp, %	0.26	0.26	0.25	0.26	0.25
Ca, %	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80
Na, %	0.30	0.30	0.30	0.30	0.30
Cl, %	0.48	0.48	0.47	0.48	0.48

[a]Diets calculated to contain 1.40% total lysine, 0.90% Ca, and 0.80% P.
[b]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[c]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.
[d]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[e]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO.

Table 3.3. Composition of experimental diets used in Phase 3 (Experiment 1, as fed basis)[a]

	Control	DWP		CHO	
Inclusion levels, %	0	6	12	6	12
Item, % Lactose,%	0	4.8	9.6	2.4	4.8
Corn	62.26	56.53	50.79	56.33	50.40
Soybean meal (48% CP)	30.00	30.00	30.00	30.00	30.00
Dry fat	3.00	3.00	3.00	3.00	3.00
Dried whey permeate	---	6.00	12.00	---	---
Carbohydrate product	---	---	---	6.00	12.00
Monocalcium phosphate	1.52	1.35	1.19	1.51	1.50
Limestone	1.07	1.07	1.08	1.04	1.01
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[b]	0.50	0.50	0.50	0.50	0.50
Salt	0.41	0.26	0.10	0.33	0.24
Trace mineral premix[c]	0.10	0.10	0.10	0.10	0.10
Antibiotic[d]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
DL-met	0.04	0.06	0.07	0.06	0.07
L-thr	0.04	0.06	0.07	0.06	0.07
Biolys	0.26	0.28	0.30	0.28	0.31
Calculated composition					
ME, kcal/kg	3,393	3,404	3,415	3,411	3,428
Lys, %	1.20	1.20	1.20	1.20	1.20
TSAA, %	0.68	0.68	0.68	0.68	0.68
Thr, %	0.78	0.78	0.78	0.78	0.78
Trp, %	0.23	0.23	0.23	0.23	0.23
Ca, %	0.80	0.80	0.80	0.80	0.80
P, %	0.70	0.70	0.70	0.70	0.70
Na, %	0.19	0.19	0.19	0.19	0.19
Cl, %	0.30	0.30	0.30	0.30	0.30

[a]Diets calculated to contain 1.20% total lysine, 0.80% Ca, and 0.70% P.
[b]Provided the following per kilogram of the diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[c]Provided the following per kilogram of the diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[d]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO.

Table 3.4. Composition of experimental diets used in Phase 1 (Experiments 2 and 3, as fed basis)[a]

	Control	DWP		CHO	
Inclusion levels, %	0	6	12	6	12
Item, % Lactose,%	0	4.8	9.6	2.4	4.8
Corn	58.17	52.43	46.70	52.24	46.31
Soybean meal (48% CP)	22.00	22.00	22.00	22.00	22.00
Fishmeal menhaden	7.00	7.00	7.00	7.00	7.00
SDPP[b]	4.00	4.00	4.00	4.00	4.00
Dry fat	3.00	3.00	3.00	3.00	3.00
Red blood cells[c]	2.00	2.00	2.00	2.00	2.00
Dried whey permeate	---	6.00	12.00	---	---
Carbohydrate product	---	---	---	6.00	12.00
Monocalcium phosphate	0.94	0.77	0.61	0.93	0.92
Limestone	0.71	0.71	0.71	0.67	0.64
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[d]	0.50	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Salt	0.42	0.26	0.10	0.33	0.24
Trace mineral premix[e]	0.10	0.10	0.10	0.10	0.10
Antibiotic[f]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
DL-met	0.07	0.08	0.10	0.08	0.10
L-thr	0.02	0.04	0.05	0.04	0.05
Biolys	0.01	0.03	0.05	0.03	0.05
Calculated composition					
ME, kcal/kg	3,448	3,459	3,470	3,466	3,484
Lys, %	1.60	1.60	1.60	1.60	1.60
TSAA, %	0.91	0.91	0.91	0.91	0.91
Thr, %	1.04	1.04	1.04	1.04	1.04
Trp, %	0.31	0.30	0.30	0.30	0.30
Ca, %	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80
Na, %	0.35	0.35	0.35	0.35	0.35
Cl, %	0.42	0.42	0.42	0.42	0.42

[a]Diets calculated to contain 1.60% total lysine, 0.90% Ca, and 0.80% P.
[b]Blood plasma (AP-920) was obtained from American Protein Corp., Ames, IA.
[c]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[d]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.
[e]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[f]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO.

Table 3.5. Composition of experimental diets used in Phases 2 and 3 (Experiments 2 and 3, as fed basis)[a]

		Control	DWP		CHO		Phase 3
	Inclusion levels,%	0	3	6	3	6	0
Item, %	Lactose,%	0	2.4	4.8	1.2	2.4	0
Corn		60.60	57.73	54.87	60.60	57.64	62.58
Soybean meal (48% CP)		25.00	25.00	25.00	25.00	25.00	30.00
Fishmeal menhaden		5.00	5.00	5.00	5.00	5.00	---
Dry fat		3.00	3.00	3.00	3.00	3.00	3.00
Red blood cells[b]		2.00	2.00	2.00	2.00	2.00	---
Dried whey permeate		---	3.00	6.00	---	---	---
Carbohydrate product		---	---	---	---	3.00	---
Monocalcium phosphate		1.42	1.34	1.26	1.42	1.42	1.51
Limestone		0.74	0.74	0.74	0.74	0.72	1.07
Sodium bentonite		0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[c]		0.50	0.50	0.50	0.50	0.50	0.50
Zinc oxide		0.28	0.28	0.28	0.28	0.28	---
Salt		0.26	0.18	0.10	0.26	0.21	0.10
Trace mineral premix[d]		0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[e]		0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride		0.05	0.05	0.05	0.05	0.05	0.05
DL-met		0.08	0.09	0.10	0.08	0.09	0.04
L-thr		0.07	0.08	0.09	0.07	0.08	0.04
Biolys		0.15	0.16	0.17	0.15	0.16	0.26
Calculated composition							
ME, kcal/kg		3,416	3,421	3,372	3,416	3,425	3,404
Lys, %		1.40	1.40	1.40	1.40	1.40	1.20
TSAA, %		0.80	0.80	0.80	0.80	0.80	0.68
Thr, %		0.91	0.91	0.91	0.91	0.91	0.78
Trp, %		0.26	0.26	0.25	0.26	0.26	0.23
Ca, %		0.90	0.90	0.90	0.90	0.90	0.80
P, %		0.80	0.80	0.80	0.80	0.80	0.70
Na, %		0.16	0.16	0.16	0.16	0.16	0.07
Cl, %		0.25	0.25	0.25	0.25	0.25	0.11

[a]Diets calculated to contain 1.40% total lysine, 0.90% Ca, and 0.80% P during phase 2 and 1.20% total lysine, 0.80% Ca, and 0.70% P during phase 3.

[b]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.

[c]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.

[d]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.

[e]Neo-terra 10/10 from Nutra Blend LLC Neosho.

Daily gain and ADFI were not affected by DWP, but G/F was reduced by the high level of DWP ($P < 0.1$) during phase 2 compared with pigs fed the control diet. During phase 3, when all pigs were fed the same diet with no lactose, pigs fed diets with either DWP or CHO during the previous phases had increased ($P < 0.1$) ADFI, but ADG was not affected ($P > 0.1$). Gain:feed was reduced ($P < 0.1$) only for pigs fed diets with CHO during the previous phases. In the overall data, pigs fed diets with either DWP or CHO had increased ($P < 0.1$) ADFI compared with pigs fed the control diet. Daily gain was increased ($P < 0.1$) only for pigs fed diets with CHO, and G/F was not affected with the inclusion of either DWP or CHO. There was a source effect of CHO in ADFI during phase 1, ADG and ADFI during phase 2, and ADG during phase 3. In the overall data, no source or level effect were observed between CHO and DWP in ADG, ADFI, or G/F.

Experiment 3

The results of Experiment 3 are shown in Tables 3.10 and 3.11. During phase 1, ADG, ADFI, and G/F were not affected ($P > 0.1$) by either DWP or CHO. During phase 2, pigs fed diets with DWP or CHO had increased ($P > 0.1$) ADG, but ADFI and G/F were not affected ($P > 0.1$). During phase 3, when all pigs were fed a common diet, no carry over effects were observed ($P > 0.1$) in ADG, ADFI, or G/F in pigs fed diets with DWP or CHO during the previous phases. In the overall data, pigs fed diets with DWP had increased ($P < 0.1$) ADG, but ADFI and G/F were not affected. Gain, ADFI, and G/F were not affected by CHO compared with pigs fed the control diet. There was no source effect during any phase of the experiment.

Table 3.6. Effect of dried whey permeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs (Experiment 1)[1]

Item,	C[2]	DWP-Low	DWP-High	CHO-Low	CHO-High	P-value	SEM
Phase 1							
ADG, g	286[b]	321[a]	329[a]	339[a]	326[a]	0.06	12
ADFI, g	316[b]	401[a]	385[a]	422[a]	406[a]	0.003	15
G/F	0.87	0.80	0.85	0.81	0.80	0.40	0.04
Phase 2							
ADG, g	517	558	534	545	561	0.70	25
ADFI, g	714	817	773	785	805	0.51	43
G/F	0.73	0.68	0.70	0.69	0.70	0.71	0.03
Phase 3							
ADG, g	569	570	597	607	560	0.74	28
ADFI, g	1061	1098	1111	1101	1099	0.95	47
G/F	0.54[ab]	0.52[ab]	0.54[ab]	0.55[a]	0.51[b]	0.25	0.01
Overall							
ADG, g	480	510	510	521	509	0.60	18
ADFI, g	740	818	800	810	815	0.47	33
G/F	0.65	0.62	0.64	0.64	0.63	0.55	0.01

[1]Data are means of 4 replications with 4 pigs per pen.
[2]C = Control diet.
[a,b]Treatment means with different superscripts on the same row are significantly different, *P* < 0.1.

Table 3.7. Probabilities of carbohydrate source [dried whey permeate (DWP) and a carbohydrate product (CHO)] and level on growth performance of nursery pigs (Experiment 1)

Item,	Source[a]	Level[b]	Source*Level	C[1] vs.DWP	C vs.CHO
Phase 1					
ADG, g	0.52	0.79	0.39	0.02	0.007
ADFI, g	0.20	0.32	1.00	0.001	0.0002
G/F	0.63	0.66	0.53	0.16	0.08
Phase 2					
ADG, g	0.78	0.87	0.42	0.36	0.26
ADFI, g	0.10	0.79	0.47	0.15	0.15
G/F	0.69	0.65	0.96	0.19	0.31
Phase 3					
ADG, g	1.00	0.73	0.22	0.68	0.68
ADFI, g	0.93	0.91	0.88	0.47	0.51
G/F	0.92	0.40	0.05	0.56	0.61
Overall, d 0 to 28					
ADG, g	0.79	0.75	0.75	0.20	0.14
ADFI, g	0.91	0.83	0.74	0.12	0.10
G/F	0.86	0.10	0.26	0.22	0.27

[a]Source effect is both levels of CHO product vs. both levels of DWP.
[b]Level effect is the low levels of both sources vs. the high levels of both sources.
[1]C = Control diet.

Table 3.8. Effect of dried whey permeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs (Experiment 2)[1]

Item,	C[2]	DWP-Low	DWP-High	CHO-Low	CHO-High	P-value	SEM
Phase 1							
ADG, g	296[b]	302[b]	313[ab]	313[ab]	341[a]	0.21	14
ADFI, g	386[b]	421[ab]	387[b]	428[ab]	459[a]	0.14	22
G/F	0.73[b]	0.72[b]	0.78[a]	0.71[b]	0.75[b]	0.47	0.02
Phase 2							
ADG, g	481[b]	480[b]	477[b]	507[ab]	518[a]	0.15	13
ADFI, g	755[c]	784[bc]	796[abc]	832.10[a]	821[ab]	0.07	19
G/F	0.64[a]	0.61[ab]	0.60[b]	0.61[ab]	0.63[ab]	0.34	0.01
Phase 3							
ADG, g	574[b]	594[ab]	627[a]	572[b]	584[ab]	0.23	18
ADFI, g	955[b]	1040[a]	1038[a]	1015[ab]	1030[a]	0.14	26
G/F	0.60[ab]	0.57[ab]	0.60[a]	0.56[b]	0.57[ab]	0.25	0.02
Overall							
ADG, g	461[b]	470[ab]	482[ab]	479[ab]	497[a]	0.30	12
ADFI, g	726[b]	770[a]	763[ab]	791[a]	796[a]	0.06	17
G/F	0.63	0.61	0.63	0.61	0.62	0.35	0.01

[1]Data are means of 6 replications with 5 pigs per pen.
[2]C = Control diet.
[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.1$.

Table 3.9. Probabilities of carbohydrate source [dried whey permeate (DWP) and a carbohydrate product (CHO)] and level on growth performance of nursery pigs (Experiment 2)

Item,	Source[a]	Level[b]	Source*Level	C[1] vs.DWP	C vs.CHO
Phase 1, d 0 to 6					
ADG	0.17	0.17	0.56	0.49	0.08
ADFI	0.08	0.94	0.16	0.52	0.04
G/F	0.40	0.08	0.70	0.61	0.85
Phase 2, d 6 to 21					
ADG	0.02	0.74	0.62	0.88	0.07
ADFI	0.07	0.99	0.54	0.15	0.006
G/F	0.28	0.71	0.28	0.09	0.38
Phase 3, d 21 to 28					
ADG	0.09	0.22	0.57	0.11	0.84
ADFI	0.51	0.77	0.76	0.01	0.04
G/F	0.17	0.26	0.40	0.54	0.09
Overall, d 0 to 28					
ADG	0.31	0.23	0.82	0.31	0.07
ADFI	0.13	0.95	0.75	0.06	0.004
G/F	0.62	0.10	0.84	0.37	0.20

[a]Source effect is both levels of CHO product vs. both levels of DWP.
[b]Level effect is the low levels of both sources vs. the high levels of both sources.
[1]C = Control diet.

Table 3.10. Effect of dried whey permeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs (Experiment 3)[1]

Item,	C[2]	DWP-Low	DWP-High	CHO-Low	CHO-High	P-value	SEM
Phase 1							
ADG, g	192	195	191	175	217	0.71	19
ADFI, g	274	285	274	260	301	0.89	27
G/F	0.62	0.68	0.70	0.69	0.72	0.64	0.05
Phase 2							
ADG, g	381[b]	440[a]	456[a]	420[ab]	440[a]	0.14	20
ADFI, g	619	694	684	665	639	0.47	32
G/F	0.62[c]	0.63[bc]	0.67[ab]	0.64[abc]	0.69[a]	0.18	0.02
Phase 3							
ADG, g	517	545	525	547	499	0.73	28
ADFI, g	918	966	904	838	896	0.60	55
G/F	0.56[b]	0.57[ab]	0.59[ab]	0.66[a]	0.56[b]	0.33	0.04
Overall							
ADG, g	367[b]	398[a]	404[a]	374[ab]	398[ab]	0.20	12
ADFI, g	599	659	635	602	611	0.63	31
G/F	0.62	0.62	0.63	0.62	0.65	0.76	0.02

[1]Data are means of 4 replications with 4 pigs per pen.
[2]C = Control diet.
[a,b]Treatment means with different superscripts on the same row are significantly different, P<0.1.

Table 3.11. Probabilities of carbohydrate source [dried whey permeate (DWP) and carbohydrate product (CHO)] and level on growth performance of nursery pigs (Experiment 3)

Item,	Source[a]	Level[b]	Source*Level	C[1] vs.DWP	C vs. CHO
Phase 1, d 0 to 7					
ADG, g	0.88	0.35	0.27	0.96	0.86
ADFI, g	0.96	0.61	0.39	0.87	0.85
G/F	0.76	0.70	0.90	0.24	0.17
Phase 2, d 7 to 20					
ADG, g	0.37	0.39	0.93	0.02	0.07
ADFI, g	0.27	0.58	0.81	0.10	0.42
G/F	0.66	0.06	0.75	0.20	0.11
Phase 3, d 20 to 27					
ADG, g	0.66	0.25	0.62	0.61	0.88
ADFI, g	0.24	0.97	0.30	0.80	0.46
G/F	0.40	0.28	0.13	0.79	0.35
Overall, d 0 to 27					
ADG, g	0.24	0.48	0.27	0.05	0.24
ADFI, g	0.22	0.82	0.60	0.24	0.85
G/F	0.48	0.35	0.75	0.88	0.47

[a]Source effect is both levels of CHO product vs. both levels of DWP.
[b]Level effect is the low levels of both sources vs. the high levels of both sources.
[1]C = Control diet.

DISCUSSION

Results from Experiment 1 showed that the inclusion of DWP and CHO increased ADG and ADFI compared with pigs fed the control diet during phase 1. These results are consistent with previous studies showing that highly digestible carbohydrate sources improve growth performance during the first week after weaning. However, G/F was reduced for pigs fed diets with CHO as feed intake was 5 and 31% greater compared with pigs fed diets with DWP or the control diet, respectively. The sucrose portion of CHO was probably responsible for the increased feed intake as Diaz et al. (1956) suggested that adding sucrose to the diet increased sweetness, palatability, and encouraged nursery pigs to eat more. However, no effects were observed in ADG, ADFI, or G/F during phase 2, 3, and overall in pigs fed diets with DWP or CHO when compared with pigs fed the control diet. Similarly, Mavromichalis et al. (2001) also observed no difference in ADG and ADFI between pigs fed diets with sugars (lactose or sucrose) or without sugars during d 10 to 30 after weaning. However, deRodas et al. (1998) reported improved ADG and ADFI during phase 2 in pigs fed diets with a high sucrose containing product compared with pigs fed the control diet with 10% dried whey and weaned at 23 d of age.

In Experiment 2 and 3, growth responses were not consistent even though the same dietary treatments were used. In Experiment 2, the inclusion of CHO improved ADG and ADFI during phase 1, 2, and overall compared with pigs fed the control diet. These results are in agreement with those reported by deRodas et al. (1998) showing that pigs fed diets with a high sucrose containing product had increased ADG and ADFI during phase 2. However, the inclusion of DWP did not affect ADG during phases 2, 3, and overall, but ADFI was increased during phase 3 and overall compared with pigs fed the control diet. Cromwell et al. (2008) reported that the inclusion of lactose in mid to late nursery phase diets, not only served as an energy source, but stimulated the pig's appetite as reflected in an increased ADFI. The authors reported linear improvements in ADG with increasing levels of lactose reaching a numerical plateau at 7.5% lactose. However, in those experiments, pigs were weaned at 15 to 20 d of age, whereas in our Experiment 2, pigs were weaned at 26 d of age. At the beginning of phase 2, our pigs had an average BW of 9.4 kg and were 33 d of age. Mahan (2004) indicated that the lactose levels necessary to achieve maximum growth rate declined as pigs became older and heavier, probably because the pig's digestive tract was more mature and had an increased enzyme secretion to digest complex substrates.

In Experiment 3, there was no effect of CHO on ADG, ADFI, or G/F throughout the nursery feeding program, except for an improvement in ADG during phase 2 compared with pigs fed the control diet. However, pigs fed diets with DWP trended to have an improvement in ADG in all phases, which was reflected in the overall data with a significant improvement in ADG compared with pigs fed the control diet.

The original objective of these experiments was to compared DWP and CHO as carbohydrate sources in diets for nursery pigs. These products have been shown to improve ADG and ADFI compared with pigs fed a diet without lactose. The importance of including a highly digestible carbohydrate source in diets for nursery pigs is more evident as pigs are weaned lighter and younger. Dried whey permeate has been shown to improve ADFI and stimulate appetite of nursery pigs, and to have a greater response in ADG when pigs are weaned at 21 d of age. However, when pigs are weaned at 26 d of age, diets with CHO improved ADG and ADFI to a greater extent. This response may be attributed to the changes in the digestive tract and secretion of digestive enzymes as the weaning pigs matures. Nevertheless, highly digestible carbohydrate sources such as DWP or CHO improved growth performance of nursery pigs.

CHAPTER 4

THE EFFECT OF A FORTIFIED NUTRIENT PACK (FNP) ON GROWTH PERFORMANCE AND APPARENT TOTAL TRACT DIGESTIBILITY IN GROWING/FINISHING PIGS

INTRODUCTION

New feed additives are constantly being evaluated in growing/finishing pig diets to maximize growth rate and feed efficiency. A fortified nutrient pack product (FNP), which consists of a mixture of fumaric, malic, citric, phosphoric, and lactic acids, L-carnitine, chromium picolinate, inulin, d-pantothenic acid, and niacin has been suggested to improve growth performance and carcass characteristics of late finishing pigs during the last 40 to 50 d before market. The addition of FNP may increase diet digestibility; however, no research has been published in this area. Therefore, the objective of this research was to evaluate the effect of FNP on growth performance and apparent total tract digestibility of nutrients in diets for growing/finishing pigs.

MATERIALS AND METHODS

All experimental protocols used in these experiments were approved by the Louisiana State University (LSU) Agricultural Center Animal Care and Use Committee. Pigs (Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc) were obtained from the LSU Agricultural Center Swine Unit and housed in an enclosed building in 1.8 m × 2.4 m pens with slotted metal floors (Experiment 1) or in a curtain-sided building in 1.5 m × 3.0 m pens with concrete slated floors (Experiment 2). Each pen was equipped with one nipple waterer per pen, and a two-hole self-feeder to provide *ad libitum* access to water and feed. Experiment 1 lasted for 14 d, whereas Experiment 2 was divided into 2 phases: d 0 to 14 (phase 1) and d 14 to 28 (phase 2). All pigs and feeders were weighed on d 0 and 14 (Experiments 1and 2) and d 28 (Experiment 2) for determination of ADG, ADFI, and feed efficiency (G/F). Total tract digestibility coefficients for DM, CP, and GE were determined by the indicator technique using chromic oxide (Cr_2O_3) and acid insoluble ash (AIA) as digestibility markers. In Experiment 1, Cr_2O_3 and AIA were both added together to all dietary treatments at 0.5 and 1%, respectively. In Experiment 2, Cr_2O_3 was added to all dietary treatments as the digestibility marker at 0.5%.

On the morning of d 10, 11, and 12 (Experiments 1 and 2) and d 26, 27, and 28 (Experiment 2), fresh feces from each pig were collected by rectal palpation and frozen at 0° C until the last day of the collection. At the end of each experiment, fecal samples were thawed and combined within day, pig, and pen resulting in 1 sample per pen. All fecal samples were oven dried at 60° C for 96 h to determine DM content, and ground (Retsch Grindomix, model GM200) for further chemical analyses.

Feed and fecal samples were analyzed for GE by the bomb calorimetry method (AOAC, 1990) at the Analytical Lab of Kansas State University. Crude protein was determined by the Kjeldahl (racks) procedure (AOAC, 1990) and acid insoluble ash by a modified method described by Scott and Boldaji (1997). Chromium concentration was determined by wet-ashing samples in a nitric- perchloric acid mixture and diluted for analysis using the inductively coupled atomic emission spectrometry (ICP) at the LSU AgChemistry. Digestibility coefficients for DM, CP, and GE were determined by the following equation:

$$\text{Percent apparent digestibility} = \frac{N_d/A_d - N_s/A_s \times 100}{N_d/A_d}$$

A_d = percent of marker in feed
A_s = percent of marker in sample
N_d = percent nutrient in feed
N_s = percent nutrient in sample

Experiment 1

A total of 54 growing/finishing barrows with an average initial BW of 50 ± 2.90 kg were randomly allotted to 3 dietary treatments. Each treatment was replicated with 6 pens of 3 pigs per pen. All diets were formulated based on the nutrient values reported by NRC (1998) for corn (C) and soybean meal (SBM) and to meet or exceed the nutrient requirement for 50 to 80 kg pigs (NRC, 1998). All diets were formulated to contain 0.80% total Lys, 0.55% P, and 0.50% Ca. Dietary treatments are shown in Table 4.1 and included: 1) C + SBM, 2) C + SBM + 0.25% FNP, and 3) C + SBM + 0.50% FNP. The FNP was added to diets 2 and 3 at the expense of corn. A basal diet that included all ingredients except for corn was mixed with the addition of the digestibility markers Cr_2O_3 and AIA. Each dietary treatment was mixed individually with the only addition of corn in Diet 1 and corn and FNP in Diets 2 and 3.

Experiment 2

A total of 54 late-finishing pigs (n = 36 barrows and n = 36 gilts) with an average initial BW of 85 ± 5.60 kg were allotted to 3 dietary treatments. Each treatment was replicated with 6 pens of 3 pigs per pen. Pigs were blocked by initial BW and sex, with a total of 3 reps of barrows and 3 reps of gilts for each treatment. Dietary treatments were similar to those used in Experiment 1, but diets were re-formulated to meet or exceed the nutrient requirements of 80 to120 kg pigs (NRC, 1998). All diets were formulated to contain 0.55% total Lys, 0.38% P, and 0.42% Ca. Dietary treatments are shown in Table 4.2 and included: 1) C-SBM, 2) C-SBM + 0.25% FNP, and 3) C-SBM + 0.50% FNP. Chromic oxide was added at 0.5% to all diets as the digestibility marker.

Statistical Analysis

Data were analyzed by ANOVA as a completely randomized design (Experiment 1) or a randomized complete block design (Experiment 2) using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). Each pen served as the experimental unit in both experiments. Differences in digestibility coefficients were determined using the one way ANOVA at a significance level set at 0.10. In Experiment 2, the treatment × sex interaction was not significant; therefore it was removed from statistical analysis. Sources of variation in Experiment 2 included treatment, replicate (initial BW), and sex.

RESULTS

Growth performance and digestibility results of Experiment 1 are shown in Tables 4.3 and 4.4, respectively. From d 0 to 14, the addition of 0.25 and 0.50% FNP to the diets did not affect ($P > 0.1$) ADG, ADFI, or G/F. Similarly, no differences ($P > 0.1$) in DM, CP, or GE digestibility coefficients were observed when using either Cr_2O_3 or AIA as digestibility markers. However, DM and GE digestibility were linearly decreased as FNP increased ($P < 0.04$ to 0.06), and the effects were consistent regardless of the digestibility marker. No linear or quadratic effects were observed in CP digestibility.

Growth performance and digestibility results of Experiment 2 are shown in Tables 4.5 and 4.6, respectively. From d 0 to 14 and from d 14 to 28, the addition of 0.25 and 0.50% FNP to the diets did not affect ($P > 0.1$) ADG, ADFI, or G/F. No linear or quadratic effects were observed in any growth variable. Digestibility coefficients were determined using Cr_2O_3 as the digestibility marker. However, because of high variation in the Cr values determined in the feed for both phases of the experiment, digestibility coefficients were determined using the calculated Cr content of feed, which was 3,352 ppm.

Table 4.1. Composition of experimental diets used in Experiment 1, as fed basis

	Control	FNP, %	
Item, %	C+SBM	0.25	0.50
Corn	81.85	81.60	81.35
Soybean meal (48% CP)	15.75	15.75	15.75
Limestone	0.90	0.90	0.90
Monocalcium phosphate	1.10	1.10	1.10
L-Lys·HCl	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25
Fortified nutrient pack (FNP)	0.00	0.25	0.50
Acid insoluble ash	1.00	1.00	1.00
Chromic oxide	0.50	0.50	0.50
Total, %	101.50	101.50	101.50
Calculated composition			
ME, kcal/kg	3,278	3,256	3,256
CP, %	13.75	13.73	13.71
Lys, %	0.80	0.80	0.80
Ca, %	0.59	0.59	0.59
P, %	0.55	0.55	0.55
Cr, ppm	3,352	3,352	3,352
AIA, %	1.00	1.00	1.00
Analyzed values			
CP, %	12.50	12.74	12.57
GE, kcal/kg	4,004	3,982	3,934
Cr, ppm	3,171	3,357	3,205
AIA, %	1.48	1.55	1.59

Table 4.2. Composition of experimental diets used in Experiment 2, as fed basis

	Control	FNP, %	
Item, %	C-SBM	0.25	0.50
Corn	88.35	88.10	87.85
Soybean meal (48% CP)	7.00	7.00	7.00
Limestone	0.75	0.75	0.75
Monocalcium phosphate	0.50	0.50	0.50
L-Lys·HCl	0.15	0.15	0.15
Dry fat	3.00	3.00	3.00
Vitamin premix	0.25	0.25	0.25
Fortified nutrient pack (FNP)	0.00	0.25	0.50
Chromic oxide	0.50	0.50	0.50
Total, %	100.50	100.50	100.50
Calculated composition			
ME, kcal/kg	3,454	3,432	3,432
CP, %	10.11	10.09	10.07
Lys, %	0.55	0.55	0.55
Ca, %	0.42	0.42	0.42
P, %	0.38	0.38	0.37
Cr, ppm	3,352	3,352	3,352
Analyzed values,			
CP, %; d 0 to 14	13.32	12.72	12.06
GE, kcal/kg; d 0 to 14	4,442	4,442	4,421
CP, %; d 14 to 28	9.24	10.06	9.97
GE, kcal/kg; d 14 to 28	4,300	4,246	4,227

Table 4.3. Growth performance of growing/finishing pigs supplemented with 2 graded levels of a fortified nutrient pack (FNP) in Experiment 1[1]

Treatments	ADG, g	ADFI, g	G/F
C+SBM	827	2,382	0.35
C+SBM+ 0.25% FNP	824	2,389	0.35
C+SBM+ 0.50% FNP	770	2,306	0.33
SEM	44	62	0.02
Trt P-value	0.59	0.58	0.87
Linear	0.37	0.40	0.63
Quadratic	0.64	0.56	0.87

[1]Data are means of 6 replications with 3 pigs per replicate.

Table 4.4. Effect of 2 graded levels of a fortified nutrient pack (FNP) on DM, CP, and GE digestibility coefficients using acid insoluble ash and chromic oxide as digestibility markers in Experiment 1[a]

Treatments	DMD[1], %		CPD[2], %		GED[3], %	
	AIA	Cr_2O_3	AIA	Cr_2O_3	AIA	Cr_2O_3
C+SBM	83.95	85.40	67.72	70.63	80.26	82.05
C+SBM+0.25% FNP	83.76	84.57	68.59	70.13	80.16	81.15
C+SBM+0.50% FNP	82.64	84.11	64.84	67.82	78.40	80.22
SEM	0.44	0.41	1.26	1.22	0.63	0.58
CV	1.3	1.2	4.6	4.3	1.9	1.7
Trt P-value	0.11	0.11	0.12	0.25	0.10	0.11
Linear	0.06	0.04	0.13	0.13	0.06	0.04
Quadratic	0.40	0.71	0.15	0.56	0.30	0.99

[a]Data are means of 6 replications with 3 pigs per replicate.
[1]= Apparent dry matter digestibility
[2]= Apparent crude protein digestibility
[3]= Apparent gross energy digestibility.

Table 4.5. Growth performance of growing/finishing pigs supplemented with 2 graded levels of a fortified nutrient pack (FNP) in Experiment 2[1]

	C+SBM	C+SBM+ 0.25% FNP	C+SBM+ 0.50% FNP	P-value[2]	SEM	Lin.	Quad.
Day 0 to 14							
ADG, g	592	564	587	0.65	23	0.88	0.37
ADFI, g	2,815	2,836	2,883	0.96	161	0.77	0.95
G/F	0.21	0.20	0.21	0.62	0.01	0.65	0.40
Day 14 to 28							
ADG, g	694	631	669	0.47	35	0.63	0.27
ADFI, g	3,181	3,031	2,857	0.65	240	0.36	0.97
G/F	0.22	0.21	0.25	0.62	0.03	0.52	0.47

[1]Data are means of 6 replications with 3 pigs per replicate.
[2]Overall treatment P value.

Table 4.6. Effect of 2 graded levels of a fortified nutrient pack (FNP) on DM, CP, and GE digestibility values determined with chromic oxide as digestibility marker in Experiment 2[y]

	C+SBM	C+SBM +0.25% FNP	C+SBM+ 0.50%OP	P-value	SEM	Lin.	Quad.
Day 0 to 14							
DMD[1], %	73.81[b]	73.86[b]	77.37[a]	0.11	1.26	0.07	0.28
CPD[2], %	54.22	53.94	58.27	0.47	2.70	0.31	0.50
GED[3], %	67.62	68.07	72.02	0.20	1.79	0.11	0.44
Day 14 to 28							
DMD[1], %	79.21	79.37	77.38	0.26	0.90	0.18	0.35
CPD[2], %	72.40[b]	81.60[a]	78.96[c]	<.0001	1.01	.0006	.0005
GED[3], %	64.94[b]	76.19[a]	72.04[a]	0.01	2.22	0.04	0.02

[1]= Apparent dry matter digestibility.
[2]= Apparent crude protein digestibility.
[3]= Apparent gross energy digestibility.
[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.1$.
[y]= Digestibility values determined with calculated Cr for all diets (3,352 ppm)

From d 0 to 14, DM digestibility was linearly increased ($P = 0.07$) with increasing levels of FNP and was significantly increased when 0.50% FNP was added to the diet. However, no differences ($P > 0.1$) were observed in CP and GE digestibility. From d 14 to 28, no differences ($P > 0.1$) were observed in DM digestibility with increasing levels of FNP. However, linear and quadratic effects were observed in CP and GE digestibility coefficients. Crude protein digestibility was increased by the 0.25% FNP but then decreased by the 0.50% FNP addition. Similarly, GE digestibility was increased by the 0.25% FNP addition, but decreased by 0.50% FNP addition.

DISCUSSION

Results from Experiment 1 showed that there was no beneficial effect on growth performance of growing/finishing pigs fed diets with addition of FNP. Similarly, total tract digestibilities of DM, GE, and CP were not affected by the FNP addition. No data have been published evaluating the effect of FNP in 50-kg pigs. However, research has shown that there are beneficial effects with the supplementation of organic acids, specifically in weanling pigs (Gabert and Sauer, 1994). Fumaric acid, which is the major component in FNP, has been reported to increase protein digestibility and apparent ileal digestibilities of AA in weanling pigs (Blank et al., 1999). Siljander-Rasi et al. (1998) evaluated the effect of organic acids in growing and finishing pigs and reported no beneficial effect of organic acid supplementation.

The efficacy of FNP may be more evident during the last 40 d of growth in late finishing pigs. Therefore, in Experiment 2, the initial BW of the pigs was 85 kg and growth and feces were analyzed in 2 different phases. However, no beneficial effects were observed in growth performance during either growth phase. Our results are in accordance with those reported by Bergstrom et al. (2007), where the inclusion of FNP to diets for 100-kg pigs did not improve ADG, ADFI, or G/F. However, they reported that the inclusion of FNP to the diets increased loin depth. Similarly, Frank et al. (2008) reported that the addition of FNP to the diet did not affect ADG or ADFI in 100-kg pigs, but G/F and loin depth were increased.

During d 0 to 14, DM digestibility was improved with the addition of FNP, whereas no differences were observed in GE and CP digestibility. However, this response was not consistent during d 14 to 28. During d 14 to 28, no differences were observed in DM digestibility, whereas linear and quadratic effects were observed in GE and CP digestibility. The addition of 0.25% FNP to the diets increased CP and GE digestibility. Our data suggest that as pigs become older and heavier, beneficial effects in nutrient digestibility may be more evident from FNP addition. Therefore, further research should be conducted evaluating the effect of FNP on ileal digestibility of AA in late finishing pigs. Our data suggest that research should be conducted evaluating FNP in low crude protein diets as CP digestibility was increased with the addition of 0.25% FNP.

CHAPTER 5

COMPARISON OF CHROMIC OXIDE AND ACID INSOLUBLE ASH AS DIGESTIBILITY MARKERS IN THE DETERMINATION OF APPARENT TOTAL TRACT DIGESTIBILITY IN FINISHING PIGS

INTRODUCTION

Total fecal collection digestion-trials are laborious and are subject to errors associated with contamination and lack of total collection. This method requires moving pigs into metabolism crates, meticulous records of feed intake, output of feces, and usually daily feed intake is restricted and held constant at a lower level than the voluntary feed intake if fed *ad libitum*. The indicator technique, or marker method, can be used instead of total collection by random grab sampling of feces, but an indigestible marker must be added to the diet at a known concentration. This marker should be chemically easily to analyze, nonabsorbable, nonessential, nontoxic, completely inert, and uniformly mixed within the feed and feces (Aldeola, 2001). Chromic oxide (Cr_2O_3) has been widely used as an indigestible marker in digestibility studies with pigs (Jorgensen et al., 1984; Aldeola et al., 1986; Mroz et al., 1996), but several problems have been associated with its use, including accurate and consistent analysis, interference with other minerals (Saha and Gilbreath, 1991), and environmental concerns. Natural markers such as acid insoluble ash (AIA) have been proposed as an alternative to Cr_2O_3 (McCarthy et al., 1974) for determining nutrient digestibility in pig diets. Acid insoluble ash naturally occurs at variable levels in feed and is usually present in low concentrations in cereal-based diets (Kavanagh et al., 2001). McCarthy et al. (1974) reported that AIA was a superior marker than Cr_2O_3 for determining digestibility in pig diets and that no additional source of AIA such as celite was needed. However, more accurate results have been reported when celite was added to the diet to complement the low levels of natural AIA (Scott and Hall, 1998). Despite the strong evidence that Cr_2O_3 is a reliable marker for digestibility studies in pigs, alternative markers should be evaluated with pigs fed *ad libitum*. Therefore, the objective of this research was to compare the total tract digestibility coefficients of dry matter (DM), crude protein (CP), and gross energy (GE) determined with chromic oxide and acid insoluble ash in early and late finishing pigs fed *ad libitum*.

MATERIALS AND METHODS

All experimental protocols used in these experiments were approved by the Louisiana State University (LSU) Agricultural Center Animal Care and Use Committee. Pigs (Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc) were obtained from the LSU Agricultural Center Swine Unit and housed in an enclosed building in 1.8 m × 2.4 m pens with slotted metal floors (Experiment 1) or in a curtain-sided building in 1.5 m × 3.0 m pens with concrete slated floors (Experiment 2). In both experiments, each pen was equipped with one nipple waterer and a two-hole self-feeder to provide *ad libitum* access to water and feed. All pigs and feeders were weighed at d 0 and 14 for determination of ADG, ADFI, and feed efficiency (G/F). Pigs were checked twice daily for any abnormalities and feed was provided in mash form.

On the morning of d 10, 11, and 12, fresh feces from each pig were collected by rectal palpation and frozen at 0° C until the last day of the collection. At the end of each experiment, fecal samples were thawed and combined within day, pig, and pen resulting in 1 sample per pen. All fecal samples were oven dried at 60° C for 96 h to determine DM content and ground (Retsch Grindomix, model GM200) for further chemical analyses.

Feed and fecal samples were analyzed for GE by the bomb calorimetry method (AOAC, 1990) at the Analytical Lab of Kansas State University. Crude protein was determined by the Kjeldahl (racks) procedure (AOAC, 1990) and acid insoluble ash by a modified method described by Scott and Boldaji (1997). Chromium concentration was determined by wet-ashing samples in a nitric- perchloric acid mixture and diluted for analysis using the inductively coupled atomic emission spectrometry (ICP) at the LSU AgChemistry. Digestibility coefficients for DM, CP, and GE were determined by the following equation:

$$\text{Percent apparent digestibility} = \frac{N_d/A_d - N_s/A_s \times 100}{N_d/A_d}$$

A_d = percent of marker in feed
A_s = percent of marker in sample
N_d = percent nutrient in feed
N_s = percent nutrient in sample

Experiment 1

A total of 18 growing barrows with an average initial BW of 50 ± 2.90 kg were randomly assigned to 6 pens. All pigs were fed the same corn and soybean meal diet formulated to contain 0.80% total Lys, 0.55% P, and 0.50% Ca (Table 5.1). Chromic oxide and AIA were both added together on top of the diet at 0.5 and 1% respectively. Feed samples were collected at the end of feed manufacture.

Experiment 2

A total of 36 late-finishing pigs (18 barrows and 18 gilts) with an average initial BW of 85 ± 5.90 kg were allotted to 2 dietary treatments. Each treatment was replicated with 6 pens of 3 pigs per pen. Each treatment included 3 reps of barrows and 3 reps of gilts. All pigs were fed the same corn and soybean meal diet (C+SBM) formulated to contain 0.55% total Lys, 0.38% P, and 0.42% Ca (Table 5.1). Digestibility markers were added separately to the same diet resulting in the following dietary treatments: 1) (C+SBM) + 0.5% Cr_2O_3, and 2) (C+SBM) + 1% AIA. Feed samples were collected at the end of feed manufacture.

Statistical Analysis

Data were statistically analyzed by ANOVA as a completely randomized design (Experiment 1) or a randomized complete block design (Experiment 2) using the GLM procedures in SAS (SAS Inst. Inc., Cary, NC). Each pen of pigs served as the experimental unit in both experiments. Differences in digestibility coefficients were determined using the one way ANOVA at a significance level set at 0.10. In Experiment 2, the treatment × sex interaction was not significant; therefore it was removed from statistical analysis. Sources of variation in Experiment 2 included treatment, replicate (initial BW), and sex.

RESULTS

In Experiment 1, pigs had an ADG of 827 g, ADFI of 2,382 g, and G/F of 0.35. The diet analyzed to contain 1.48% AIA and 3,171 ppm Cr. The 1.48% AIA is because both the diatomaceous earth and the Cr_2O_3 contributed to the total AIA in the diet. No differences ($P > 0.1$) were observed in CP digestibility coefficients determined using Cr_2O_3 or AIA as digestibility markers. However, DM and GE digestibility coefficients were greater ($P < 0.1$) when determined with Cr_2O_3 (Fig. 5.1).

In Experiment 2, no differences ($P > 0.1$) were observed in growth performance of pigs fed the diet with the addition of Cr_2O_3 or AIA as digestibility markers (Table 5.2). Diet 1 was analyzed to contain 3,484 ppm Cr and Diet 2 was analyzed to contain 1.0% AIA. As in Experiment 1, no significant differences ($P > 0.1$) were observed in CP digestibility coefficients when determined with either Cr_2O_3 or AIA. However, DM and GE digestibility coefficients were greater ($P < 0.1$) when determined using AIA (Fig. 5.2).

Table 5.1. Composition of experimental diets used in Experiments 1 and 2, as fed basis

	Experiment 1	Experiment 2	
Item, %	Cr_2O_3+AIA	Cr_2O_3	AIA
Corn	81.85	88.35	88.35
Soybean meal (48% CP)	15.75	7.00	7.00
Limestone	0.90	0.75	0.75
Monocalcium phosphate	1.10	0.50	0.50
L-Lysine HCL	0.15	0.15	0.15
Dry Fat	---	3.00	3.00
Hubbard Vitamins Premix	0.25	0.25	0.25
Chromic oxide (Cr_2O_3)	0.50	0.50	---
Acid insoluble ash (AIA)[a]	1.00	---	1.00
Total, %	101.50	100.50	101.00
Calculated composition			
ME, kcal/kg	3,278	3,454	3,454
CP, %	13.75	10.11	10.11
Lys, %	0.80	0.55	0.55
Ca, %	0.59	0.42	0.42
P, %	0.55	0.38	0.38
Cr, ppm	3,352	3,352	---
AIA, %	1.00	---	1.00
Analyzed values			
CP, %	12.50	13.32	12.11
GE, kcal/kg	4,004	4,442	4,510
Cr, ppm	3,171	3,484	---
AIA, %	1.48	---	1.00

[a]Acid insoluble ash in the form of diatomaceous earth obtained from Perma-Guard Inc.

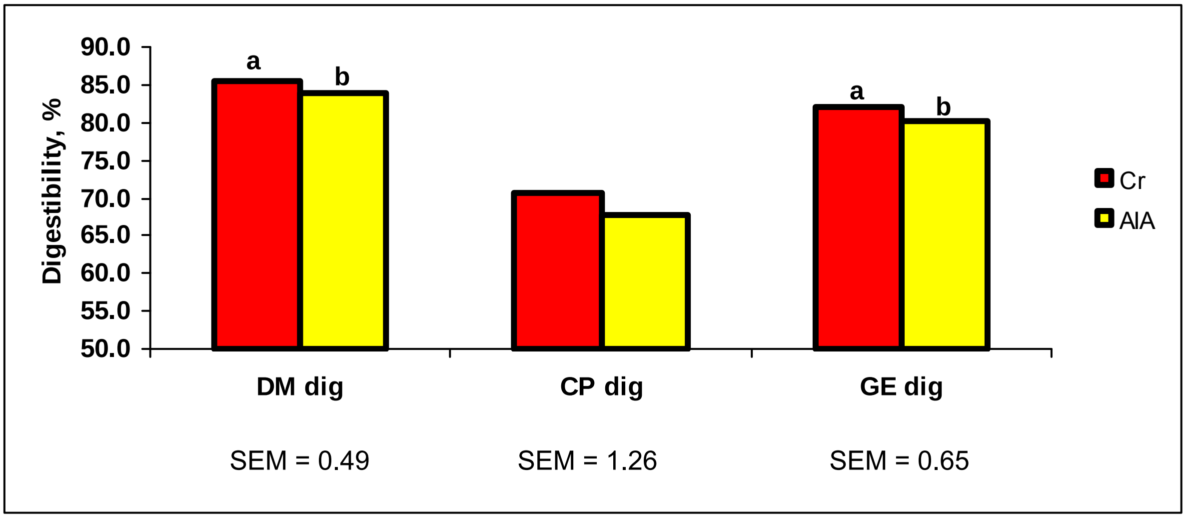

Figure 5.1. Digestibility coefficients determined with chromic oxide (Cr_2O_3) and acid insoluble ash (AIA), when both markers were added together to the diet in Experiment 1.

Table 5.2. Growth performance of finishing pigs fed diets with the addition of chromic oxide (Cr_2O_3) and acid insoluble ash (AIA) as digestibility marker in Experiment 2

Treatments	ADG. g	ADFI, g	G:F
Day 0 to 14			
Cr_2O_3	592.38	2815.20	0.21
AIA	628.74	2825.64	0.22
Trt P-value	0.43	0.96	0.62
SEM	30.01	132.38	0.02

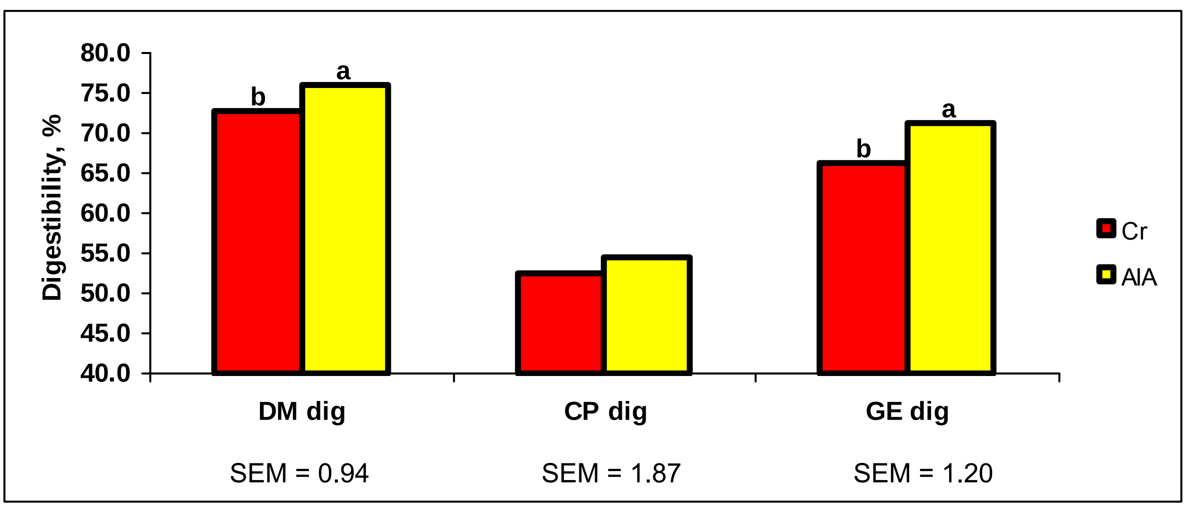

Figure 5.2. Digestibility coefficients determined with chromic oxide (Cr_2O_3) and acid insoluble ash (AIA), when each marker was added individually to the diet in Experiment 2.

DISCUSSION

The marker method for digestibility studies in pigs has been shown to be an accurate alternative to the total fecal collection method (Adeola et al., 1986 and Mroz et al., 1992) using either Cr_2O_3 or AIA as digestibility markers (Kavanagh et al., 2001). Despite the strong evidence that suggests that Cr_2O_3 or AIA are reliable markers for digestibility studies, several problems have been reported. Some digestibility studies using Cr_2O_3 reported analytical and accuracy problems, interference with some minerals (Saha and Gilbreath, 1991), and low marker recovery rates (McCarthy et al., 1974). Similarly, Bakker and Jongbloed (1994) reported that AIA was not a suitable marker for fecal digestibility studies in pigs; however, in their experiment, no extra source of AIA was added to the diets. Both markers have been studied under different experimental conditions. It has been shown that the reliability of the marker varies according to the ingredients used in the diet, marker mixing procedure, total d of collection, feed sampling technique, level of marker in the diet, and if animals were penned in metabolic crates or in group-housed pens.

Results from our experiments showed that digestibility coefficients for DM and GE are more susceptible to variation with a specific marker than CP digestibility. In Experiments 1 and 2, digestibility coefficients for CP were not affected regardless of whether Cr_2O_3 or AIA was used. However, digestibility for DM and GE were higher in Experiment 1 when determined with Cr_2O_3, whereas in Experiment 2, DM and GE digestibility were higher when determined with AIA.

Differences in CP digestibility coefficients were not significant, but variability in the CP content of samples was greater than the variability found in GE and DM content. Crude protein was determined using the Kjelhdal rack procedure, which requires the technician's ability to identify color change in the titration procedure. All samples were analyzed by the same technician; however, all samples were not analyzed on the same day and this may have affected the technician's ability to determine the same color change during titration. However, DM and GE fecal samples are less variable because determination is not based on subjective technician's observation.

The analyzed values for Cr and AIA in both experiments showed that AIA content was closer to the intended dosage in the diet. In Experiment 1, both markers were added together to the diet and the analyzed value of AIA was 1.48%, which accounted for the 1% AIA and the 0.5% Cr_2O_3. Kavanagh (2001) reported that when Cr_2O_3 and AIA are both added together to the same diet, the amount of chromic oxide would be part of the insoluble fraction and therefore contribute to the AIA content of the diet. In Experiment 2, the diet analyzed to contain 1% AIA, which was the exact intended dosage of the diet. However, results for Cr content in diets were not as close to the intended dosage of the diet. In Experiment 1, the Cr content of the diet was 6.4% less than the calculated value, whereas in Experiment 2 the Cr content was 3.94% greater than the calculated values. Inconsistencies in Cr values and analytical limitations have been reported when using Cr_2O_3 as a digestibility marker, and it may be attributed to laboratory problems or the inability of the marker to properly mix in the diet.

Usually, digestibility markers are added to the diet 3 to 5 d before the fecal or ileal collection period to give the animal an adaptation period to the diet (Adeola, 2001). However, in our studies, feed was manufactured one time for each experiment and the markers were added to the diet at that time. Many countries have banned the use of Cr, which is a heavy metal, because of environmental concerns. Also, it becomes cost prohibitive to use Cr_2O_3 in large digestibility studies with pigs fed *ad libitum* due to the high cost of the marker and the cost associated with contamination. Acid insoluble ash is a more inexpensive marker and with less environmental effects.

In conclusion, AIA and Cr_2O_3 offer a rapid and reliable technique for the determination of total tract digestibility in finishing pigs using the grab sampling method. However, AIA seemed to have superior characteristics compared with Cr_2O_3 as its analyzed values are more consistent and closer to the calculated values, present less environmental concerns, and are more cost effective compared with Cr_2O_3.

CHAPTER 6

SUMMARY AND CONCLUSIONS

This research was conducted to: 1) compare the effect of source and level of inclusion of dried whey peremeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs, 2) to evaluate the effect of a fortified nutrient pack (FNP) on growth performance and total tract nutrient digestibility in growing/finishing pigs, and 3) to compare chromic oxide (Cr_2O_3) and acid insoluble ash (AIA) as digestibility markers for total tract digestibility determination in growing/finishing pigs.

Three experiments were conducted to compare the feeding value of DWP (80% lactose) and CHO (40% lactose, 30% sucrose, and 10% glucose) in diets for nursery pigs. These experiments indicate that the inclusion of DWP and CHO improved ADG and ADFI compared with pigs fed a diet without lactose. A highly digestible carbohydrate source in diets for nursery pigs is more beneficial as pigs are weaned lighter and younger.

Two experiments were conducted to evaluate the effect of FNP fumaric, malic, citric, phosphoric, and lactic acids, L-carnitine, chromium picolinate, inulin, d-pantothenic acid, and niacin) on growth performance and total tract nutrient digestibility in growing/finishing pigs. These experiments indicate that the inclusion of 0.25 or 0.50% FNP to the diets did not improve ADG, ADFI, or G/F of growing/finishing pigs. Dry matter, CP, and GE digestibility were not improved with the inclusion of FNP in 50-kg pigs. However, the inclusion of 0.25% FNP in diets for 85-kg pigs during the last 14 d of growth improved CP and GE digestibility.

Two experiments were conducted to compare Cr_2O_3 and AIA as digestibility markers for total tract digestibility determination in growing/finishing pigs fed *ad libitum*.

These experiments indicate that Cr_2O_3 and AIA offer rapid and reliable techniques for digestibility determination in growing/finishing pigs. However, AIA showed superior characteristics compared with Cr_2O_3 as its analyzed values are more consistent, produce less environmental impact, and is more cost effective.

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VITA

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