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Evaluation of Supplemental Fat Sources and Pre-Farrow Essential Fatty Acid Intake on Lactating Sow Performance and Essential Fatty Acid Composition of Colostrum, Milk, and Adipose Tissue

Julia P. Holen, Jason C. Woodworth, Mike D. Tokach, Robert D. Goodband, Joel M. DeRouchey, and Jordan T. Gebhardt[1]

Summary

A total of 91 sows (Line 241, DNA Genetics) were used to evaluate the effects of supplemental fat sources and essential fatty acid intake on lactating sow farrowing performance, litter growth performance, and essential fatty acid composition of colostrum, milk, and adipose tissue. At approximately d 107 of gestation, sows were blocked by body weight and parity, then allotted to 1 of 5 experimental treatments as part of a 2 × 2 + 1 factorial arrangement. Experimental diets were corn-soybean meal-based with a control diet that contained no added fat, or diets with 3% added fat as either beef tallow or 3% soybean oil, with consumption of the added fat diets starting on d 107 or 112 of gestation. Thus, sows were provided low essential fatty acids (EFA; as linoleic and α-linolenic acid) in diets without supplemental fat, or with beef tallow or high EFA in the diet with soybean oil. Sows were provided approximately 6 lb/d of their assigned lactation diet pre-farrow. After farrowing, sows were provided *ad libitum* access to their assigned dietary treatment. Although sows consuming diets with beef tallow had greater lactation ADFI, daily linoleic acid (LA) and α-linolenic acid (ALA) intake was lower than for sows that consumed diets with soybean oil (fat source, $P < 0.001$). Supplemental fat sources providing either low or high EFAs did not influence litter growth performance (fat source, $P > 0.05$). Pre-farrow consumption of EFA for sows provided by beef tallow did not influence LA composition of colostrum. However, lactation diets with high EFA provided by soybean oil on d 107 of gestation increased colostrum LA composition compared to providing diets on d 112 of gestation (fat source × time, $P = 0.084$; time, $P < 0.001$). Additionally, regardless of pre-farrow timing, ALA composition of colostrum increased when sows consumed diets with soybean oil compared to beef tallow (fat source, $P < 0.001$). Both LA and ALA composition of milk at weaning was greater for sows that consumed diets with soybean oil compared to beef tallow (fat source, $P < 0.001$). Furthermore, concentrations of LA and ALA within adipose tissue were higher at weaning when sows consumed diets with high EFA compared to low EFA (fat source, $P < 0.05$). These responses suggest that providing dietary fat sources

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with high concentrations of EFAs can increase colostrum LA and ALA concentrations that can be maintained throughout lactation. However, in this experiment, changes in colostrum and milk composition did not alter litter growth performance.

Introduction

Nutrient requirements for modern lactating sows have increased dramatically to support growth of larger and heavier litters that result from genetic advancements. Supplemental fat sources are an effective and widely accepted method to increase energy density of sow diets and provide essential fatty acids (EFA). Essential fatty acids, defined as linoleic acid (LA) and α-linolenic acid (ALA), are necessary for neonatal brain, vision, and immune system function and development. Vegetable oil sources typically contain higher concentrations of EFA compared to animal fat sources, and therefore, may be an ideal fat source to improve dietary EFA intakes. The NRC (2012)[2] currently recommends 6.0 g/d EFA intake for lactating sows. Research conducted since then by Rosero et al. (2016)[3] suggests that a minimum dietary EFA intake must incorporate both 100 g/d LA and 10 g/d ALA to maximize reproductive performance of lactating sows. Therefore, the first objective of this trial was to determine EFA status of lactating sows fed diets containing no supplemental fat (low EFA), beef tallow (low EFA), or soybean oil (high EFA) through evaluation of colostrum, milk, and adipose tissue fatty acid composition. The second objective of this experiment was to evaluate the timing of feeding low or high EFA diets prior to farrowing (approximately d 107 or 112 of gestation) on colostrum and milk EFA composition.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This trial was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. All diets were manufactured at the Kansas State University Poultry Unit, Manhattan, KS.

Animals and diets

A total of 91 sows (Line 241, DNA Genetics) were used across four batch farrowing groups from January to August 2020. On d 107 of gestation, sows were weighed and moved into the farrowing house. Sows were blocked by entry body weight and parity, then allotted to 1 of 5 experimental treatments as part of a 2 × 2 + 1 factorial arrangement. Experimental diets were corn-soybean meal-based and contained either no supplemental fat, 3% beef tallow or 3% soybean oil to provide low EFA in diets without supplemental fat or with beef tallow, or high EFA provided through soybean oil. Sows were assigned to begin consumption of experimental diets at either d 107 or d 112 of gestation. Sows assigned to the diet without supplemental fat (Control) began consumption of the lactation diet at d 112 of gestation. All diets were formulated to meet or exceed NRC[2] requirement estimates and contained 1.1% SID Lys (Table 1). Projected daily EFA intakes were as follows: 1) Control: 77 g/d LA and 4 g/d ALA; 2) Beef tallow: 79 g/d LA and 5 g/d ALA; and 3) Soybean oil: 155 g/d LA and 15 g/d ALA (assumed 12 lb ADFI).

[2] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

[3] Rosero, D. S., R. D. Boyd, M. McCulley, J. Odle, and E. van Heugten. 2016. Essential fatty acid supplementation during lactation is required to maximize the subsequent reproductive performance of the modern sow. Anim. Repro. Sci. 168:151-163. doi:10.1016/j.anireprosci.2016.03.010.

From d 107 of gestation until farrowing, sows were offered approximately 6 lb/d of their respective dietary treatment distributed by an electronic feeding system (Gestal Solo Feeders, Jyga Technologies, Quebec City, Quebec, Canada). After farrowing, sows were then allowed *ad libitum* access to feed. Sow feed intake was monitored by daily recordkeeping of feed additions and weighing remaining feed every 7 d until weaning. Sow body weight and backfat depth at the P2 position were recorded at d 107 of gestation, after parturition, and at weaning (Renco Lean Meter, S.E.C. Repro Inc., Golden Valley, MN). Litters of pigs were cross-fostered within 48 h of parturition to standardize litter size within treatments. Piglets were individually ear notched within 24 h of parturition and then weighed at 48 h postpartum and at weaning. All instances and reasons for piglet mortalities were recorded.

Colostrum was collected from each sow by hand stripping all functional teats, with an attempt to collect equal samples from all teats for one representative sample within 12 hours of the onset of parturition. Milk samples were collected as previously described on d 10 of lactation and one day prior to weaning. To initiate milk letdown on d 10 and at weaning, 10 IU of oxytocin was administered via IM injection. All samples were immediately frozen and stored at -20°F until analysis.

Adipose tissue samples were collected at the P2 position from a subset of sows (n = 49) at d 107 of gestation and at weaning using a biopsy instrument as per the procedure outlined by Stephenson et al.[4] Samples were immediately frozen and stored at -20°F until analysis.

Chemical analysis

Feed samples of each dietary treatment were pooled to represent all farrowing groups and sent for proximate and fatty acid profile analysis (Midwest Labs, Omaha, NE; and University of Missouri ESCL, Columbia, MO; Table 2). Additionally, colostrum and milk samples were sent to the University of Missouri ESCL for crude fat analysis. Fatty acid profiles of fat biopsy tissue, colostrum, and milk were completed at the Kansas State University Lipidomics Center (Manhattan, KS).

Statistical analysis

Data were analyzed using the GLIMMIX procedure in SAS (v. 9.4, SAS Institute, Inc., Cary, NC) and considered sow (litter) as the experimental unit. The statistical model considered fixed effects of fat source, pre-farrow start date, and random effects of block within farrowing group. The following data responses were fitted by a binomial distribution in the statistical model: percentage of pigs born alive, stillborn, mummified, survival of pigs from birth to d 2 and from d 2 to wean, and sow wean-to-estrus interval. All data are reported as least square means and considered statistically significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

[4] Stephenson, E. W., M. A. Vaughn, D. D. Burnett, C.B. Paulk, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, R. D. Goodband, J. C. Woodworth, and J. M. Gonzalez. 2016. Influence of dietary fat source and feeding duration on finishing pigs growth performance, carcass composition, and fat quality. J. Anim. Sci. 94:2851-2866. doi: 10.2527/jas.2015-9521.

Results and Discussion

Sow performance

As expected, initial sow BW and backfat were similar ($P > 0.10$) on d 107 of gestation across experimental treatments (Table 3). Furthermore, there was no evidence for differences in sow BW within 24 h of parturition or at weaning ($P > 0.10$). As a result, lactation BW loss was similar across treatments. Additionally, there was no influence of fat source or timing on backfat depth change during lactation ($P > 0.10$).

Prior to farrowing, sows assigned to lactation diets with beef tallow consumed more feed compared to those assigned to soybean oil diets (fat source, $P < 0.05$). The differences observed for pre-farrow intake were unexpected, but may be a reflection of deviation among the volumetric feed allowance and manual feed weigh-backs. Overall, sows assigned to beef tallow diets had greater lactation ADFI than sows assigned to soybean oil diets (fat source, $P = 0.030$). Regardless of differences in lactation feed intake, daily intake of LA and ALA was greater for sows that consumed diets with soybean oil compared to beef tallow (fat source, $P < 0.001$).

Sows that consumed lactation diets with soybean oil had larger total litter sizes and count of pigs born alive per litter compared to sows that consumed diets with supplemental beef tallow diet (fat source, $P < 0.05$). The differences observed in farrowing performance are likely a result of biological variation of fetal growth and development within a small sample size of sows, rather than true treatment influences. Furthermore, sows that began consumption of the beef tallow diet on d 107 produced fewer stillborn pigs (fat source × time, $P = 0.014$) compared to sows fed beef tallow on d 112 or soybean oil on d 107, while the other treatments were intermediate. There was no evidence for differences among treatments in the number or percentage of mummified pigs produced per litter ($P > 0.10$).

Wean-to-estrus interval increased when sows began consumption of diets with soybean oil on d 112 of gestation compared to d 107, but for sows assigned to the beef tallow diet, wean-to-estrus intervals decreased (fat source × time, $P = 0.061$, fat source, $P = 0.024$).

Litter performance

Although there were differences in the number of piglets born alive per litter, litter size at 48 h of age and at weaning were not different among treatments ($P > 0.10$; Table 4). This is a reflection of the reduced piglet survivability from birth to 48 h of life that occurred among litters of sows that consumed diets with soybean oil starting at d 112 of gestation (fat source × time, $P = 0.035$). However, from d 2 of lactation to weaning, piglet survivability was similar across treatments ($P > 0.10$).

Sows that began consuming diets with soybean oil on d 112 of gestation, which produced larger litters, also produced heavier litters of piglets compared to sows that began consuming beef tallow diets on d 107 of gestation (fat source × time, $P = 0.009$). However, overall litter gain, litter ADG and piglet ADG were similar among treatments (fat source × time, $P > 0.10$).

Fatty acid composition of colostrum, milk, and sow adipose tissue

Sows that consumed diets with beef tallow had marginally greater concentrations of colostrum total fat compared to sows that consumed diets with soybean oil (fat source $P = 0.076$; Table 5). Although timing of lactating diet consumption did not influence LA composition of colostrum from sows fed diets with beef tallow, providing lactation diets with soybean oil to sows at d 107 increased colostrum LA concentration compared to providing soybean oil diets to sows on d 112 of gestation (fat source × time, $P = 0.084$; time, $P < 0.001$). Regardless of pre-farrow timing, ALA composition of colostrum increased when sows consumed diets with soybean oil compared to beef tallow (fat source, $P < 0.001$).

At weaning, there was no evidence for differences among total fat concentrations of milk ($P > 0.10$). However, both LA and ALA concentration of milk was significantly greater when sows consumed soybean oil compared to beef tallow diets (fat source, $P < 0.001$). These responses suggest that providing dietary fat sources with high concentrations of EFAs can subsequently increase colostrum and milk EFA concentration throughout lactation.

Although changes in adipose tissue LA and ALA concentrations between d 107 to weaning were not observed among treatments (fat source, $P > 0.10$), sows that consumed diets with soybean oil maintained greater concentrations of LA and ALA within adipose tissue at weaning (fat source, $P < 0.05$).

In summary, although sows consuming diets with beef tallow exhibited greater lactation ADFI, providing diets with soybean oil increased daily LA and ALA intake. Pre-farrow timing of lactation diets did not influence LA composition of colostrum from sows provided beef tallow, but lactation diets with soybean oil provided at d 107 of gestation increased LA concentration of colostrum. Furthermore, providing diets with soybean oil increased the LA and ALA composition of milk at weaning compared to diets with beef tallow or no supplemental fat, regardless of pre-farrow access to lactation feed. However, these changes in colostrum and milk composition did not alter litter growth performance in this experiment.

Table 1. Diet composition (as-fed basis)

Item	Control	Beef tallow	Soybean oil
Ingredient, %			
Corn	63.28	60.05	60.05
Soybean meal, 47% CP	32.82	33.05	33.05
Beef tallow	---	3.00	---
Soybean oil	---	---	3.00
Calcium carbonate	1.25	1.25	1.25
Monocalcium P (21% P)	1.15	1.15	1.15
Salt	0.50	0.50	0.50
L-Lys-HCl	0.15	0.15	0.15
DL-Met	0.08	0.08	0.08
L-Thr	0.05	0.05	0.05
Sow add pack	0.25	0.15	0.15
Trace mineral premix	0.15	0.25	0.25
Vitamin premix	0.25	0.25	0.25
Phytase[1]	0.08	0.08	0.08
Total	100.00	100.00	100.00
Calculated analysis			
SID AA, %			
Lys	1.10	1.10	1.10
Ile:Lys	70	70	70
Leu:Lys	143	141	141
Met:Lys	33	33	33
Met and Cys:Lys	59	59	59
Thr:Lys	64	64	64
Trp:Lys	21	21	21
Val:Lys	76	75	75
His:Lys	46	45	45
SID Lys:NE, g/Mcal	4.61	4.38	4.35
NE, kcal/lb	1,082	1,139	1,148
CP, %	21.2	20.9	20.9
Ca, %	0.92	0.92	0.92
STTD P, %	0.51	0.51	0.51
Linoleic acid, %	1.41	1.45	2.84
α-Linolenic acid, %	0.07	0.09	0.27

[1]Ronozyme HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) was added with an assumed release value of 0.13 available P.

Table 2. Chemical analysis of diets (as-fed basis)[1,2]

Item, %	Control	Beef tallow	Soybean oil
Dry matter	87.91	88.46	88.22
Crude protein	20.6	19.6	20.0
Crude fat[3]	2.60	5.22	5.53
Crude fiber	2.38	2.28	2.24
Ash	5.92	6.74	6.28
Linoleic acid	1.38	1.53	2.82
α-Linolenic acid	0.08	0.08	0.26

[1]Diet samples were pooled by farrowing group prior to analysis. Values represent the analyzed composition from 4 samples collected from January to August 2020.
[2]Proximate analysis and fatty acid profile analysis was completed by the University of Missouri Experiment Station Chemical Laboratories (Columbia, MO).
[3]Crude fat analysis was completed by Midwest Laboratories (Omaha, NE).

Table 3. Effect of dietary fat source and timing of diets offered pre-farrow on lactating sow performance[1]

		Beef tallow		Soybean oil			*P* =		
Trait	Control	d 107	d 112	d 107	d 112	SEM	Source × time	Fat source	Time
Sows, n	18	16	18	19	20	---	---	---	---
Parity	1.2	1.3	1.2	1.2	1.3	0.26	0.619	0.831	0.701
Lactation length, d	19.2	19.1	19.2	19.2	18.9	0.15	0.189	0.321	0.673
Sow BW, lb									
d 107 gestation	542.3	538.3	532.1	546.8	541.9	13.94	0.947	0.102	0.338
Post-farrow	522.1	523.3	510.2	514.0	518.2	13.71	0.156	0.909	0.466
Wean	503.5	509.4	494.7	489.8	501.3	14.56	0.097	0.409	0.838
Change (farrow to wean)	-16.3	-10.1	-12.7	-25.2	-17.8	6.66	0.447	0.130	0.729
Sow backfat, mm									
d 107	13.4	14.0	13.1	13.9	14.3	0.55	0.166	0.270	0.619
Post-farrow	13.1^{ab}	13.8^{a}	12.4^{b}	12.8^{ab}	13.3^{ab}	0.52	0.058	0.862	0.318
Wean	11.1	12.0	10.8	10.9	11.1	0.50	0.132	0.367	0.309
Change (farrow to wean)	-1.9	-1.8	-1.5	-2.0	-2.2	0.39	0.578	0.247	0.805
Sow ADFI, lb									
Pre-farrow	6.7^{a}	6.6^{a}	6.4^{ab}	5.9^{b}	6.1^{ab}	0.29	0.382	0.033	0.983
Lactation	12.5^{ab}	13.9^{a}	13.3^{ab}	12.1^{b}	13.0^{ab}	0.51	0.138	0.030	0.704
Linoleic acid intake, g/d[2]	78.5^{c}	95.9^{b}	92.7^{b}	154.4^{a}	166.1^{a}	4.90	0.110	< 0.001	0.360
α-linolenic acid intake, g/d[2]	4.6^{c}	5.0^{c}	4.9^{c}	14.2^{b}	15.3^{a}	0.41	0.118	< 0.001	0.216
Total EFA intake, g/d[2]	82.5^{c}	100.9^{b}	97.6^{b}	168.7^{a}	181.4^{a}	5.29	0.110	< 0.001	0.346
Farrowing performance									
Total pigs born, n	16.6^{ab}	15.9^{b}	16.5^{ab}	17.4^{ab}	18.6^{a}	0.85	0.679	0.033	0.276
Pigs born alive, n	14.8^{b}	14.9^{ab}	13.6^{b}	14.8^{b}	16.7^{a}	0.68	0.020	0.027	0.609
Stillborn, n	1.4^{ab}	0.9^{b}	2.5^{a}	2.3^{a}	1.5^{ab}	0.48	0.014	0.699	0.370
Mummy, n	0.4	0.2	0.3	0.4	0.3	0.20	0.705	0.609	0.773
Pigs born alive, %	90.3^{ab}	93.6^{a}	85.1^{b}	86.0^{b}	91.0^{ab}	2.10	< 0.001	0.446	0.271
Stillborn, %	7.3^{ab}	5.2^{b}	13.4^{a}	12.2^{a}	7.4^{ab}	1.90	< 0.001	0.521	0.255
Mummy, %	1.6	0.8	1.1	1.3	1.1	0.63	0.662	0.666	0.824
Wean to estrus interval, d	4.2^{ab}	4.3^{ab}	4.0^{b}	4.3^{ab}	4.6^{a}	0.15	0.061	0.024	0.904

$^{a-c}$Means within row with different superscripts differ ($P < 0.05$).

[1]A total of 91 sows (Line 241, DNA Genetics, Columbus, NE) and their litters were used in 4 farrowing groups over 28-d experimental periods with 16 to 20 sows per treatment.

[2]Calculated using analyzed LA and ALA values and overall lactation ADFI.

Table 4. Effects of fat source and diet consumption pre-farrow on litter performance[1,2]

		Beef tallow		Soybean oil			*P* =		
Trait	Control	d 107	d 112	d 107	d 112	SEM	Source × time	Fat source	Time
Litter count, n									
Birth	14.8[b]	14.9[ab]	13.6[b]	14.8[b]	16.7[a]	0.68	0.020	0.027	0.609
d 2	13.7	13.6	12.8	13.8	14.2	0.59	0.316	0.167	0.753
Wean	12.8	13.0	12.4	13.0	13.6	0.54	0.247	0.247	0.971
Piglet survivability, %									
Birth to d 2	93.6[ab]	94.1[ab]	94.2[ab]	95.3[a]	88.1[b]	1.86	0.035	0.257	0.042
d 2 to wean	94.4	96.1	97.6	95.1	96.6	1.33	0.912	0.387	0.200
Litter weight, lb									
Birth	45.15[ab]	48.95[a]	42.16[b]	45.93[ab]	47.53[a]	1.609	0.009	0.459	0.102
d 2	42.62	47.50	44.34	45.92	44.96	1.774	0.536	0.787	0.249
Wean	147.56	152.27	151.79	149.69	153.35	7.157	0.767	0.942	0.820
Litter gain (d 2 to wean), lb	104.86	104.50	107.56	103.70	108.41	6.029	0.887	0.997	0.505
Litter ADG (d 2 to wean), lb	6.48	6.46	6.61	6.37	6.70	0.382	0.798	0.995	0.515
Piglet BW, lb									
Birth	3.03	3.33	3.10	3.09	2.85	0.147	0.985	0.103	0.123
d 2	3.13[b]	3.57[a]	3.57[a]	3.36[ab]	3.24[ab]	0.133	0.647	0.047	0.656
Wean	11.49	11.92	12.40	11.51	11.38	0.438	0.477	0.101	0.685
Piglet ADG (d 2 to wean), lb	0.424	0.428	0.455	0.414	0.426	0.019	0.702	0.251	0.293

[a-c]Means within row with different superscripts differ ($P < 0.05$).
[1]A total of 91 sows (Line 241, DNA Genetics, Columbus, NE) and their litters were used in a 28-d study.
[2]Cross-fostering of piglets occurred within treatment in an attempt to standardize litter size within 48-h post-farrow.

Table 5. Effects of fat source and diet consumption pre-farrow on adipose tissue, colostrum, and milk essential fatty acid composition[1,2]

		Beef tallow		Soybean oil			*P* =		
Trait	Control	d 107	d 112	d 107	d 112	SEM	Source × time	Fat source	Time
Colostrum									
Total fat, %	5.16[b]	5.35[ab]	5.68[a]	5.22[ab]	5.17[b]	0.17	0.272	0.076	0.417
Linoleic acid, % of total FA[3]	26.19[bc]	23.25[c]	23.64[c]	32.13[a]	28.25[b]	1.219	0.084	0.155	< 0.001
α-Linolenic acid, % of total FA[3]	1.50[b]	1.40[b]	1.27[b]	2.41[a]	2.19[a]	0.143	0.743	< 0.001	0.239
Milk, weaning									
Total fat, %	8.03	7.27	7.59	8.15	8.30	0.572	0.885	0.161	0.672
Linoleic acid, % of total FA[3]	10.36[b]	9.83[b]	9.51[b]	15.10[a]	16.21[a]	0.736	0.311	< 0.001	0.575
α-Linolenic acid, % of total FA[3]	0.56[b]	0.55[b]	0.51[b]	1.20[a]	1.37[a]	0.062	0.102	< 0.001	0.290
Last-rib adipose tissue[3,4]									
Linoleic acid, % of total FA									
d 107 gestation	13.55	13.46	13.15	14.20	14.04	0.447	0.851	0.575	0.056
Weaning	13.93[ab]	13.34[ab]	13.73[b]	14.95[a]	14.32[ab]	0.512	0.262	0.018	0.794
Change (d 107 to wean)	0.52	-0.16	0.42	0.66	0.34	0.409	0.271	0.369	0.759
α-Linolenic acid, % of total FA									
d 107 gestation	0.61	0.57	0.53	0.65	0.54	0.047	0.390	0.089	0.308
Weaning	0.46	0.49	0.46	0.59	0.55	0.046	0.966	0.048	0.467
Change (d 107 to wean)	-0.15	-0.07	-0.07	-0.06	0.01	0.056	0.529	0.347	0.532

[a-c]Means within row with different superscripts differ ($P < 0.05$).

[1]A total of 91 sows (Line 241, DNA Genetics, Columbus, NE) and their litters were used in a 28-d study. 10 sows per treatment were selected for collection and analysis of colostrum and milk fatty acid profiles.

[2]FA = fatty acid.

[3]Percentage by weight.

[4]A random subset of sows (n = 49; 9 to 10 sows/treatment) were biopsied for evaluation of adipose tissue essential fatty acid composition.