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Dried distillers grains with solubles in diets during late gestation affects behavior and maintains the performance of sows

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ABSTRACT - We examined the effect of dried distillers grains with solubles (DDGS) in diets for late gestating sows on sow and litter performance, colostrum chemical composition, and sow behavior. Sixty gestating sows of 3.77±1.65 parity were divided into three groups of 20 animals, in a randomized block design with 0 (corn-soybean meal diet), 150, or 300 g kg^{-1} DDGS from 84 days of gestation until farrowing. Sows fed 300 g kg^{-1} DDGS presented a lower frequency of standing position and eating activity. The lying lateral position was more frequent in the first 40 min post-feeding for sows fed the highest DDGS level. There was no effect of diets on sow and litter performance; however, DDGS inclusion tended to increase lactation feed intake. Inclusion of DDGS was inclined to produce more lactose and less protein in colostrum, but did not affect colostrum fat, total solids, and ash contents. Inclusion of up to 300 g kg^{-1} DDGS in the diet of late gestation sows does not change sow and litter performance and colostrum composition compared with corn-soybean meal diets, but it favored animal welfare.

Keywords: alternative feedstuff, animal behavior, colostrum, DDGS, sow performance

1. Introduction

Corn ethanol production is a recent activity and has grown in Brazil as a consequence of the high availability of the grain, which can generate significant amounts of dried distillers grains with solubles (DDGS). It is estimated that in the dry-milling process, the use of 100 kg grains results in 40.2 L ethanol, 32.3 kg DDGS, and 32.3 kg CO_2 (Chatzifragkou et al., 2015), suggesting a significant increase in the production of this co-product in the years to come.

The high levels of crude protein (285 to 368 g kg^{-1}; Li et al., 2015), phosphorus (3.30 to 10.10 g kg^{-1}; Li et al., 2015), and metabolizable energy (3,445-3,609 kcal/kg; Corassa et al., 2017; Corassa et al., 2019) in DDGS allow its use in swine diets. Although its neutral detergent fiber contents (310 to 466 g kg^{-1}; Li et al., 2015) may restrict its use for young pigs, it may actually represent an advantage for gestating sows. However, the effects of DDGS inclusion in diet for late gestating sows (Wang et al., 2013; Sotak-Peper et al., 2015) have not been completely elucidated, especially in relation to colostrum synthesis, performance, and animal behavior.

The fiber in diets for gestating sows alleviates prolonged farrowing duration by softening the feces, relieving the constipation effects, maintaining insulin homeostasis, alleviating postpartum anorexia, maintaining normal reproductive performance (Li et al., 2021), promoting gastrointestinal tract fill, increasing feed intake during lactation and the sensation of satiety, and preventing stereotypies (Agyekum and Nyachoti, 2017). In addition, high soluble fiber diets seem to promote greater welfare through a higher frequency of lying lateral behavior (Zonderland et al., 2004), while other studies showed no difference on lying lateral behavior, despite the reduction on stereotypic behavior of gilts fed high-insoluble fiber diets (Bernardino et al., 2021). Moreover, to our knowledge, no studies have been conducted with sows fed DDGS in Brazil.

Therefore, the inclusion of DDGS in diet for late gestating sows could have positive effect on sow and litter performance, but it does not influence colostrum characteristics nor favors animal welfare. On this basis, the present study was conducted to examine the effect of different DDGS levels in diets during late gestation on sow and litter performance, colostrum composition, and animal behavior.

2. Material and Methods

Procedures with animals were approved by the institutional Ethics Committee in Animal Use (Protocol n. 23108.700673/14-4) in accordance to the ethical principles by the National Council for the Control of Animal Experimentation (CONCEA).

The study involved 60 gestating sows of the Genétipórc® line (PIC, Brazil), with an average of 3.77±1.65 parity, inseminated with semen of the same line, on a commercial piglet farm located in Sinop, in the state of Mato Grosso, Brazil (−11°51'51" S, −50°30'09" W, and 384 m above sea level).

The experiment was set up as a randomized block design with three experimental diets and two blocks. The blocks were formed according to sows' feeding start date, since there was a difference of thirty days between the first and the second blocks. Each sow was considered an experimental unit, in a total of 20 replicates per experimental diet, for the analysis of sow and litter performance and colostrum composition data.

Animals were housed into groups of 10 sows, each one according to the average parity, and were distributed into the pens of 5.15 m^2 per animal, to receive one of the three experimental treatments, which consisted of diets including 0, 150, or 300 g kg^{-1} of corn DDGS (Table 1). Experimental diets were formulated to meet nutritional requirements of the category, as recommended by Rostagno et al., (2017). Each experimental diet was offered to two groups of ten sows each, totalizing twenty sows per treatment. All diets were supplied for about 84 to 114 days of gestation. After farrowing, all sows received the same lactation diet (Table 1). The DDGS, obtained from the ethanol-producing industry in Brazil, and generated from corn ethanol production contained 287.80 g crude protein, 65.20 g ether extract, 48.60 g ash, 124.40 g crude fiber, <150 ppb zearalenone, and <20 ppb aflatoxin per kilogram.

The pens had concrete floor and were equipped with nipple drinkers and feed troughs under fiber-cement tiles, without temperature recording and control. Mean minimum and maximum temperatures in the region were 25 °C and 31.3 °C, respectively. The occurrence of distinct body positions and activities performed by all sows were recorded at five-minute intervals in the two hours immediately after starting feeding, for three consecutive days, in each experimental block. Data were recorded simultaneously from the direct observation performed by three trained evaluators, and there was a rotation among evaluators over the three days.

The body positions were defined as: standing – body supported on the four legs; sitting – leaning on the front limbs and sitting on the hind limbs; lying ventral – animal with belly resting on the floor and all legs under the body; and lying lateral – lying on the side with all legs stretched horizontally. The activities were: eating – animals eating feed; drinking – animals drinking water in the nipple-type drinker; and inactivity – animals that show no behavior or activity. This protocol was based on Zonderland et al. (2004).

Sows were fed once daily, at 05:00 h, for 30.35±3.79 days, at the end of gestation. After 114 days of gestation, they were transferred to the maternity pen and housed in individual cages (1.5 × 2.1 m)

Table 1 - Nutritional composition of the diets

Ingredient	Gestation DDGS (g kg^{-1}) 0	150	300	Lactation
Corn	784.00	719.20	591.44	650.93
Soybean meal, 45%	180.00	93.10	70.60	310.00
DDGS	0	150.00	300.00	-
Dicalcium phosphate	21.93	19.69	18.80	22.90
Calcitic limestone	3.27	4.74	5.39	4.23
Common salt	3.63	3.60	3.60	4.77
L-Lysine	2.00	4.50	5.00	2.00
Mineral-vitamin mix[1]	5.17	5.17	5.17	5.17
Gross energy (kcal)[3]	3,785	3,862	4,037	3,720
Metabolizable energy (kcal)[2]	3,252	3,292	3,321	3,300
Crude protein[3]	179.30	175.30	189.70	217.10
Digestible lysine (g)[2]	7.44	7.43	7.43	10.57
Ether extract[3]	36.60	45.90	50.20	44.10
Mineral matter[3]	58.50	52.20	51.40	65.40
Calcium[3]	9.90	9.70	9.50	9.90
Phosphorum[3]	4.20	4.00	3.90	4.20
Crude fiber[3]	26.70	52.60	65.60	29.80
Neutral detergent fiber[2]	117.90	173.20	229.8	124.90

DDGS - dried distillers grains with solubles.
[1] Composition of supplement per kg of diet: vitamin A, 1800 IU; vitamin B1, 2.7 mg; vitamin B2, 6.48 mg; vitamin B6, 3.6 mg; vitamin B12, 0.0414 mg; vitamin D3, 4.680 IU; vitamin E, 43.2 mg; vitamin K3, 4.68 mg; nicotinic acid, 30.6 mg; pantothenic acid, 16.2 mg; folic acid, 2.88 mg; calcium, 8.4 g; phosphorus, 1.12 g; phytase, 0.664 FTU; sodium, 2.32 g; cobalt, 0.14 mg; copper, 0.096 mg; iron, 0.1152 mg; zinc, 0.116 mg; manganese, 0.0576 mg; selenium, 0.56 mg; iodine, 1.44 mg; choline, 0.6 mg; biotin, 0.2 mg.
[2] Calculated composition per kg of mixture based on dry matter.
[3] Analyzed composition per kg of mixture based on dry matter.

on concrete floor, which were equipped with a concrete feeder and a nipple-type drinker. A lactation diet was then provided from that period until the day of weaning. On the day of farrowing, each sow received 2.0 kg of the lactation diet. Subsequently, the volume of feed provided was gradually increased to meet the feed intake requirements of sows. Water was available *ad libitum* throughout the experiment. The amount of feed provided during lactation throughout the experimental period was recorded.

Each sow was weighed (body weight, BW) individually on a floor scale (B650, Líder Balanças, Araçatuba, SP, Brazil) at 83.65±3.79 (sow initial BW) and 114 days of gestation (sow prepartum BW) and at 19.03±2.93 days of lactation (sow weaning BW). On the same dates, backfat thickness was measured with an ultrasound machine (Pie Medical 200, Maastricht, Netherlands) equipped with a 3.5-MHz linear probe (ASP-18) in the last rib, 6 cm off the back midline, on the left and right sides (sow initial, prepartum, and weaning backfat thickness) considering the average of both values (Corassa et al., 2014).

Immediately after birth, each piglet was wrapped in drying powder, had their navel cut, were disinfected with glycerinated iodine, and then were sent to the first suckle. In the following hours, piglets were injected with iron dextran. Twenty-four hours post-farrowing, the total born, live-born, stillborn, and mummified piglets were counted and the weight of each class was determined by weighing them collectively. On the same occasion, the number of piglets per sow was adjusted to standardize the litter size. In total, each sow gave birth to 11.99±1.36 live piglets, with an average piglet weight of 1.54±0.19 kg. On the second day of life, the teeth and tail of all piglets were clipped and docked, respectively. Male piglets were castrated on the fifth day of life.

The lactation period lasted 19.03±2.93 days. At the time of weaning, the number of piglets that died during lactation and weaned piglets were counted and weighed, and the latter were transferred to the nursery.

After farrowing, small samples of colostrum were randomly collected from the teats of each sow. Samples were stored in plastic bags that were then frozen at −20 °C for later analysis of the lactose, crude protein, fat, ash, and total solids contents.

The lactose content of the colostrum was measured by Fehling's reduction technique (Instituto Adolfo Lutz, 1985); crude protein content was determined by the Kjedahl method, and fat was calculated by an adaptation of the method proposed by Geber (Instituto Adolfo Lutz, 1985), which consisted of diluting a 5.5-mL colostrum sample into 5.5 mL of distilled water. The diluted sample was then pipetted and added to a milk butyrometer. Next, 2 mL amyl alcohol was added and the solution was centrifuged for 10 min, with a pause after 5 min. Subsequently, the butyrometer was read and the result multiplied by 2 to determine milk fat content. The total solids content was obtained by the gravimetric method in an oven at 102 °C for 3 h, whereas the ash content was determined by incineration in a muffle furnace at 550 °C for 4 h.

The used statistical model was:

$$Yij = \mu + \alpha i + \gamma j + \varepsilon ij,$$

with i = 1, 2, 3 and j = 1, 2, in which Yij is the observed value of treatment with DDGS (α), within block (j); μ is the population mean for the variable; αi is the effect of the DDGS level; γj is the block effect j; and εij is the error of the experimental unit factor i and factor j.

Means were compared by Tukey's test at 0.05 and tendency at 0.10 significance levels using the mixed procedure of SAS software (Statistical Analysis System, version 9.0). Because the variables backfat thickness in gestation and lactation, numbers of stillborn and mummified piglets, and rate of piglet mortality did not show normal probability distribution, they were log-transformed (log^{10} (n+1)) for a subsequent comparison of means. Weight-related variables (weight gain, weight change, backfat thickness, and feed intake during lactation) were analyzed using initial sow weight as a co-variable.

For the investigation of behavioral variables, frequency analysis was performed based on the averages of each position and behavior displayed by the sows. Statistical analysis was performed using Bayesian inference, generating Markov chains and by using a Gibbs sampler. The total Markov evaluated chain size was equal to 100,000 cycles, with a burn-in period of 10,000 and a thin period every 10 cycles. To obtain the posterior distributions, the conjugate prior distribution of the normal type was used for the parameters of the equation; the residual variance component was adopted *a priori* with an inverse Gamma distribution. All analyzes were performed with SAS program, using the Markov chain Monte Carlo procedure (proc MCMC). The frequencies of the positions of pregnant sows fed 0, 150, and 300 g kg^{-1} DDGS, observed *in loco* and estimated from the models were designed in graphics for visual comparison.

3. Results

The Bayesian analysis showed that sows fed 300 g kg^{-1} DDGS presented a lower frequency of standing position, compared with the others, which did not differ from each other ($P<0.05$) (Table 2). The frequencies of the sitting, lying ventral, and lying lateral positions of the sows were not altered by the different diets ($P>0.05$) (Table 2). The frequency of eating activity of sows fed 300 g kg^{-1} DDGS was lower if compared with the others, which did not differ from each other ($P<0.05$) (Table 3). The frequencies of inactivity and drinking were not altered ($P>0.05$) (Table 3).

The visual analysis of observed dates shows that sows fed the diet containing 300 g kg^{-1} DDGS stood standing (Figure 1A) and eating (Figure 2A) less frequently than the others, until 55 min post-feeding, while those that received the other diets showed similar frequencies throughout the evaluation period.

Table 2 - Posterior means, standard deviation, credibility interval, and Geweke's test value with associated probability (P-value) of the frequencies of the positions of pregnant sows fed 0, 150 and 300 g kg^{-1} DDGS

DDGS (g kg^{-1})	Mean b	SD	CI		Geweke		Model
			IL	SL	Z	P-value	
Standing							
0	−0.8101	0.0363	−0.8788	−0.7368	0.4433	0.6576	y = 108.9 – 0.8101x
150	−0.8314	0.0327	−0.8970	−0.7683	0.8088	0.4186	y = 109.6 – 0.8314x
300	−0.6443	0.0421	−0.7282	−0.5632	0.9089	0.3634	y = 94.5818 – 0.6443x
Sitting							
0	0.0594	0.0133	0.0335	0.0850	0.4852	0.6275	y = −0.5908 + 0.0594x
150	0.0889	0.0155	0.0590	0.1192	0.2140	0.8306	y = −1.2402 + 0.0889x
300	0.0593	0.0145	0.0297	0.0862	1.0133	0.3109	y = −0.3477 + 0.0593x
Lying ventral							
0	0.5338	0.0317	0.4712	0.5959	1.3433	0.1792	y = −8.4445 + 0.5338x
150	0.5238	0.0351	0.4534	0.5912	0.5620	0.5741	y = −8.9292 + 0.5238x
300	0.4050	0.0332	0.3420	0.4723	1.1118	0.2662	y = −1.1272 + 0.405x
Lying lateral							
0	0.2953	0.0293	0.2371	0.3526	0.5287	0.5970	y = −6.2448 + 0.2953x
150	0.2798	0.0311	0.2216	0.3430	0.0731	0.9417	y = −4.4089 + 0.2798x
300	0.2814	0.0310	0.2215	0.3420	1.7474	0.0806	y = −1.3826 + 0.2814x

DDGS - dried distillers grains with solubles.

Table 3 - Posterior means, standard deviation, credibility interval, and Geweke's test value with associated probability (P-value) of the frequencies of the activities of pregnant sows fed 0, 150, and 300 g kg^{-1} DDGS

DDGS (g kg^{-1})	Mean b	SD	CI		Geweke		Model
			IL	SL	Z	P-value	
Eating							
0	−0.9305	0.0395	−1.0057	−0.8530	−0.7232	0.4695	y = 105.8 – 0.9305x
150	−0.9807	0.0319	−1.0401	−0.9146	−1.0712	0.2841	y = 108.4 – 0.9807x
300	−0.7188	0.0402	−0.7934	−0.6366	−0.3366	0.7364	y = 89.8951 – 0.7188x
Inactivity							
0	0.9108	0.0335	0.8459	0.9762	1.1401	0.2543	y = −15.63938 + 0.9108x
150	1.0107	0.0311	0.9508	1.0720	1.4445	0.1486	y = −16.3422 + 1.0107x
300	0.7631	0.0428	0.6816	0.8473	−0.7050	0.4808	y = −3.0943 + 0.7631x
Drinking							
0	0.0237	0.0172	−0.0089	0.0589	0.8711	0.3837	y = 3.4517 + 0.0237x
150	0.0267	0.0113	0.0046	0.0486	0.0534	0.9574	y = 1.8064 + 0.0267x
300	0.0215	0.0187	−0.0137	0.0598	1.2762	0.2019	y = 3.7119 + 0.0215x

DDGS - dried distillers grains with solubles.

The exact opposite result was observed for the inactivity, for which the sows that consumed the diet with 300 g kg^{-1} DDGS exhibited a greater frequency until 55 min. Those that received the diet containing 150 g kg^{-1} of the test ingredient were the most inactive from 70 min on, until the end of the evaluation period (Figure 2C). The frequency of drinking by the gestating sows receiving diets with different levels of DDGS fluctuated through the evaluation period, which prevented a more in-depth analysis (Figure 2B).

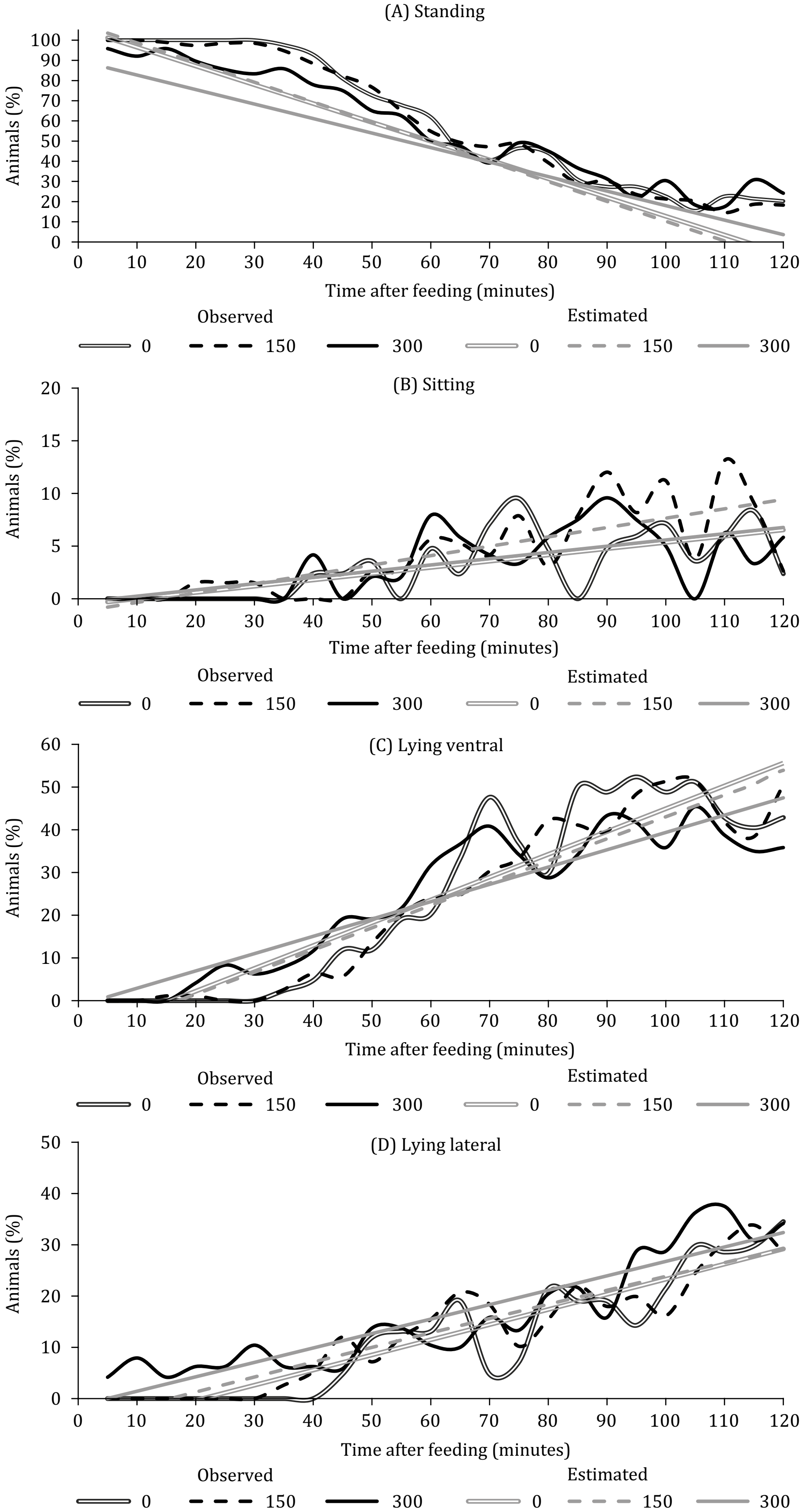

Figure 1 - Relative frequency (%) of standing (A), sitting (B), lying ventral (C), and lying lateral (D) positions of gestating sows fed diets containing 0, 150, or 300 g kg^{-1} dried distillers grains with solubles as a function of time (min) after feeding based on observed dates or estimated by Bayesian analysis.

After 35 min post-feeding, the frequency of sitting behavior (Figure 1B) increased considerably, although it varied greatly between the animals in the different treatment groups, without a definitive characterization.

The frequency of lying ventral position among the sows was considerably high after 15 min and more pronounced in the animals that fed the diet with 300 g kg^{-1} DDGS compared with the other groups

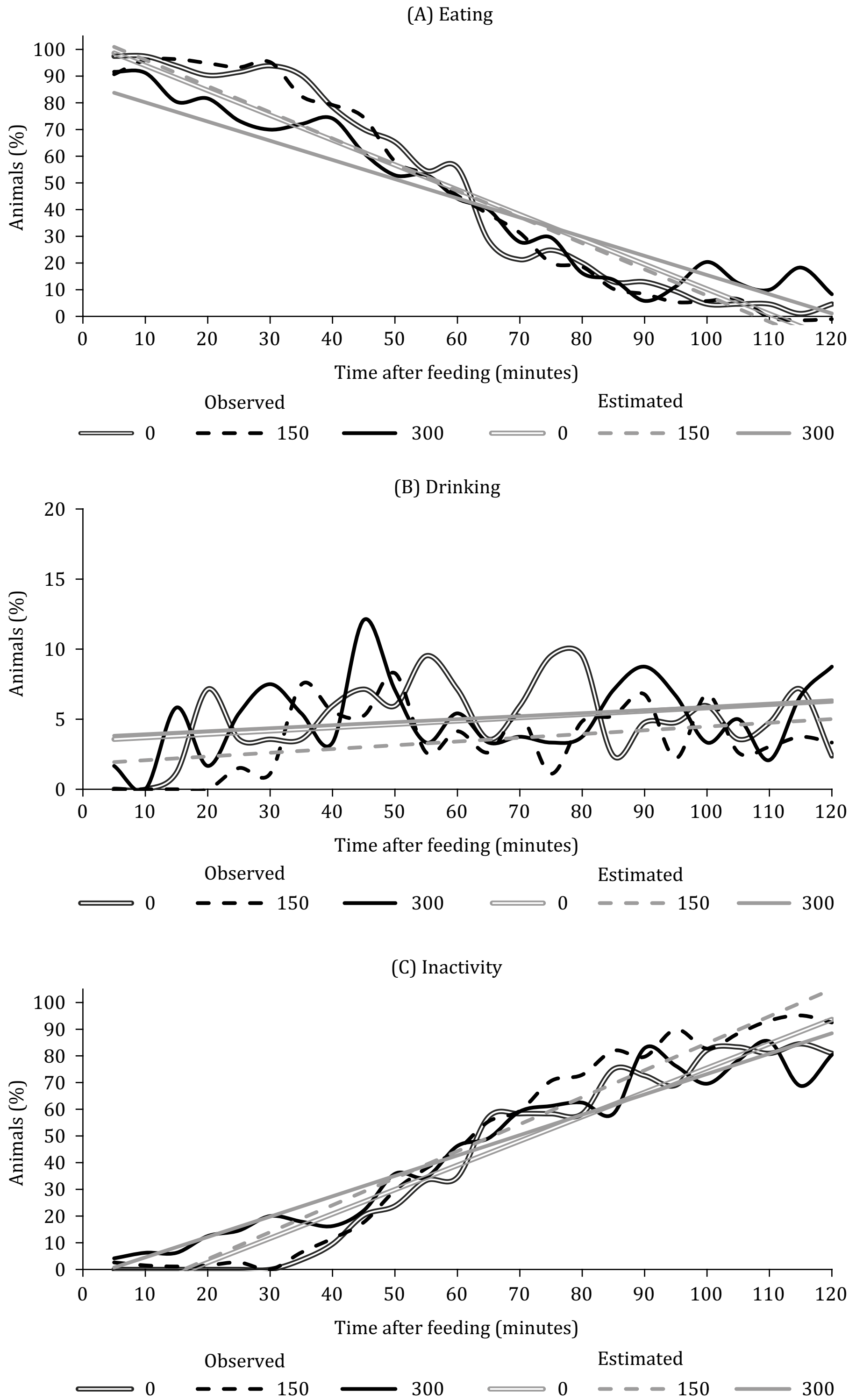

Figure 2 - Relative frequency (%) of eating (A), drinking (B), and inactivity (C) behaviors of gestating sows fed diets containing 0, 150, or 300 g kg^{-1} dried distillers grains with solubles as a function of time (min) after feeding based on observed dates or estimated by Bayesian analysis.

until 65 min post-feeding, and after this time the frequencies were similar (Figure 1C). In the animals fed diets with 0 and 150 g kg^{-1} DDGS, the lying ventral position was only observed after 30 min post-feeding. In the same way, sows fed 300 g kg^{-1} DDGS were in lying lateral position more frequently in the first 40 min post-feeding, whereas those that received diets with 0 and 150 g kg^{-1} DDGS started to lie in this position approximately 30 and 40 min after feeding, respectively (Figure 1D).

Inclusion of DDGS in the diet of gestating sows did not influence (P>0.05) sow's parameters: initial BW, prepartum BW, BW change prepartum–initial, weaning BW, initial backfat thickness, BW change weaning–prepartum, prepartum backfat thickness, backfat thickness change prepartum–initial, and backfat thickness change weaning–prepartum (Table 4).

Inclusion of 150 and 300 g kg^{-1} DDGS in the diets of sows at the end of gestation did not affect (P>0.05) sow BW at weaning. However, DDGS inclusion influenced (P<0.05) sow backfat thickness at weaning. At the end of the lactation period, sows fed 150 g kg^{-1} DDGS showed a thicker backfat than those in the control group (g kg^{-1} DDGS), but no difference was observed in relation to the treatment groups. Sows that received the diet including 300 g kg^{-1} DDGS tended (P<0.10) to show more feed intake during lactation.

No effect was detected (P>0.05) in the total number of born piglets, live-born, stillborn and mummified piglets, litter weight (live-born), average litter weight, weaned piglets, mortality, and weight of weaned piglets (Table 5).

The highest level of the ingredient in the diet (300 g kg^{-1}) tended (P≤0.10) to increase colostrum protein content when compared with the lower DDGS inclusion level (150 g kg^{-1}). Lactose, in turn, showed an upward tendency (P≤0.10) as the DDGS inclusion level in the diet was elevated. Fat, total solids, and mineral matter contents of colostrum were not affected (P>0.05) (Table 6).

4. Discussion

In this study, the lower frequency of animals in the standing position and eating activity of sows fed 300 g kg^{-1} DDGS, which we observe from the Bayesian analysis, is related to the higher levels of fiber in the diet. The increase of dietary fiber has increased swelling and water binding capacity in the stomach, resulting in lower physical activity because of these satiating properties (Jørgensen et al., 2010).

Table 4 - Characteristics of sows fed diets containing different levels of dried distillers grains with solubles (DDGS)

	DDGS (g kg^{-1})			P-value	SEM
	0	150	300		
Sows (n)	20	20	20	-	-
Average parity (n)	3.80	3.75	3.76	0.9941	0.213
Sow initial BW (kg)	231.26	236.98	237.2	0.1423	4.245
Sow prepartum BW (kg)	262.56	260.64	259.9	0.6597	4.520
Prepartum–initial (kg)	27.31	26.77	24.3	0.3655	0.886
Sow weaning BW (kg)	227.01	219.97	218.1	0.1985	4.325
Weaning–prepartum (kg)	35.54	40.67	41.87	0.1880	1.561
Sow initial backfat (mm)	13.66	14.47	14.54	0.5026	0.349
Sow prepartum backfat (mm)	16.07	16.45	16.44	0.8807	0.379
Prepartum–initial (mm)	2.51	2.47	2.47	0.6578	0.207
Sow weaning backfat (mm)	12.24b	13.74a	13.51ab	0.0190	0.246
Weaning–prepartum (mm)	2.61	2.53	2.55	0.3345	0.268
Lactation feed intake (kg/d)	3.99	3.98	4.23	0.1009	0.051

a,b,c - Within a row, means with different letters differ (P<0.05) by Tukey's test.

Table 5 - Litter performance of sows fed diets containing different levels of dried distillers grains with solubles (DDGS)

	DDGS (g kg^{-1})			P-value	SEM
	0	150	300		
Total born piglets (n)	13.68	13.60	13.10	0.7265	0.307
Live born piglets (n)	12.32	11.95	11.95	0.8405	0.282
Stillborn piglets (n)	2.41	2.42	2.37	0.1250	0.136
Mummified piglets (n)	2.31	2.33	2.34	0.4409	0.117
Birth litter weight (kg)	18.91	18.32	18.40	0.9717	0.455
Average birth weight (kg)	1.53	1.53	1.54	0.9717	0.025
Weaning (n)	9.93	10.04	10.04	0.9729	0.225
Mortality (%)	2.50	2.47	2.46	0.5687	0.235
Litter weight at weaning (kg)	50.74	54.42	52.91	0.4917	1.485
Average weaning weight (kg)	5.11	5.42	5.27	0.4702	0.117
Average daily gain piglet (g/d)	188	205	196	0.3466	5.887
Simulated 21 days weight (kg)	5.48	5.82	5.66	0.5040	0.126

SEM - standard error of the mean.

Table 6 - Composition of colostrum from sows fed diets containing different levels of dried distillers grains with solubles (DDGS)

Item	DDGS (g kg^{-1})			P-value	SEM
	0	150	300		
Protein	145.40	118.90	125.40	0.0980	4.814
Lactose	22.80	25.50	26.80	0.0912	0.667
Fat	54.70	56.30	54.00	0.9097	2.174
Total solids	23.05	23.03	21.63	0.8350	8.178
Ash	6.70	7.00	6.50	0.1495	0.131

SEM - standard error of the mean.

The present findings corroborate those reported by Gentilini et al. (2003), who observed that animals fed a high-fiber diet had lower frequency of the standing position and a higher frequency of lying at 10 min after morning feeding and a lower frequency of the sitting position at 30 min after morning feeding compared with animals fed a low-fiber diet. The results of the behaviors of this study are in agreement to Bernardino et al. (2021), who found no difference for the lying position, when comparing high- and low-fiber diets, but the stereotypic behavior in sows was reduced when fed high-fiber diet.

In this regard, the longer a sow takes to be fed during this phase of gestation, even having less volume of feed available, the greater their welfare will be (Robert et al., 1993). This is a result of reduced aggressiveness and stereotypies, as the sow will be engaged in feed intake and, soon after eating, it shall seek for a resting position.

Behaviors such as lying lateral and lying ventral positions and inactivity are used as indicators that there is less hunger sensation and greater satiety sensation, culminating in a supposedly better state of welfare in sows (Zonderland et al., 2004; Bernardino et al., 2021).

The inclusion of 300 g kg^{-1} DDGS in the diet of gestating sows tends to elicit an early display of lying or inactivity behavior. Therefore, the fiber provided through DDGS favors welfare to gestating sows, despite the worsening in the digestibility coefficient of the diet compared with corn-soybean meal diets (Corassa et al., 2019). Furthermore, according to De Leeuw et al. (2005), sows fed high-fiber diets, exhibit less frequent posture changes during gestation, which reduces aggressiveness and occurrence of other stressing factors during this period, which is especially important for housed group like in this study.

Lower standing and higher lying frequency may be related to the heat production of the digestive process after meals and the attempt to enlarge the contact area with the solid floor to facilitate heat dissipation (Zonderland et al., 2004) in sows fed more fibrous diets, because of non-digestible carbohydrates and lignin, present in DDGS that can be fermented into gas and organic acids by microbiota in the large intestine (Li et al., 2021).

A higher frequency of resting behavior and a reduction in the sudden act of chewing are findings of high-fiber diets to gestating sows (Sapkota et al., 2016). Even with no difference in the frequency of lying lateral (145 vs 252), lying ventral (284 vs 404), and standing (33 vs 28) positions of gestating sows with low or high fiber up to 3 h after feeding, Budiño et al. (2014) believe that high fiber diets lead to better animal welfare and comfort. In another study, Loisel et al. (2013) reported that the duration of the farrowing process was not affected by high-fiber diets; however, the birth process began faster in sows fed the high-fiber diet than in the group fed the low-fiber diet.

Diets containing DDGS at 150 or 300 g kg^{-1} supplied to late gestating sows did not change their performance, compared with the corn and soybean meal diet. As initially hypothesized, no great alterations are expected in performance results when diets are formulated with alternative ingredients with a similar nutritional base to commonly used diets, even when there are differences in neutral detergent fiber content between the diets.

Because the fiber content of DDGS is higher than that of corn and soybean meal, its dietary inclusion was expected to generate the sensation of satiety, as promoted by gastrointestinal tract filling, thereby reducing stress and encouraging these animals to seek for resting positions and increase their intake capacity during lactation. Moreover, these animals have a great ability to partially digest fiber, because they are adults with a well-developed gastrointestinal tract. In this way, after fermentation and generation of short-chain fatty acids, the fiber starts to contribute for the supply of energy to those animals (Agyekum and Nyachoti, 2017).

No effect of DDGS inclusion on sow performance has also been reported (Wang et al., 2013; Xu et al., 2020). Wang et al. (2013) observed no effect of inclusion of 200 and 400 g kg^{-1} of DDGS in diet on performance of late gestating sows when compared with the control diet. Recently, Xu et al. (2020) reported the same reproductive performance of sows fed 0, 150, 300, or 450 g kg^{-1} high-oil or de-oiled DDGS. Nonetheless, Song et al. (2010) reported that lactating sows fed diets with 100, 200, or 300 g kg^{-1} DDGS tend to increase their average daily feed intake.

A larger backfat thickness was found in sows that fed the diet containing 150 g kg^{-1} DDGS compared with control diet. However, there was no difference for this parameter between the sows fed the control diet and that with 300 g kg^{-1}. There was a numerical difference of 0.81 mm in backfat thickness between the sows receiving control treatment and the diet with 150 g kg^{-1} DDGS in the start of gestation evaluation. Later, at weaning, this difference rose to 1.5 mm; this statistical effect was likely due to this difference which had been present since the start of the observations of that parameter. Song et al. (2010) supplied increasing levels of DDGS (100, 200, and 300 g kg^{-1}) to lactating sows and observed that the dietary treatments had no effect on backfat thickness during lactation. Their finding was corroborated by Baidoo et al. (2014), who fed lactating sows with diets containing 300 g kg^{-1} DDGS and observed no changes in backfat thickness, feed intake, or weight change during lactation, and also no effects on the weaning-to-estrus interval.

There was an upward tendency in feed intake by the sows during the lactation period, which may be related to the ability of fiber to promote dilation of the stomach walls, favoring the ingestion of larger volumes of feed during lactation. As stated by Guillemet et al. (2010), sows fed high-fiber diets during gestation (120 g kg^{-1} crude fiber) consumed more feed during lactation when compared with those fed a control diet and low fiber levels (35 g kg^{-1} crude fiber). This indicates that the dietary fiber provided to sows during gestation leads to an increase in feed intake during lactation, which is a positive factor, considering that their nutritional requirements increase due to the milk production activity. Other studies are necessary to confirm the results of this research.

The equal litter performance observed between different levels of DDGS is related to the similar nutrient concentration of these diets, which ensured nutrient supply to sows during the milk production process. A piglet's weaning weight depends on milk intake during lactation and on the sow's ability to produce sufficient milk to meet the requirements of the litter. The feeding of sows at the end of gestation is a factor of great importance for the piglets, because during this period, after ninety days of gestation, the processes of hypertrophy and muscle maturation in the fetuses continue. Therefore, maternal nutrition and nutrient and oxygen flow affect piglet birth weight (Almeida, 2009).

The present study demonstrates that replacing part of the traditional ingredients in the diet of gestating sows with DDGS, at levels up to 300 g kg^{-1}, does not compromise litter performance; on the contrary, it yields satisfactory results. In this regard, Song et al. (2010) also did not observe an effect of dietary DDGS on litter performance. However, the piglets born from sows fed diets containing 100, 200, or 300 g kg^{-1} DDGS grew faster than those born from animals fed the control diet. In another study, Hanson et al. (2012) included 400 g kg^{-1} DDGS in the diet of sows during gestation, 200 g kg^{-1} DDGS during lactation, and 300 g kg^{-1} DDGS in the diet of piglets after weaning and observed that the DDGS present in the diet did not contribute to the incidence of mulberry heart disease, which shows that the antioxidant status of the piglets was not changed by the inclusion of the ingredient. Likewise, Loisel et al. (2013) offered high-fiber diets to gestating sows and found that although the diet did not influence piglet weight gain at birth and during lactation, the litter showed a lower mortality rate at weaning, which may be explained by the increased intake of colostrum by the piglets that were lighter at birth, born from sows fed high-fiber diets.

However, providing diets containing 400 g kg^{-1} DDGS during gestation and 200 g kg^{-1} DDGS during lactation expressed smaller litter size, more stillborns, and litters with less weight than sows fed corn-soybean meal diets after three cycles (Li et al., 2014). The comparison between these results with the present study may suggest that levels greater than 300 g kg^{-1} DDGS in gestating sows' diets may not be interesting. Supply of feeds with a potential content of peroxided oil such as DDGS may also create an oxidative stress in late gestation sows (Li et al., 2014).

The tendency of DDGS inclusion to affect the milk protein content shows that as the ingredient is added to the sow diets, the protein concentration in their colostrum decreases. Theil et al. (2014) observed a lower protein content in the colostrum of sows fed beet pectin or pulp waste compared with the colostrum of sows fed potato pulp. However, the percentage reduction in the protein content of colostrum did not influence piglet performance. Additionally, in our study, the highest DDGS levels (300 g kg^{-1}) tended to increase the protein content of colostrum by 6.5% compared with its inclusion at 150 g kg^{-1} DDGS.

There was an upward tendency in the lactose concentration in the colostrum as the level of DDGS included in the diet was increased. Lactose, specifically, serves as an important substrate for lactic acid-producing bacteria, resulting in an unfavorable environment to pathogenic bacteria (Kim et al., 1978). Moreover, it may increase the proliferation of beneficial bacteria in the gastrointestinal tract (Pierce et al., 2007). Further, microbial lactose fermentation stimulates the production of short-chain fatty acids, especially butyric acid, which, in turn, stimulates the proliferation and differentiation of gastrointestinal tract epithelial cells, thereby increasing the nutrient absorption area in piglets (Pierce et al., 2007). The tendency towards increase in lactose concentration in colostrum is positive for newborn piglets; however, new studies are necessary for better understanding this.

Inclusion of DDGS in the diet of sows at the end of gestation did not cause alterations in fat, total solids, and ash contents, thus preserving its characteristics. Therefore, this alternative ingredient can be recommended with no harm to the litter. No differences in protein, lactose, fat, and total solids were also observed by Xu et al. (2020) in colostrum from sows fed 0-450 g kg^{-1} high-oil or de-oiled corn DDGS. Similar results were obtained by Song et al. (2010), who tested the inclusion of 100, 200, and

300 g kg^{-1} DDGS in diets of lactating sows and found no effect on the composition of milk. Likewise, Wang et al. (2013) did not observe alterations in lactose, total solids, fat, or protein contents of colostrum from sows fed diets with 200 and 400 g kg^{-1} DDGS during gestation.

5. Conclusions

Diets with 150 and 300 g kg^{-1} DDGS does not change sow and litter performance and the chemical composition of colostrum compared with the control diet, whereas 300 g kg^{-1} DDGS improves animal welfare.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: A. Corassa, L.L. Silva, C. Souza, C. Kiefer and M. Sbardella. Data curation: A. Corassa, L.L. Silva, C. Souza, C.V. Araújo and V.L. Rothmund. Formal analysis: A. Corassa, L.L. Silva and C. Souza. Funding acquisition: A. Corassa. Investigation: L.L. Silva, C. Souza and M. Sbardella. Methodology: A. Corassa, C. Souza, L.J. Rodrigues, G.A. Lemes, M. Sbardella, C.V. Araújo and A.S. Oliveira. Project administration: A. Corassa. Software: C.V. Araújo. Supervision: A. Corassa. Validation: C. Kiefer. Visualization: C. Kiefer, M. Sbardella and V.L. Rothmund. Writing-original draft: A. Corassa, L.L. Silva, C. Kiefer and M. Sbardella. Writing-review & editing: A. Corassa, C. Kiefer and M. Sbardella.

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