

# Effects of emulsification, fat encapsulation, and pelleting on weanling pig performance and nutrient digestibility<sup>1</sup>

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**ABSTRACT:** Two experiments were conducted to evaluate the effect of lysolecithin on performance and nutrient digestibility of nursery pigs and to determine the effects of fat encapsulation by spray drying in diets fed in either meal or pelleted form. In Exp. 1, 108 pigs (21 d of age;  $5.96 \pm 0.16$  kg BW) were allotted to one of four dietary treatments (as-fed basis): 1) control with no added lard, 2) control with 5% added lard, 3) treatment 2 with 0.02% lysolecithin, and 4) treatment 2 with 0.1% lysolecithin in a 35-d experiment. Added lard decreased ADG ( $P = 0.02$ ) and ADFI ( $P < 0.06$ ) during d 15 to 35 and overall. Lysolecithin improved ADG linearly ( $P = 0.04$ ) during d 15 to 35 and overall, but did not affect ADFI or G:F. Addition of lard decreased the digestibility of DM ( $P = 0.10$ ) and CP ( $P = 0.05$ ) and increased ( $P = 0.001$ ) fat digestibility when measured on d 10. Lysolecithin at 0.02%, but not 0.10%, tended to improve the digestibility of fat ( $P = 0.10$ ). On d 28, digestibilities of DM, fat, CP, P, ( $P = 0.001$ ), and GE ( $P = 0.03$ ) were increased with the addition of lard, and lysolecithin supplementation linearly decreased digestibilities of DM ( $P = 0.003$ ), GE ( $P = 0.007$ ), CP, and P ( $P = 0.001$ ). In Exp. 2, 144 pigs (21 d of age,  $6.04 \pm 0.16$  kg BW) were allotted to one of six treatments in a 3 ×

2 factorial randomized complete block design. Factors included 1) level (as-fed basis) and source of fat (control diet with 1% lard; control diet with 5% additional lard; and control diet with 5% additional lard from encapsulated, spray-dried fat) and 2) diet form (pelleted or meal). Addition of lard decreased feed intake during d 0 to 14 ( $P = 0.04$ ), d 15 to 35 ( $P = 0.01$ ), and overall ( $P = 0.008$ ), and improved G:F for d 15 to 35 ( $P = 0.04$ ) and overall ( $P = 0.07$ ). Encapsulated, spray-dried lard increased ADG ( $P = 0.004$ ) and G:F ( $P = 0.003$ ) during d 15 to 28 compared with the equivalent amount of fat as unprocessed lard. Pelleting increased ADG ( $P = 0.006$ ) during d 0 to 14, decreased feed intake during d 15 to 35 ( $P = 0.01$ ), and overall ( $P = 0.07$ ), and increased G:F during all periods ( $P < 0.02$ ). Fat digestibility was increased ( $P = 0.001$ ) with supplementation of lard, and this effect was greater when diets were fed in meal form (interaction,  $P = 0.004$ ). Pelleting increased the digestibility of DM, OM, and fat ( $P < 0.002$ ). Results indicate that growth performance may be improved by lysolecithin supplementation to diets with added lard and by encapsulation of lard through spray drying.

Key Words: Digestibility, Emulsifier, Encapsulated Fat, Lysolecithin, Spray Drying, Swine

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## Introduction

The response of nursery pigs to supplemental fat in diets has been variable (Pettigrew and Moser, 1991).

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The addition of fat to the diet of weanling pigs has been reported to improve daily gain and feed efficiency, primarily during the later stages of the nursery period (Cera et al., 1990; Howard et al., 1990; Li et al., 1990). The lack of response to fat supplementation in the early nursery phase may be explained by the low digestibility of fat, particularly when fats of animal origin are used (Cera et al., 1988, 1989). Sow milk contains high levels of fat (40% on a DM basis), which has been reported to be 95% digestible by the suckling piglet (Frobish et al., 1967). Emulsification of fat (as in sow milk) may improve fat digestibility and growth performance of weaned pigs fed supplemental fat. Jones et al. (1992) reported an increase in fat digestibility when lecithin

**Table 1.** Composition (as-fed basis) of the experimental diets (Exp. 1)

Item	Diets fed from d 0 to 14		Diets fed from d 15 to 35	
	0% lard	5% lard <sup>a</sup>	0% lard	5% lard <sup>a</sup>
Ingredient, % as fed				
Corn	51.67	42.99	63.11	53.78
Soybean meal (48.5% CP)	16.87	20.51	27.01	31.41
Lard	0	5	0	5
Whey	20	20	5	5
Plasma protein	4	4	—	—
Menhaden fish meal	5	5	1.0	1.0
Dicalcium phosphate	0.71	0.72	1.52	1.51
Limestone	0.52	0.50	0.76	0.74
Vitamin mineral premix <sup>b</sup>	0.25	0.25	0.25	0.25
Salt	0.1	0.1	0.5	0.5
Antibiotic <sup>c</sup>	0.5	0.5	0.5	0.5
Copper sulfate	0.08	0.08	0.08	0.08
Lysine·HCl	0.20	0.20	0.20	0.14
DL-Methionine	0.10	0.15	0.07	0.09
Calculated composition				
ME, kcal/kg	3,192	3,383	3,260	3,454
Lysine, %	1.51	1.60	1.25	1.32
Lysine:ME, g/Mcal	4.73	4.73	3.83	3.82
Ca, %	0.90	0.90	0.85	0.85
P, %	0.75	0.75	0.70	0.70

<sup>a</sup>Lysolecithin product (Lysoforte, Kemin Americas, Inc., Des Moines, IA) was added at 0, 0.1, or 0.5% at the expense of lard to provide 0, 0.02, or 0.1% of added lysolecithin. Diets fed from d 0 to 14 were analyzed to contain 2.24, 6.87, 6.90, and 5.73% crude fat, and diets fed from d 15 to 35 were analyzed to contain 2.70, 6.56, 6.79, and 6.82% crude fat for the control, the 5% added lard without lysolecithin, the 5% added lard with 0.02% lysolecithin, and the 5% added lard with 0.10% lysolecithin diets, respectively.

<sup>b</sup>Supplied per kilogram of complete diet: 5,540 IU of vitamin A as retinyl acetate; 1,108 IU of vitamin D<sub>3</sub>; 22 IU of vitamin E as DL- $\alpha$ -tocopherol acetate; 1.98 mg of vitamin K as menadione dimethylpyrimidinol bisulfite; 165 mg of choline as choline chloride; 22 mg of niacin; 17.6 mg of D-pantothenic acid as DL-calcium pantothenate; 4.4 mg of riboflavin; 1.1 mg of pyridoxine as pyridoxine·HCl; 0.55 mg thiamine as thiamine mononitrate; 0.022 mg of vitamin B<sub>12</sub>; 0.33 mg of folic acid; 0.04 mg of D-biotin; 110 mg Zn as ZnSO<sub>4</sub>; 110 mg Fe as FeSO<sub>4</sub>; 22 mg Cu as CuSO<sub>4</sub>; 55 mg Mn as MnO; 0.28 mg I as ethylenediamine dihydriodide; and 0.30 mg Se as NaSeO<sub>3</sub>.

<sup>c</sup>Supplied 27.6 mg carbadox/kg of complete feed.

or lysolecithin were added to nursery diets containing soybean oil or tallow, but not in diets containing lard. However, other studies (Øverland et al., 1993a,b; 1994) using soy lecithin as an emulsifier did not show a benefit in weanling pigs or in growing-finishing pigs as measured by growth performance and fat digestibility.

Processing technologies such as spray drying or encapsulation of fat by milk proteins may change the physical structure of both animal fats and vegetable oils and may facilitate digestion and absorption by the weanling pig. However, little is known about the nutritional benefits of including encapsulated fat processed by spray drying in diets for nursery pigs or the stability of the spray-dried encapsulated fat globule in the pelleting process.

Therefore, the objectives of this research were to 1) evaluate the effect of lysolecithin supplementation on performance and nutrient digestibility of nursery pigs, and 2) determine the effects of fat encapsulation by spray drying in diets fed in either meal or pelleted form to weanling pigs.

### Materials and Methods

The North Carolina State University Institutional Animal Care and Use Committee approved all experimental procedures.

### Experiment 1

One hundred eight pigs ([Landrace × Yorkshire] × [Hampshire × Duroc]) were weaned at approximately 21 d of age ( $5.96 \pm 0.16$  kg BW) and allotted to one of four dietary treatments based on body weight, sex, and litter of origin in a randomized complete block design (six blocks per treatment). Treatments (as-fed basis) were as follows: 1) control with no added lard, 2) control diet with 5% added lard, 3) Treatment 2 with 0.02% lysolecithin (Lysoforte, Kemin Americas, Inc., Des Moines, IA; contained 20% lysolecithin), and 4) Treatment 2 with 0.1% lysolecithin. The lysolecithin added in Treatments 3 and 4 replaced an equal amount of added lard. Diets were formulated using highly digestible ingredients and contained 4.7 and 3.8 g of total lysine/Mcal of ME for the first diet fed from 0 to 14 d and the second diet fed from 15 to 35 d, respectively (Table 1). Levels of other AA (methionine, threonine, and tryptophan) were kept constant at ratios suggested by Baker and Chung (1992). All diets were fed in meal form.

Pigs were housed four or five pigs per pen (1.73 m × 0.83 m), using 24 pens (12 pens of gilts and 12 pens of barrows), in an environmentally controlled nursery with raised slatted flooring. Initial temperature in the

nursery was 27°C and was lowered by 1°C each week. Pens were equipped with two-hole self-feeders and two nipple waterers allowing ad libitum access to feed and water throughout the experiment. Pig body weights and feed consumption were measured weekly for the 5-wk experimental period.

On d 10 and d 28 of the experiment, fecal grab samples were collected immediately following defecation to determine the digestibility of DM, fat, CP, P, and GE. Samples were taken randomly from at least two pigs per pen, pooled by pen, and then stored at -20°C. Chromium oxide (0.2%) was used as an indigestible marker in both diet phases to calculate digestibility coefficients. Before analysis, diet and fecal samples were dried in an oven (60°C; 24 h for diets and 48 h for feces), and then homogenized using a laboratory grinder (0.5-mm screen for diets and 1-mm screen for feces). Feed and feces were analyzed to determine their DM, CP, and crude fat content using AOAC (1997) procedures. Phosphorus concentrations were analyzed colorimetrically using the vanadomolybdate procedure (AOAC, 1997). Gross energy was determined by adiabatic bomb calorimetry (model 5001, IKA Works, Wilmington, NC). Analysis of chromium was conducted using an atomic absorption spectrophotometer (model 5000, Perkin-Elmer, Shelton, CT) according to the method of Williams et al. (1962).

## Experiment 2

A total of 144 crossbred pigs ([Landrace × Yorkshire] × [Hampshire × Duroc]) was weaned at approximately 21 d of age (6.04 ± 0.16 kg BW). Pigs were blocked by weight, sex, and litter of origin and subsequently allotted to one of six dietary treatments in a 3 × 2 factorial randomized complete block design. Factors included 1) level (as-fed basis) and source of fat (control diet containing 1% lard, control diet with 5% additional lard (6% total lard), and 5% additional lard obtained from 8.4% encapsulated lard (Merrick's Company, Middleton, WI; 6% total lard), and 2) diet form (pelleted or meal). Pigs were housed in a nursery facility located at the North Carolina State University Swine Educational Unit using a total of 48 pens. Each treatment was fed to four pens containing two barrows and one gilt and four pens containing two gilts and one barrow. The pens (1.73 m × 0.83 m) were located in an environmentally controlled nursery as described in Exp. 1. Pig weight and feed consumption were measured on a weekly basis for the 5-wk experimental period.

The encapsulated lard was produced by combining choice-grade lard with casein, whey, and lecithin in a special spray-drying process that caused the milk proteins to encapsulate the fat particles as they dried (Keogh and O'Kennedy, 1999). The encapsulated fat product contained 59.5% lard, 36.3% whey, 3.6% casein, and 6% lecithin. These ingredients were obtained from the same source and were included at identical levels in all experimental diets. Ingredients were blended to-

gether in liquid form and then pasteurized at 65°C for 30 min before spray drying (box drier, Marriott Walker, Birmingham, MI). The inlet temperature of the drier was 185°C and the outlet temperature was 78°C. The size of the fat particles was in the range of 2 to 10 μm. Lecithin, whey, and casein were added to the control diet and the diet with 6% total lard to mimic the composition of the diet with encapsulated fat. Therefore, the only difference between the diets with 6% total lard was that one diet contained unprocessed lard and the other diet contained encapsulated lard. The source of lard, casein, and lecithin used in all diets was identical.

The trial was divided into two phases. The first-phase diets were offered from d 0 to 14 and the second-phase diets were fed from d 15 to 35 (Table 2). Experimental diets were formulated to meet the minimum nutrient requirement estimates suggested by NRC (1998). The first-phase diets were formulated to contain 1.59% lysine, 0.47% methionine, 1.03% threonine, and 0.30% tryptophan, and the second-phase diets were formulated to contain 1.31% lysine, 0.40% methionine, 0.85% threonine, and 0.27% tryptophan (as-fed basis). Within each phase, all diets were formulated to a constant lysine:ME ratio.

The first-phase diets were manufactured as a 600-kg master-batch, of which 250 kg were bagged as meal feed and 300 kg of feed were pelleted. The second-phase diets were manufactured as a 1,600-kg master-batch, of which 800 kg were bagged as mash feed, and 800 kg were pelleted. The mixed mash was conditioned at a 60°C. The retention time in the conditioner was approximately 0.5 min. The pellet die size was 3 mm. The corresponding pellet exit temperatures averaged 68°C. The pellet die knife was set 13 mm from the die face. The pellets were pneumatically transferred to a cyclone cooler, with the retention time of the pellets in the cooler being 10 min. The pellets were then screened on a two-screen rotex before bagging.

Pellet durability was evaluated using a Kansas State tumbling can tester (ASAE, 1987). Representative pellet feed samples were taken after cooling, and the fines were screened through a No. 6 sieve. Screened pellets (500 g) were then placed into the tumbling can/rotating device for 10 min at 50 rpm. The pellets were then removed and the fines were screened through a No. 6 sieve. This procedure was determined for an average of four individual samples per treatment for each diet phase. The pellet durability index (**PDI**) was defined as the pellet weight after 10 min of tumbling as a percentage of the pellet weight before tumbling.

Fecal samples were collected from at least one pig per pen immediately following defecation on d 19, 20, and 21, and again on d 26, 27, and 28 to determine the digestibility of DM, OM, and fat. All samples were collected during the period when the second-phase diet was fed, at multiple times to obtain a representative sample. Chromium oxide was added at 0.1% to all diets as an indigestible marker. Fecal samples were pooled by pen and stored at -20°C until they were analyzed.

**Table 2.** Composition (as-fed basis) of the experimental diets (Exp. 2)<sup>a</sup>

Item	Diets fed from d 0 to 14			Diets fed from d 15 to 35		
	Control	Lard	Encapsulated lard	Control	Lard	Encapsulated lard
Ingredient, % as fed						
Corn	45.28	34.82	34.82	56.16	46.53	46.53
Soybean meal (48.5% CP)	20.42	25.95	25.95	26.90	31.54	31.54
Dried whey	20.00	20.00	16.95	7.50	7.50	4.45
Menhaden fish meal	5.00	5.00	5.00	2.50	2.50	2.50
Spray-dried plasma	5.00	5.00	5.00	—	—	—
Blood meal	—	—	—	2.5	2.5	2.5
Unprocessed lard	1.00	6.00	1.00	1.00	6.00	1.00
Encapsulated lard <sup>b</sup>	—	—	8.40	—	—	8.40
Dried casein	0.30	0.30	—	0.30	0.30	—
Lecithin	0.05	0.05	—	0.05	0.05	—
Dicalcium phosphate	0.80	0.75	0.75	1.18	1.15	1.15
Limestone	0.51	0.50	0.50	0.50	0.53	0.53
Antibiotic <sup>c</sup>	0.50	0.50	0.50	0.50	0.50	0.50
Premix <sup>d</sup>	0.25	0.25	0.25	0.25	0.25	0.25
Salt	0.20	0.20	0.20	0.40	0.40	0.40
L-Lysine	0.09	0.05	0.05	0.035	0.003	0.003
DL-Methionine	0.09	0.12	0.12	0.045	0.067	0.067
Chromium oxide	0.10	0.10	0.10	0.10	0.10	0.10
Copper sulfate	0.08	0.08	0.08	0.08	0.08	0.08
Zinc oxide	0.33	0.33	0.33	—	—	—
Analyzed composition, %						
CP	23.30	25.04	24.99	21.64	23.03	22.99
Crude fat	4.12	8.83	8.89	4.35	9.06	9.12

<sup>a</sup>Diets fed during d 0 to 14 were formulated to contain 1.59 and 1.70% total lysine for the control and the added fat diets, respectively, resulting in a lysine:ME ratio of 4.83 g/Mcal for all treatments. Diets fed during d 15 to 35 were formulated to contain 1.31 and 1.40% total lysine for the control and the added lard diets, respectively, resulting in a lysine:ME ratio of 3.94 g/Mcal for all treatments.

<sup>b</sup>Encapsulated lard (Merrick's Co., Middleton, WI) was produced by combining choice-grade lard with casein, whey, and lecithin in a special spray-drying process causing the milk proteins to encapsulate the fat particles as they dried. These ingredients were obtained from the same source and diets contained identical amounts of casein, whey, and lysolecithin.

<sup>c</sup>Supplied 55 g of carbadox/kg of feed for the diet fed from d 0 to 14, and 110 mg of tylosin and 110 mg of sulfamethazine/kg of feed for the diet fed from d 15 to 35.

<sup>d</sup>Supplied per kilogram of complete diet: 11,025 IU of vitamin A as retinyl acetate; 1,103 IU of vitamin D<sub>3</sub>; 50 IU of vitamin E as DL- $\alpha$ -tocopherol acetate; 4 mg of vitamin K as menadione dimethylpyrimidinol bisulfite; 166 mg of choline as choline chloride; 55 mg of niacin; 33 mg of D-pantothenic acid as DL-calcium pantothenate; 9.9 mg of riboflavin; 0.04 mg of vitamin B<sub>12</sub>; 165 mg Zn as ZnSO<sub>4</sub>; 165 mg Fe as FeSO<sub>4</sub>; 22 mg Cu as CuSO<sub>4</sub>; 40 mg Mn as MnO; 0.3 mg I as ethylenediamine dihydriodide; and 0.3 mg Se as NaSeO<sub>3</sub>.

Diets and feces were processed and analyzed as described in Exp. 1. In addition, ash was determined (AOAC, 1997) to calculate organic matter digestibility.

### Statistical Analyses

Data for both experiments were analyzed by ANOVA as a randomized complete block design using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC). Pen was used as the experimental unit in both experiments. The model for Exp. 1 included block, sex, and dietary treatment. Contrast comparisons were made to determine the effect of lard supplementation (lard only, without lysolecithin) vs. control and to evaluate linear and quadratic effects of lysolecithin supplementation (Steel and Torrie, 1980). The model for Exp. 2 included block, lard level and source, diet form and the lard level, and a source  $\times$  diet form interaction. One pen of pigs (pelleted control diet) had extremely poor performance during the first week of the experiment (weight loss of 90 g/d compared with an average of 181 g/d gain). This pen

was determined to be an outlier using the Univariate Procedure of SAS and was therefore removed from the dataset before statistical analysis. Preplanned nonorthogonal contrast comparisons were made to evaluate the effects of lard addition (6% total lard vs. control), lard encapsulation (6% total unprocessed lard vs. 6% total encapsulated lard), and pelleting (meal vs. pellet). Least squares means are reported and differences were considered statistically significant at  $P < 0.05$  and were considered tendencies when  $0.05 < P < 0.10$ .

## Results

### Experiment 1

Daily gain during the first phase (d 0 to 14) was not affected by dietary treatments (Table 3); however, during d 15 to 35 and overall, ADG was decreased ( $P = 0.02$ ) when lard was included in the diet, resulting in a 10.4% reduction in final BW. The effect of lard supplementation on ADG seemed to be directly related to a

**Table 3.** Effect of fat and lysolecithin supplementation on nursery pig performance (Exp. 1)<sup>a</sup>

Variable	Lard, %:	0	5	5	5	SEM	P-value <sup>b</sup>		
	Lysolecithin, %:	0	0	0.02	0.10		Fat	Linear	Quadratic
Body weight, kg									
d 0		5.97	5.97	5.91	6.01	0.11	1.00	0.78	0.57
d 35		21.07	18.87	20.77	21.24	0.60	0.02	0.02	0.40
ADG, g									
d 0 to 14		312	303	305	320	11	0.61	0.29	0.62
d 15 to 35		526	427	519	527	26	0.02	0.04	0.28
d 0 to 35		444	379	437	448	18	0.02	0.04	0.38
ADFI, g (as-fed basis)									
d 0 to 14		483	434	474	476	22	0.13	0.21	0.51
d 15 to 35		1,099	940	959	972	55	0.06	0.70	0.96
d 0 to 35		864	746	774	782	40	0.05	0.55	0.86
G:F									
d 0 to 14		0.65	0.70	0.66	0.67	0.03	0.23	0.58	0.46
d 15 to 35		0.48	0.46	0.55	0.54	0.03	0.66	0.14	0.32
d 0 to 35		0.52	0.52	0.57	0.57	0.03	0.97	0.20	0.46

<sup>a</sup>Values represent least squares means of six pens with four pigs per pen.

<sup>b</sup>Probability values for the effect of fat supplementation (5% added lard only vs. control) and linear and quadratic effects of lysolecithin supplementation.

reduction in feed intake during d 15 to 35 ( $P = 0.06$ ) and overall ( $P = 0.05$ ). Lysine and ME intakes (data not shown), on the other hand, were not different among treatments. Supplementation of lysolecithin resulted in a linear ( $P = 0.04$ ) improvement in ADG during d 15 to 35 and overall. Final BW was increased ( $P = 0.02$ ) by 10.1 and 12.6% when lysolecithin was supplemented at 0.02 and 0.10%, respectively. However, feed intake was not affected by lysolecithin supplementation. Supplementation of lard or lysolecithin did not affect feed efficiency.

During the first diet phase, digestibility of DM ( $P = 0.10$ ) and CP ( $P = 0.05$ ) was reduced when lard was added to the diet (Table 4); however, the digestibility of fat was much higher ( $P = 0.001$ ) in the lard-supplemented diets. Supplementation of 0.02% of lysolecithin,

but not 0.10%, tended to improve the digestibility of fat (quadratic effect;  $P = 0.10$ ). During the second diet phase, digestibilities of DM ( $P = 0.001$ ), fat ( $P = 0.001$ ), GE ( $P = 0.03$ ), CP ( $P = 0.001$ ), and P ( $P = 0.001$ ) were increased with the addition of lard to the diet. Supplementation of lysolecithin linearly decreased the digestibilities of DM ( $P = 0.003$ ), GE ( $P = 0.007$ ), CP ( $P = 0.001$ ), and P ( $P = 0.001$ ) during the second diet phase.

*Experiment 2*

No significant interactions were observed between type and level of lard and diet form and, therefore, the main effects of treatments were presented. Pigs fed the added-lard diets (6% total added lard) had decreased feed intake during d 0 to 14 ( $P = 0.04$ ), d 15 to 28 ( $P =$

**Table 4.** Effect of fat and lysolecithin supplementation on nutrient digestibility in nursery pigs (Exp. 1)<sup>a</sup>

Variable	Lard, %:	0	5	5	5	SEM	P-value <sup>b</sup>		
	Lysolecithin, %:	0	0	0.02	0.10		Fat	Linear	Quadratic
Measurement on d 10									
Digestibility, %									
DM		87.4	82.5	86.8	85.2	2.0	0.10	0.43	0.32
Fat		45.4	68.6	75.9	64.6	3.6	0.001	0.54	0.10
GE		86.6	83.8	86.1	83.6	1.8	0.29	0.96	0.38
CP		84.9	77.7	83.3	78.9	2.5	0.05	0.77	0.18
Measurement on d 28									
Digestibility, %									
DM		78.2	84.1	80.4	78.8	1.1	0.001	0.003	0.41
Fat		36.2	77.6	77.7	73.9	3.7	0.001	0.27	0.50
GE		82.2	85.8	83.2	81.2	1.1	0.03	0.007	0.78
CP		71.9	81.2	78.0	74.6	1.3	0.001	0.001	0.97
P		26.0	48.4	47.1	37.1	2.1	0.001	0.001	0.03

<sup>a</sup>Values represent least squares means of six observations.

<sup>b</sup>Probability values for the effect of fat supplementation (5% added lard only vs. control) and linear and quadratic effects of lysolecithin supplementation.

**Table 5.** Main effects of fat level and source, and diet form on performance of nursery pigs (Exp. 2)<sup>a</sup>

Variable	Source of fat			SEM	P-value lard <sup>b</sup>	P-value source <sup>c</sup>	Diet form		SEM	P-value form <sup>d</sup>
	Control	Lard	Encapsulated lard				Pellet	Meal		
BW, kg										
Initial	6.07	6.07	6.09	0.02	0.75	0.40	6.09	6.06	0.02	0.18
Final	22.6	22.0	22.1	0.35	0.22	0.81	22.5	22.0	0.29	0.23
ADG, g										
d 0 to 14	324	315	292	13	0.19	0.19	331	289	10	0.006
d 15 to 28	472	437	484	11	0.41	0.004	460	468	9	0.55
d 15 to 35	570	547	568	11	0.36	0.20	559	565	9	0.63
d 0 to 35	472	455	457	10	0.22	0.85	468	455	9	0.27
ADFI, g <sup>e</sup>										
d 0 to 14	348	325	294	14	0.04	0.13	323	322	12	0.95
d 15 to 28	638	612	611	13	0.10	0.96	594	647	10	0.001
d 15 to 35	787	739	742	14	0.01	0.87	734	779	12	0.01
d 0 to 35	611	573	563	12	0.008	0.56	569	596	10	0.07
G:F										
d 0 to 14	0.934	0.975	1.022	0.046	0.26	0.46	1.044	0.910	0.038	0.02
d 15 to 28	0.741	0.718	0.794	0.017	0.49	0.003	0.776	0.725	0.014	0.01
d 15 to 35	0.725	0.744	0.771	0.012	0.04	0.12	0.765	0.728	0.010	0.02
d 0 to 35	0.773	0.793	0.821	0.015	0.07	0.19	0.825	0.767	0.012	0.002

<sup>a</sup>Values represent least squares means of 16 and 24 pens with four pigs per pen for the main effect means of source of fat and diet form, respectively. No interactions between level and source of fat and diet form were observed.

<sup>b</sup>Orthogonal contrast comparison of no added lard vs. added lard.

<sup>c</sup>Orthogonal contrast comparison of unprocessed lard vs. encapsulated lard.

<sup>d</sup>Main effect of diet form.

<sup>e</sup>As-fed basis.

0.10), d 15 to 35 ( $P = 0.01$ ), and overall ( $P = 0.008$ ) compared with pigs fed the control diets (1% added lard; Table 5). Gain:feed was greater for pigs fed the added-lard diets during d 15 to 35 ( $P = 0.04$ ) and overall ( $P = 0.07$ ) than for control pigs; however, G:F was not affected ( $P = 0.26$ ) during the first diet phase. Pigs fed the diets with encapsulated, spray-dried lard had greater ADG ( $P = 0.004$ ) and G:F ratios ( $P = 0.003$ ) during d 15 to 28 than did pigs fed the equivalent amount of fat in the form of unprocessed lard. This effect was lost, however, during the last week of the study, resulting in no differences between fat sources for the second diet phase.

Pelleting increased ADG ( $P = 0.006$ ) during the first diet phase, but did not affect ADG during any of the other periods. Feed intake was decreased from d 15 to 28 ( $P = 0.001$ ), d 15 to 35 ( $P = 0.01$ ), and tended to be decreased for the entire experimental period ( $P = 0.07$ )

in pigs fed pelleted diets compared with pigs fed meal diets. Pigs fed pelleted diets were more efficient than their counterparts fed meal diets from d 0 to 14 ( $P = 0.02$ ), d 15 to 28 ( $P = 0.01$ ), d 15 to 35 ( $P = 0.02$ ), and overall ( $P = 0.002$ ).

There were no differences in DM or OM digestibility due to dietary fat level and source (Table 6); however, apparent fat digestibility was increased ( $P = 0.001$ ) when lard was supplemented to control diets, regardless of whether lard was encapsulated. The magnitude of this increased fat digestibility was greater when the diets were fed in meal form compared with the pelleted form (interaction,  $P = 0.004$ ). Pelleting increased the digestibility of DM ( $P = 0.002$ ), OM ( $P = 0.001$ ), and fat ( $P = 0.001$ ).

The PDI (Table 7) of the pelleted diets ranged from 95.2 to 97.6% for the first-phase diets and from 85.6 to 96.2% for the second-phase diets. Pellet durability in-

**Table 6.** Effects of fat level and source, and diet form on nutrient digestibility in nursery pigs (Exp. 2)<sup>a</sup>

Variable	Pellet			Meal			SEM	P-value <sup>b</sup>		
	Control	Lard	Encapsulated lard	Control	Lard	Encapsulated lard		Lard	Source	Form
Digestibility, %										
DM	85.8	86.3	87.0	84.7	85.0	85.1	0.53	0.22	0.41	0.002
OM	87.6	87.8	88.7	86.2	86.2	86.8	0.52	0.30	0.18	0.001
Crude fat <sup>c</sup>	70.2	76.7	76.9	54.7	75.2	72.9	1.94	0.001	0.60	0.001

<sup>a</sup>Values represent least squares means of eight observations. Digestibility measurements were conducted during the second diet phase only, using pooled samples obtained on d 19, 20, 21, 26, 27, and 28.

<sup>b</sup>Orthogonal contrast comparisons of no added lard vs. added lard (lard), unprocessed lard vs. encapsulated lard (source), and main effect of diet form (form).

<sup>c</sup>Source of fat  $\times$  diet form interaction ( $P = 0.004$ ).

**Table 7.** Pellet durability index (%) of the experimental diets

Diets	Control	Lard	Encapsulated lard
Diet fed from d 0 to 14	97.6	95.2	95.9
Diet fed from d 15 to 35	89.5	85.6	96.2

dex was lower for the added-lard diets compared with the control diet. The second-phase diet containing encapsulated, spray-dried fat had a greater PDI than the diet containing unprocessed lard.

## Discussion

In Exp. 1, supplementation of lard resulted in decreased ADG and ADFI without affecting G:F; however, in Exp. 2, pigs fed supplemental lard consumed less feed without affecting ADG, resulting in improved feed efficiency. It is not clear why the response in G:F of pigs supplemented with lard was different between experiments. The levels of total lard added were 5% in Exp. 1 and 6% in Exp. 2, and the lysine:ME ratio was kept constant between treatments in each experiment. Pettigrew and Moser (1991) summarized data from 92 studies evaluating effects of fat on nursery pig performance and reported a reduction in feed intake and an improvement in G:F, without affecting ADG, when fat was supplemented and a constant AA:calorie ratio was maintained. Tokach et al. (1995) observed no effects of soybean oil supplementation from 0 to 14 d after weaning; however, G:F was improved with the addition of soybean oil. Other studies have reported improvements in G:F (Dove and Haydon, 1992) and ADG and G:F (Dove, 1993) during the latter part of the nursery period when diets were supplemented with animal fat. Øverland and Sundstol (1995) reported that the addition of 6% rendered fat (lard) significantly improved weight gain, feed intake, and feed conversion in weanling pigs.

Supplementation of lard to diets fed from d 0 to 14 seemed to negatively affect digestibility of DM and CP; however, digestibility of DM, GE, CP, and P was improved during the second diet phase of Exp. 1. Improved digestibility of nutrients may be expected, resulting from a slower passage rate of digesta in the intestinal tract with the addition of fat. Li and Sauer (1994) observed improved digestibility of CP at the ileal level with the supplementation of fat. Digestibility of fat was improved in both experiments of the current study, which is in agreement with the observations of Frobish et al. (1969) and Øverland et al. (1994). Part of the improved apparent digestibility of fat may be explained by a relatively lower contribution of endogenous fat from pigs fed supplemental fat compared with that from pigs without supplemental fat.

Because the value of supplemental fat for weanling pig diets has been variable (Pettigrew and Moser, 1991), it was deemed worthwhile to examine how fat utiliza-

tion might be consistently improved. A number of factors may contribute to the utilization of supplemental fat in weanling pigs, including the composition of the supplemental fat, the presence of emulsifiers, and the physical form of the fat. Indeed, fat in sow milk is composed of lipid droplets surrounded by a monolayer of phospholipids and proteins derived from the secreting cell (Jensen et al., 1991), and it is highly digestible. In contrast, physical factors, including difficulties in the formation of a micellar phase in the small intestine of the weanling pigs (Bayler and Lewis, 1963), may limit fatty acid digestibility in dry diets. Thus, supplementation of emulsifiers may aid in the digestion of fats added to weanling pig diets. Furthermore, processing technologies such as spray drying or encapsulation may change the physical structure of fats to improve their utilization (Keogh and O'Kennedy, 1999).

Lysolecithin supplementation improved pig performance when added to diets containing 5% added fat (Exp. 1); however, this improvement in performance did not seem to be related to nutrient digestibility measurements, which actually decreased with lysolecithin supplementation. It is not clear why the discrepancy between improved growth and decreased nutrient digestibility was observed. However, fecal digestibility measurements include nutrient disappearance through absorption, endogenous losses, and bacterial assimilation of nutrients in the small and large intestine and cecum, but does not account for post-absorptive utilization of nutrients. Thus, fecal digestibility measurements may not be positively correlated to growth performance. Jones et al. (1992) reported an increase in fat digestibility when lecithin or lysolecithin were added to nursery diets containing soybean oil or tallow, but not in diets containing lard. Relative improvements in digestibility of tallow ranged from 3.2 to 9.3% for lecithin and up to 3.7% for lysolecithin in that study. Other studies (Øverland et al., 1993a,b; 1994) using soy lecithin as an emulsifier did not show a benefit in weanling pigs or in growing-finishing pigs as measured by growth performance and fat digestibility. Wieland et al. (1993) showed that the effectiveness of different emulsifiers in increasing the absorption of medium-chain triglycerides varied. Under the conditions used in their experiment, Tween 80 (polyoxy-ethylene [20] sorbitan monooleate) was a more effective emulsifier than either soy lecithin or gum arabic. Soares and Lopez-Bote (2002) reported that lecithin enhanced the apparent digestibility of unsaturated fatty acids of lard. Øverland and Sundstol (1995) found a positive effect of lecithin when 6% rendered fat was added in weanling pig diets compared with a diet containing no added lard. In the current study, apparent digestibility of fat was not affected when lysolecithin was supplemented.

Encapsulation of fat resulted in an improvement of ADG and G:F for the 2-wk period following the first diet phase, regardless of pelleting. This indicates that the physical structure of the lard obtained by spray drying did not appear to be compromised by the pel-

leting process. Although this beneficial effect on pig performance was not maintained for the entire experimental period, encapsulation of fat may have value during certain portions of the nursery period. In addition to potential effects on pig performance, the process of spray drying can transform low-solubility liquid feed-stuffs into a free-flowing powder (Kim et al., 1996; Re, 1998). This characteristic makes encapsulated fat easy to handle and mix into diets. In contrast, solid, unprocessed forms of fat need to be melted before they can be added to the diet. In addition, when liquid fat is used in a mixing operation, a specific system is needed for handling the fat (Walter, 1990). Therefore, the improved handling quality of the encapsulated, spray-dried fat may be a sufficient incentive to justify its use. Based on the PDI measured in this study, the addition of encapsulated fat in the second-phase diet could improve pellet quality.

Added fat in compound animal feeds is known for its adverse effect on pellet hardness and pellet durability (Thomas et al., 1998). Moreover, added fat acts as a lubricant between particles and between the feed mash and the die-wall, resulting in a lower pelleting pressure (Thomas et al., 1998), which may decrease pellet quality. The PDI measured in the current experiment were slightly lower for diets with added fat, but were generally indicative of good quality. The use of the encapsulated fat product appeared to maintain the best pellet quality for the second-phase diets.

As expected, pelleting decreased feed disappearance and improved G:F; however, ADG was only affected during the first diet phase. Hancock and Behnke (2001) reported, based on eight studies, that pelleting resulted in an average improvement of 6% in ADG and 6 to 7% in feed efficiency. Improved digestibility of nutrients, as observed in the present experiment, may be an explanation for improved growth and feed efficiency. Similarly, Wondra et al. (1995) observed increased digestibility of DM, CP, and GE in finishing pigs fed pelleted diets. Increased availability of energy may explain the decrease in feed intake that we observed. Indeed, Noblet and Champion (2003) reported an increase of the DE content of diets by 2% when they were pelleted. Decreased feed wastage has been suggested to play a role in the reduced feed disappearance and improved feed efficiency we observed in the current study, but feed wastage was not specifically measured.

### Implications

Effects of fat supplementation to diets of weanling pigs on growth performance seem to be inconsistent. Improving fat utilization through the supplementation of lysolecithin was effective when considering growth performance; however, fat digestibility was not improved, and the digestibility of other nutrients seemed to be compromised. Encapsulation of fat through spray drying had no effects on nutrient digestibility, but it might improve growth performance during the nursery

period. Improved utilization of fats in nursery pigs through emulsification or fat processing is feasible; however, additional research is required to fully understand how these processes are to be implemented to their fullest potential.

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