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Comparison of dried whey permeate and a carbohydrate product in diets for nursery pigs[1,2]

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ABSTRACT: Three experiments were conducted to compare dried whey permeate (DWP; 80% lactose) and a carbohydrate product (CHO; 40% lactose, 30% sucrose, and 10% glucose) for nursery pigs. Pigs were fed in a 3-phase feeding program, and diets contained 1.6, 1.4, and 1.2% total Lys for phases 1 (d 0 to 7), 2 (d 7 to 21), and 3 (21 to 28). Dietary treatments included 1) control (no lactose), 2) low level of DWP, 3) high level of DWP, 4) low level of CHO, and 5) high level of CHO. In Exp. 1 (4 reps of 4 pigs per pen; initial BW = 7 kg and 23 d of age), the low and high levels used for each source in each phase were phase 1 (12.5 and 25%), phase 2 (10 and 20%), and phase 3 (6 and 12%). In Exp. 2 (6 reps of 5 pigs per pen; initial BW = 8 kg and 26 d of age) and 3 (4 reps of 4 pigs per pen; initial BW = 6 kg and 21 d of age), the inclusion levels were phase 1 (6 and 12%), phase 2 (3 and 6%), and phase 3 (common diet with no lactose). In Exp. 1, pigs fed diets with DWP or CHO had increased ADG ($P = 0.02$ and $P = 0.01$) and ADFI ($P = 0.01$) compared with pigs fed the control diet during phase 1. Gain:feed was reduced ($P = 0.08$) for pigs fed diets with CHO. During phases 2, 3, and overall, ADG, ADFI, and G:F were not affected ($P > 0.10$) by diet. In Exp. 2, pigs fed diets with CHO had increased ADG ($P = 0.08$ and $P = 0.07$) and ADFI ($P = 0.04$ and $P = 0.01$) compared with pigs fed the control diet during phases 1 and 2. Pigs fed diets with CHO had increased ADFI ($P = 0.08$ and $P = 0.07$) in phases 1 and 2 and increased ADG ($P = 0.02$) in phase 2 compared with pigs fed diets with DWP. Overall, pigs fed diets with DWP and CHO had increased ADFI ($P = 0.06$ and $P = 0.01$) compared with pigs fed the control diet, but ADG was increased ($P = 0.07$) for pigs fed diets with CHO. In Exp. 3, ADG, ADFI, and G:F were not affected ($P > 0.10$) by DWP or CHO during phase 1. Daily BW gain was increased ($P = 0.02$ and $P = 0.07$) for pigs fed diets with DWP or CHO during phase 2 compared with pigs fed the control diet. Overall, ADG was increased ($P = 0.05$) for pigs fed diets with DWP, but ADFI and G:F were not affected. Results from the combined data of Exp. 2 and 3, indicated that overall ADG ($P = 0.05$ and $P = 0.04$) and ADFI ($P = 0.04$) were increased in pigs fed diets with DWP or CHO compared with pigs fed the control diet. These data suggest that DWP or CHO improve growth performance of weanling pigs.

Key words: carbohydrate, lactose, nursery pig, sucrose

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INTRODUCTION

Research has shown that the use of milk products such as whey, whey permeate, or crystalline lactose improves growth performance (Mahan, 1993; Owen et al., 1993; Tokach et al., 1995; Nessmith et al., 1997) of weanling pigs. Mahan (1992) reported that the lactose portion of dried whey or the inclusion of a highly digestible carbohydrate is necessary for improved growth performance of weanling pigs. Numerous studies have shown increased growth rate and feed intake with increasing lactose (Mahan et al., 2004; Cromwell et al., 2008); however, other highly available carbohydrates may also be as effective (Mahan, 1992). Research has shown that the use of simple sugars such as dextrose (Mahan and Newton, 1993) or sucrose (de Rodas et al., 1998; Mavromichalis et al., 2001) can effectively replace the lactose portion of nursery diets.

Alternative simple sugars for the replacement of lactose have been investigated in response to the variable cost and availability of lactose. Brooks (1972) and Mavromichalis et al. (2001) reported that sucrose could effectively replace lactose in diets for nursery pigs. Under conditions in which sucrose is highly available, acces-

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sible, and at competitive prices, products containing increased amounts of sucrose may be an alternative to high-lactose-containing products. Dried whey permeate (**DWP**) is routinely included in diets for nursery pigs and contains 80% lactose. A novel carbohydrate product (**CHO**) containing a blend of 40% lactose, 30% sucrose, and 10% glucose 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

All experimental protocols used in these studies were approved by the Louisiana State University Agricultural Center Animal Care and Use Committee.

General

Pigs (Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc) were obtained from the Louisiana State University Agricultural Center Swine Unit and housed in an environmentally controlled nursery building containing 34 pens. Each pen (0.97 × 1.47 m in size) had hard plastic slotted flooring, one nipple waterer, and a 4-hole self-feeder to provide ad libitum access to water and feed in meal form. 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 for phase 1, d 7 to 21 for phase 2, and d 21 to 28 for phase 3. All pigs and feeders were weighed at the beginning and end of each growth phase to determine ADG, ADFI, and G:F. Pigs were not allowed creep feed during lactation.

In all experiments, dietary treatments were formulated based on the AA and nutrient concentrations provided by International Ingredient Corporation (Fenton, MO) for DWP and CHO product. The nutrient values used for CHO were 2% CP, 40% lactose, 30% sucrose, 10% glucose, 1.4% citric acid, 0.4% lactic acid, 0.06% Lys, 0.02% Met, 0.04% Thr, 0.01% Trp, 0.05% Ile, 0.10% Val, 0.26% Ca, 0.31% P, 0.08% Mg, 1.5% salt, and 3,656 kcal/kg of ME. Nutrient values reported by NRC (1998) were used 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 AA ratios suggested by Baker (1997) for 10-to 20-kg pigs. Soybean meal was held constant within each phase, and salt content fluctuated among diets to hold the Na and Cl percentage constant. The phase 1 and 2 diets were calculated to contain 0.90% Ca and 0.80% P, whereas the phase 3 diets were calculated to contain 0.80% Ca and 0.70% P.

Exp. 1

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

Exp. 2

A total of 150 weanling pigs with an average initial BW of 7.6 ± 1.1 kg and 26 ± 3 d of age were allotted to 5 dietary treatments. Each treatment was replicated with 6 pens of 5 pigs per pen. Dietary treatments used in Exp. 2 followed the same design as those of Exp. 1, but the low and high levels for each carbohydrate source were reduced during phases 1 and 2, whereas during phase 3 all pigs were fed the same diet with no lactose (Tables 4 and 5). The levels of each carbohydrate source for each phase were phase 1 (6 and 12%), phase 2 (3 and 6%), and phase 3 (none, common diet for all pigs).

Exp. 3

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 allotted to the same dietary treatments used in Exp. 2. However, pigs in Exp. 3 were weaned on average 5 d earlier. Each treatment was replicated with 4 pens of 4 pigs per pen. Because Exp. 2 and 3 included the same dietary treatments, data were combined and analyzed together.

Statistical Analysis

Data from all experiments were analyzed as randomized complete block designs using the GLM procedures (SAS Inst. Inc., Cary, NC). Initial BW (block) and dietary treatment were used as sources of variation and each pen of pigs served as the experimental unit. Combined data of Exp. 2 and 3 were analyzed using block, dietary treatment, and experiment as sources of variation. Treatment × experiment interactions were not significant ($P > 0.10$) and were therefore removed from the model. Contrast statements were used to determine the following effects: 1) source, the 2 levels of DWP vs. the 2 levels of CHO, 2) level, the low levels vs. the high levels of DWP and CHO, 3) source × level, 4) control vs. DWP, and 5) control vs. CHO. Effects were considered significant at $P < 0.10$.

Table 1. Composition (as-fed basis) of experimental diets fed to nursery pigs in phase 1 of Exp. 1[1]

		DWP		CHO	
Item	Control	Low	High	Low	High
Ingredient, %					
Corn	57.58	45.64	33.69	45.24	32.89
Soybean meal (48% CP)	22.27	22.27	22.27	22.27	22.27
Fishmeal menhaden	7.00	7.00	7.00	7.00	7.00
Spray-dried plasma protein[2]	4.00	4.00	4.00	4.00	4.00
Dry fat[3]	3.00	3.00	3.00	3.00	3.00
Red blood cells[4]	2.00	2.00	2.00	2.00	2.00
Dried whey permeate (DWP)[5]	—	12.50	25.00	—	—
Carbohydrate product (CHO)[5]	—	—	—	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[6]	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[7]	0.10	0.10	0.10	0.10	0.10
Antibiotic[8]	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[9]	—	0.04	0.08	0.04	0.09
Calculated composition					
ME, kcal/kg	3,437	3,460	3,483	3,474	3,510
Lactose, %	0	10	20	5	10
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

[1]The low and high levels used for each source were 12.5 and 25%, respectively.
[2]AP-920 was obtained from American Protein Corp., Ames, IA.
[3]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[4]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[5]DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.
[6]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; thiamine, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[7]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, as ferrous sulfate, zinc sulfate, copper sulfate, manganese sulfate, ethylenediamine dihydroiodide, and sodium selenite, respectively, with calcium carbonate as the carrier.
[8]Neo-terra 10/10, Nutra Blend LLC, Neosho, MO. Provides per kilogram of feed, 165 mg of oxytetracycline and 116 mg of neomycin.
[9]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

RESULTS AND DISCUSSION

Exp. 1

During phase 1, pigs fed diets with DWP or CHO had increased ADG ($P = 0.02$ and $P = 0.01$, respectively) and ADFI ($P = 0.01$) compared with pigs fed the control diet (Table 6). These results are in agreement with previous research (Mahan and Newton, 1993; Mahan et al., 2004) that have reported increased growth rate during the first weeks postweaning with the inclusion of highly digestible carbohydrates. The improvement in growth rate may be attributed to the ability of lactose or sucrose to stimulate feed intake (Cromwell et al., 2008), especially during the week after weaning. Gain:feed was not affected ($P = 0.16$) for pigs fed diets with DWP, but it was reduced ($P = 0.08$) for pigs fed diets with CHO compared with pigs fed the control diet. Daily feed intake of pigs fed diets with CHO was 31% greater than pigs fed the control diet, which resulted in the reduced feed efficiency. Research has shown that pigs greatly prefer sucrose over lactose (Diaz et al., 1956; Glaser et al., 2000); however, lactose has been suggested to stimulate appetite in weanling pigs (Cromwell et al., 2008).

During phases 2, 3, and overall, ADG, ADFI, and G:F were not affected ($P > 0.10$) in pigs fed diets with DWP or CHO compared with pigs fed the control diet. During phase 3, there was a source × level effect ($P = 0.05$) in G:F. The high level of DWP improved G:F compared with the low level, whereas the high level of CHO reduced G:F compared with the low level. How-

Table 2. Composition (as-fed basis) of experimental diets fed to nursery pigs in phase 2 of Exp. 1[1]

		DWP		CHO	
Item	Control	Low	High	Low	High
Ingredient, %					
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[2]	3.00	3.00	3.00	3.00	3.00
Red blood cells[3]	2.00	2.00	2.00	2.00	2.00
Dried whey permeate (DWP)[4]	—	10.00	20.00	—	—
Carbohydrate product (CHO)[4]	—	—	—	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[5]	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[6]	0.10	0.10	0.10	0.10	0.10
Antibiotic[7]	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[8]	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
Lactose, %	0	8	16	4	8
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

[1]The low and high levels used for each source were 10 and 20%, respectively.
[2]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[3]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[4]DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.
[5]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; thiamine, 4 mg; folic acid, 3 g; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.
[6]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, as ferrous sulfate, zinc sulfate, copper sulfate, manganese sulfate, ethylenediamine dihydroiodide, and sodium selenite, respectively, with calcium carbonate as the carrier.
[7]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provides per kilogram of feed, 165 mg of oxytetracycline and 116 mg of neomycin.
[8]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

ever, there were no ($P > 0.10$) source, level, or source × level effects in ADG, ADFI, or G:F in any other phase of the experiment. Similarly, some researchers (Mavromichalis et al., 2001) have reported 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. In contrast, other researchers (Mahan et al., 2004; Cromwell et al., 2008) have shown increased growth rates to lactose during mid- to late-nursery phase or up to 25 kg of BW. Although significant responses were not observed in Exp. 1 except for phase 1, overall ADG was increased by 6% for pigs fed diets with DWP and by 7% for pigs fed diets with CHO compared with pigs fed the control diet. Similarly, overall ADFI was increased by 9 and 10% in pigs fed diets with DWP and CHO, respectively, compared with the control.

Exp. 2

During phase 1, pigs fed diets with CHO had increased ($P = 0.08$) ADG and ADFI ($P = 0.04$) compared with pigs fed the control diet (Table 7). Daily gain and ADFI were not affected ($P > 0.10$) for pigs fed diets with DWP. Pigs fed diets with CHO had increased (source effect, $P = 0.08$) ADFI compared with pigs fed diets with DWP. When compared with pigs fed the control diet, the inclusion of DWP increased ADFI by 5%, whereas the inclusion of CHO increased ADFI by 15%. Gain:feed was not affected ($P > 0.10$) for pigs fed diets with CHO or DWP compared with pigs fed the control. These results are not in full agreement with those of Exp. 1, in which significant responses were obtained in ADG and ADFI for pigs fed diets with DWP or CHO during phase 1. However, the high and low

Table 3. Composition (as-fed basis) of experimental diets fed to nursery pigs in phase 3 of Exp. 1[1]

		DWP		CHO	
Item	Control	Low	High	Low	High
Ingredient, %					
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[2]	3.00	3.00	3.00	3.00	3.00
Dried whey permeate (DWP)[3]	—	6.00	12.00	—	—
Carbohydrate product (CHO)[3]	—	—	—	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[4]	0.50	0.50	0.50	0.50	0.50
Salt	0.41	0.26	0.10	0.33	0.24
Trace mineral premix[5]	0.10	0.10	0.10	0.10	0.10
Antibiotic[6]	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[7]	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
Lactose, %	0	4.8	9.6	2.4	4.8
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

[1]The low and high levels used for each source were 6 and 12%, respectively.

[2]Fat Pak 100, Milk Specialties Co., Dundee, IL.

[3]DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.

[4]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; thiamine, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.

[5]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, as ferrous sulfate, zinc sulfate, copper sulfate, manganese sulfate, ethylenediamine dihydroiodide, and sodium selenite, respectively, with calcium carbonate as the carrier.

[6]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provides per kilogram of feed, 165 mg of oxytetracycline and 116 mg of neomycin.

[7]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

levels of inclusion of each carbohydrate source were reduced by 50% in Exp. 2 compared with Exp. 1. At this level of inclusion, DWP may not be as effective as CHO in increasing ADFI in pigs weaned at an average age of 26 d. However, ADG between pigs fed diets with DWP or CHO was not different (source effect, $P = 0.17$).

During phase 2, pigs fed diets with CHO continued to have increased ($P = 0.01$) ADFI and ADG ($P = 0.07$) compared with pigs fed the control diet, but G:F was not affected ($P > 0.10$). Daily gain and ADFI were not affected ($P > 0.10$) for pigs fed diets with DWP compared with pigs fed the control diet, but G:F was reduced ($P = 0.09$). Pigs fed diets with CHO had increased ADG (source effect, $P = 0.02$) and ADFI (source effect, $P = 0.07$) compared with pigs fed diets with DWP. Similarly de Rodas et al. (1998) reported that pigs fed diets with a high-sucrose-containing product had increased ADG and ADFI compared with pigs fed a control diet with 10% dried whey during phase 2.

During phase 3, when all pigs were fed the same diet with no lactose, pigs previously fed diets with DWP or CHO had increased ($P = 0.01$ and $P = 0.04$, respectively) ADFI, but ADG was not affected ($P > 0.10$). Similarly, a subsequent increase in ADFI has been reported in pigs fed a common diet when dried whey was provided during the initial phases (Mahan et al., 1993; Nessmith et al., 1997) compared with pigs that were not fed dried whey previously. Gain:feed was reduced ($P = 0.09$) only for pigs fed diets with CHO during the previous phases compared with pigs fed the control diet.

In the overall data, pigs fed diets with DWP or CHO had increased ($P = 0.06$ and $P = 0.01$, respectively) ADFI compared with pigs fed the control diet. Daily gain was increased ($P = 0.07$) for pigs fed diets with CHO, but G:F was not affected with the inclusion of DWP or CHO. However, there was no ($P > 0.10$) source, level, or source × level effect in ADG, ADFI, or G:F in the overall data. Overall ADG was increased by 3% for

Table 4. Composition (as-fed basis) of experimental diets fed to nursery pigs in phase 1 of Exp. 2 and 3[1]

		DWP		CHO	
Item	Control	Low	High	Low	High
Ingredient, %					
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
Spray-dried plasma protein[2]	4.00	4.00	4.00	4.00	4.00
Dry fat[3]	3.00	3.00	3.00	3.00	3.00
Red blood cells[4]	2.00	2.00	2.00	2.00	2.00
Dried whey permeate (DWP)[5]	—	6.00	12.00	—	—
Carbohydrate product (CHO)[5]	—	—	—	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[6]	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[7]	0.10	0.10	0.10	0.10	0.10
Antibiotic[8]	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[9]	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
Lactose, %	0	4.8	9.6	2.4	4.8
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

[1]The low and high levels used for each source were 6 and 12%, respectively.
[2]AP-920 was obtained from American Protein Corp., Ames, IA.
[3]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[4]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[5]DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.
[6]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; thiamine, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.
[7]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, 7.30 mg, as ferrous sulfate, zinc sulfate, copper sulfate, manganese sulfate, ethylenediamine dihydroiodide, and sodium selenite, respectively, with calcium carbonate as the carrier.
[8]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provides per kilogram of feed, 165 mg of oxytetracycline and 116 mg of neomycin.
[9]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

pigs fed diets with DWP and 6% for pigs fed diets with CHO compared with pigs fed the control diet.

Exp. 3

During phase 1, ADG, ADFI, and G:F were not affected ($P > 0.10$) by DWP or CHO (Table 8). Although Exp. 2 and 3 included the same dietary treatments, responses to DWP or CHO were not consistent. In Exp. 3, pigs were weaned at an average weaning age of 21 d (18 to 23 d). A greater response to DWP and CHO was expected in this experiment because research has shown that pigs weaned at younger ages respond more to increasing lactose than pigs weaned at older ages (Mahan et al., 2004). However, the carbohydrate amounts used in this phase may not have been large enough to maximize growth performance of this age of pigs. Mahan et al. (2004) reported that dietary lactose of 25 to 30% is necessary to maximize growth performance during the initial week postweaning.

During phase 2, pigs fed diets with DWP or CHO had increased ($P = 0.02$ and $P = 0.07$, respectively) ADG, but ADFI and G:F were not affected ($P > 0.10$). Although ADG was not significantly increased for pigs fed diets with DWP or CHO during phase 1, a possible carryover effect may have occurred that can explain the increased growth during phase 2. However, Mahan et al. (2004) suggested that lactose has a minimal carryover effect from one nursery phase to another. Gain:feed was increased at the high level of DWP or CHO (level effect, $P = 0.06$).

Table 5. Composition (as-fed basis) of experimental diets fed to nursery pigs in phases 2 and 3 of Exp. 2 and 3[1]

	Phase 2					Phase 3
		DWP		CHO		
Item	Control	Low	High	Low	High	Control
Ingredient, %						
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[2]	3.00	3.00	3.00	3.00	3.00	3.00
Red blood cells[3]	2.00	2.00	2.00	2.00	2.00	—
Dried whey permeate (DWP)[4]	—	3.00	6.00	—	—	—
Carbohydrate product (CHO)[4]	—	—	—	3.00	6.00	—
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[5]	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[6]	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[7]	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[8]	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
Lactose, %	0	2.4	4.8	1.2	2.4	0
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

[1]The low and high levels used for each source were 3 and 6%, respectively.
[2]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[3]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[4]DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.
[5]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; thiamine, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[6]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, as ferrous sulfate, zinc sulfate, copper sulfate, manganese sulfate, ethylenediamine dihydroiodide, and sodium selenite, respectively, with calcium carbonate as the carrier.
[7]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provides per kilogram of feed, 165 mg of oxytetracycline and 116 mg of neomycin.
[8]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

During phase 3, when all pigs were fed a common diet, no carryover effects were observed ($P > 0.10$) in ADG, ADFI, or G:F in pigs fed diets with DWP or CHO during the previous phases. These results are not fully consistent with those obtained in Exp. 2 in which ADFI was increased. Similarly, subsequent growth responses in pigs fed diets with lactose during the initial phase has been inconsistent in the literature.

In the overall data, pigs fed diets with DWP had increased ($P = 0.05$) ADG, but ADFI and G:F were not affected ($P > 0.10$) compared with pigs fed the control diet. Daily gain, ADFI, and G:F were not affected ($P > 0.10$) in pigs fed diets with CHO compared with pigs fed the control diet. There were no source or source × level effects in ADG, ADFI, or G:F during any phase of the experiment. Throughout the experiment, pigs fed diets with DWP had a numerically greater ADG compared with pigs fed the control diet, but it was only significant ($P = 0.02$ and $P = 0.05$, respectively) during phase 2 and overall. The response in ADG of pigs fed diets with DWP compared with those fed the control may be attributed to a better utilization of lactose by the early weaned pigs (18 to 21 d of age) as a response to increased lactase activity. However, there was no source effect in ADG.

Combined Data, Exp. 2 and 3

Even though Exp. 2 and 3 included the same dietary treatments, growth responses were inconsistent. In Exp. 2, growth performance was increased in pigs fed diets with CHO, whereas in Exp. 3 this was achieved in pigs

Table 6. Effect of dried whey permeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs in Exp. 1[1]

		DWP		CHO				Contrast P-value			Control vs.	
Item	Control	Low	High	Low	High	P-value[2]	SEM	Source[3]	Level[4]	Source × level	DWP	CHO
Phase 1												
ADG, g	286	321	329	339	326	0.06	12	0.52	0.79	0.39	0.02	0.01
ADFI, g	316	401	385	422	406	0.01	15	0.20	0.32	1.00	0.01	0.01
G:F	0.87	0.80	0.85	0.81	0.80	0.40	0.04	0.63	0.66	0.53	0.16	0.08
Phase 2												
ADG, g	517	558	534	545	561	0.70	25	0.78	0.87	0.42	0.36	0.26
ADFI, g	714	817	773	785	805	0.51	43	0.10	0.79	0.47	0.15	0.15
G:F	0.73	0.68	0.70	0.69	0.70	0.71	0.03	0.69	0.65	0.96	0.19	0.31
Phase 3												
ADG, g	569	570	597	607	560	0.74	28	1.00	0.73	0.22	0.68	0.68
ADFI, g	1,061	1,098	1,111	1,101	1,099	0.95	47	0.93	0.91	0.88	0.47	0.51
G:F	0.54	0.52	0.54	0.55	0.51	0.25	0.01	0.92	0.40	0.05	0.56	0.61
Overall												
ADG, g	480	510	510	521	509	0.60	18	0.79	0.75	0.75	0.20	0.14
ADFI, g	740	818	800	810	815	0.47	33	0.91	0.83	0.74	0.12	0.10
G:F	0.65	0.62	0.64	0.64	0.63	0.55	0.01	0.86	0.10	0.26	0.22	0.27

[1]Data are means of 4 replications with 4 pigs per pen. DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.
[2]Overall treatment P-value.
[3]Source effect is both levels of CHO product vs. both levels of DWP.
[4]Level effect is the low levels of both sources vs. the high levels of both sources.

Table 7. Effect of dried whey permeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs in Exp. 2[1]

		DWP		CHO				Contrast *P*-value				
											Control vs.	
Item	Control	Low	High	Low	High	*P*-value[2]	SEM	Source[3]	Level[4]	Source × level	DWP	CHO
Phase 1												
ADG, g	296	302	313	313	341	0.21	14	0.17	0.17	0.56	0.49	0.08
ADFI, g	386	421	387	428	459	0.14	22	0.08	0.94	0.16	0.52	0.04
G:F	0.73	0.72	0.78	0.71	0.75	0.47	0.02	0.40	0.08	0.70	0.61	0.85
Phase 2												
ADG, g	481	480	477	507	518	0.15	13	0.02	0.74	0.62	0.88	0.07
ADFI, g	755	784	796	832	821	0.07	19	0.07	0.99	0.54	0.15	0.01
G:F	0.64	0.61	0.60	0.61	0.63	0.34	0.01	0.28	0.71	0.28	0.09	0.38
Phase 3												
ADG, g	574	594	627	572	584	0.23	18	0.09	0.22	0.57	0.11	0.84
ADFI, g	955	1,040	1,038	1,015	1,030	0.14	26	0.51	0.77	0.76	0.01	0.04
G:F	0.60	0.57	0.60	0.56	0.57	0.25	0.02	0.17	0.26	0.40	0.54	0.09
Overall												
ADG, g	461	470	482	479	497	0.30	12	0.31	0.23	0.82	0.31	0.07
ADFI, g	726	770	763	791	796	0.06	17	0.13	0.95	0.75	0.06	0.01
G:F	0.63	0.61	0.63	0.61	0.62	0.35	0.01	0.62	0.10	0.84	0.37	0.20

[1]Data are means of 6 replications with 5 pigs per pen. DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.
[2]Overall treatment *P*-value.
[3]Source effect is both levels of CHO product vs. both levels of DWP.
[4]Level effect is the low levels of both sources vs. the high levels of both sources.

Table 8. Effect of dried whey permeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs in Exp. 3[1]

		DWP		CHO				Contrast P-value				
											Control vs.	
Item	Control	Low	High	Low	High	P-value[2]	SEM	Source[3]	Level[4]	Source × level	DWP	CHO
Phase 1												
ADG, g	192	195	191	175	217	0.71	19	0.88	0.35	0.27	0.96	0.86
ADFI, g	274	285	274	260	301	0.89	27	0.96	0.61	0.39	0.87	0.85
G:F	0.62	0.68	0.70	0.69	0.72	0.64	0.05	0.76	0.70	0.90	0.24	0.17
Phase 2												
ADG, g	381	440	456	420	440	0.14	20	0.37	0.39	0.93	0.02	0.07
ADFI, g	619	694	684	665	639	0.47	32	0.27	0.58	0.81	0.10	0.42
G:F	0.62	0.63	0.67	0.64	0.69	0.18	0.02	0.66	0.06	0.75	0.20	0.11
Phase 3												
ADG, g	517	545	525	547	499	0.73	28	0.66	0.25	0.62	0.61	0.88
ADFI, g	918	966	904	838	896	0.60	55	0.24	0.97	0.30	0.80	0.46
G:F	0.56	0.57	0.59	0.66	0.56	0.33	0.04	0.40	0.28	0.13	0.79	0.35
Overall												
ADG, g	367	398	404	374	398	0.20	12	0.24	0.48	0.27	0.05	0.24
ADFI, g	599	659	635	602	611	0.63	31	0.22	0.82	0.60	0.24	0.85
G:F	0.62	0.62	0.63	0.62	0.65	0.76	0.02	0.48	0.35	0.75	0.88	0.47

[1]Data are means of 4 replications with 4 pigs per pen. DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.
[2]Overall treatment P-value.
[3]Source effect is both levels of CHO product vs. both levels of DWP.
[4]Level effect is the low levels of both sources vs. the high levels of both sources.

Table 9. Effect of dried whey permeate (DWP) and a carbohydrate product (CHO) on growth performance of nursery pigs; combined data of Exp. 2 and 3[1]

		DWP		CHO				Contrast P-value				
											Control vs.	
Item	Control	Low	High	Low	High	P-value[2]	SEM	Source[3]	Level[4]	Source × level	DWP	CHO
Phase 1												
ADG, g	242	246	252	246	279	0.14	11	0.23	0.10	0.23	0.58	0.13
ADFI, g	325	350	325	345	379	0.13	17	0.14	0.78	0.08	0.52	0.07
G:F	0.68	0.70	0.74	0.70	0.73	0.46	0.03	0.75	0.16	0.99	0.22	0.33
Phase 2												
ADG, g	433	456	461	464	479	0.13	12	0.29	0.42	0.70	0.10	0.01
ADFI, g	690	737	740	755	737	0.10	17	0.67	0.67	0.55	0.02	0.01
G:F	0.63	0.62	0.63	0.62	0.65	0.30	0.01	0.29	0.10	0.32	0.78	0.56
Phase 3												
ADG, g	550	573	585	560	549	0.50	17	0.16	0.99	0.49	0.16	0.81
ADFI, g	926	996	971	930	963	0.42	30	0.21	0.90	0.34	0.12	0.58
G:F	0.59	0.58	0.60	0.61	0.57	0.51	0.02	0.95	0.76	0.08	0.90	0.87
Overall												
ADG, g	415	435	440	429	449	0.14	9	0.90	0.19	0.43	0.05	0.04
ADFI, g	660	711	697	701	707	0.21	17	0.99	0.82	0.54	0.04	0.04
G:F	0.63	0.61	0.63	0.61	0.64	0.39	0.01	0.81	0.05	0.90	0.61	0.75

[1]Data are means of the combined data from Exp. 2 and 3, which had 6 or 4 replications with 5 or 4 pigs per pen, respectively. DWP, International Ingredient Corporation, Fenton, MO; CHO, International Ingredient Corporation.

[2]Overall treatment P-value.

[3]Source effect is both levels of CHO product vs. both levels of DWP.

[4]Level effect is the low levels of both sources vs. the high levels of both sources.

fed diets with DWP. However, in the overall data of both experiments, no ($P > 0.10$) source or level effects were observed for ADG, ADFI, or G:F. Therefore, although different significant responses occurred between these 2 experiments relative to the control diet, no differences were observed between pigs fed diets with DWP or CHO. To better elucidate the effect of these carbohydrate sources, data from both experiments were combined and analyzed.

During phase 1, ADG, ADFI, and G:F were not affected ($P > 0.10$) for pigs fed diets with either DWP or CHO compared with pigs fed the control diet (Table 9). Greater levels of inclusion may be needed to maximize growth performance during the first week postweaning.

During phase 2, pigs fed diets with CHO had increased ($P = 0.01$) ADG compared with pigs fed the control diet, but ADFI was increased ($P = 0.02$ and $P = 0.01$, respectively) for pigs fed diets with DWP or CHO. Gain:feed was not affected ($P > 0.10$) for pigs fed diets with DWP or CHO. Daily gain was increased by 9% in pigs fed diets with CHO and by 5% in fed diets with DWP compared with pigs fed the control diet.

During phase 3, ADG, ADFI, and G:F were not affected ($P > 0.10$) for pigs previously fed diets with DWP or CHO. In the overall data, pigs fed diets with DWP or CHO had increased ($P = 0.05$ and $P = 0.04$, respectively) ADG and ADFI ($P = 0.04$) compared with pigs fed the control diet, but G:F was not affected ($P > 0.10$). There were no source or level effects ($P > 0.10$) in ADG, ADFI, or G:F during any phase of the combined experimental data. The reduction of the carbohydrate level in Exp. 2 and 3 decreased the magnitude of response on growth performance of weanling pigs fed complex diets. Therefore, the size of the difference to be detected among treatments may have been reduced (Aaron and Hays, 2004). Growth responses to DWP and CHO were elucidated when data from both experiments were combined and analyzed together.

The results of the combined data of Exp. 2 and 3 indicated that the inclusion of DWP or CHO improves overall ADG and ADFI of nursery pigs compared with pigs fed diets with no additional highly digestible carbohydrate source, but G:F was not affected. In Exp. 1, DWP and CHO improved ADG and ADFI during phase 1, but not in the overall data. The CHO contained 40% lactose, compared with 80% lactose in DWP, so only one-half of the lactose was replaced by sucrose (30%) and glucose (10%) in CHO. Weaning age may be a factor in the degree of response of weanling pigs to DWP or CHO. These data agree with published literature (Kim and Allee, 2001) indicating that other simple carbohydrates can replace 50% of the lactose in phase 1 and 2 pig starter diets. These data suggest that DWP or CHO improve growth performance of weanling pigs.

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