




## Effect of different levels of total dietary fiber on the performance of sows in gestation and lactation

Carlos Alexandre Oelke<sup>1\*</sup> , Andréa Machado Leal Ribeiro<sup>2</sup>, Mirela Noro<sup>1</sup>, Mari Lourdes Bernardi<sup>2</sup>, Cristiane Casagrande Denardin<sup>3</sup>, Paula Raymundo Nunes<sup>1</sup>, Fernando César Veit<sup>1</sup>, João Carlos Winckler<sup>1</sup>

<sup>1</sup> Universidade Federal do Pampa, Departamento de Medicina Veterinária, Uruguaiana, RS, Brasil.

<sup>2</sup> Universidade Federal do Rio Grande do Sul, Faculdade de Agronomia, Departamento de Zootecnia, Porto Alegre, RS, Brasil.

<sup>3</sup> Universidade Federal do Pampa, Departamento de Farmácia, Uruguaiana, RS, Brasil.

**ABSTRACT** - The present study evaluated the effect of variation in the amount of total dietary fiber (TDF) in sow diets, provided from 74 to 114 days of gestation, on the digestibility of nutrients and energy during gestation, as well as productivity and metabolism during gestation and lactation. Thirty-three sows were used in a randomized experimental design. The amounts of TDF in three treatment diets were 156, 223, and 282 g kg<sup>-1</sup>. The daily intake of nutrients and energy was similar for all diets the entire period of gestation, differing only in the volume of ration consumed, which was 2.1, 2.2, and 2.4 kg day<sup>-1</sup> (days 74 to 90) and 2.5, 2.6, and 2.8 kg day<sup>-1</sup> (days 91 to 111) for the 156, 223, and 282 g kg<sup>-1</sup> TDF diets, respectively. During gestation, the increase in TDF resulted in a significant linear decrease in the digestible energy and apparent total tract digestibility of dry matter, gross energy, crude protein, non-fibrous carbohydrates, and organic matter. During gestation, blood concentrations of protein and globulins exhibited a quadratic response to the amount of TDF in the diet, whereas cholesterol exhibited a significant linear increase. The productivity and reproductive performance of the sows during gestation and lactation or the birth weight of the piglets were not affected by the amount of TDF, but the average daily weight gain of the litter during nursing increased linearly with increasing levels of dietary fiber. Increasing the amount of TDF reduces the digestibility of nutrients and energy, without affecting the performance of the sows during gestation and lactation or that of the piglets at birth and increasing TDF during gestation improves the weight gain of piglets during lactation.

Key Words: digestibility, insulin, piglets

### Introduction

The addition of fiber to the diet of sows helps to control weight and minimize the stress associated with confinement in gestation crates and feed restrictions that pregnant females endure (Ramonet et al., 1999; Danielsen and Vestergaard, 2001; Gentilini et al., 2003). This improves the productivity of sows, since the excess energy intake during gestation impairs the formation of the mammary glands and leads to lower milk production during lactation, as well as impacts negatively the feed intake during lactation (Weldon et al., 1991). Compared with diets that contain 33 and 106 g kg<sup>-1</sup> crude fiber, a diet with 181 g kg<sup>-1</sup> of crude

fiber improves welfare by prolonging the post-prandial satiety feeling after feeding (Ramonet et al., 1999).

In addition to improving sow welfare, the addition of fiber to sow diets during gestation might positively affect the birth weight of piglets and feed intake of sows during lactation (van der Peet-Schwering et al., 2003; Veum et al., 2009). Despite the substantial debate over the use of fiber in the diet of pregnant sows, there remain uncertainties over its use (Reese et al., 2008), mainly in relation to the level of total dietary fiber (TDF) to be used. According to NRC (2012), the main challenge in measuring TDF is its implementation in nutrition laboratories. In addition, it is important to evaluate the effect of TDF and its soluble and insoluble fractions on animal metabolism, as well as on the satiety and performance of gestating sows.

This study evaluated the effect of variation in the amount of TDF in the diet, from 74 to 114 days of gestation, on nutrient digestibility, productivity, and metabolism of sows during both gestation and lactation. We hypothesized that the increase in fiber intake during gestation would increase the birth weight and reduce the number of stillborn

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\*Corresponding author: [carlosalexandroelke@gmail.com](mailto:carlosalexandroelke@gmail.com)

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piglets. Furthermore, the use of dietary fiber during gestation may increase the voluntary feed intake of sows during lactation, thus improving the weight gain of piglets during nursing.

## Material and Methods

Research on animals was conducted according to the institutional committee on animal use (case number 006/20014). The present study was conducted in Itaquí, Rio Grande do Sul – Brazil (Latitude: 29°07'31" South, Longitude: 56°33'11" West). Thirty-three sows (commercial breeders Fertilis 20 from Généticporc company), weighing 232.1±23.4 kg on average (mean ± residual standard deviation) at 74 days of gestation, were used in a completely randomized experimental design, with 11 replicates per treatment. The deliveries occurred, on average, after 115 days of gestation. Litters from each sow were standardized up to 24 h after birth to an average of 11.3±1.3 piglets, with an average weight of 1.4±0.1 kg, and standardizations were performed using animals of the same treatment. During the gestation period, the environmental temperature ranged between 17.5±2.7 °C and 24.8±3.4 °C, and during lactation, it ranged between 18.5±2.7 °C and 23.1±2.9 °C. The sows were transferred from the gestation room to the maternity room after 107 days of gestation. All sows received the same diet up to 73 days of gestation, with 13.2 MJ kg<sup>-1</sup> of digestible energy (DE), 148 g kg<sup>-1</sup> of crude protein (CP), 52 g kg<sup>-1</sup> of ash, and 43 g kg<sup>-1</sup> of crude fiber (CF). Rations were given in one meal per day at 08.00 h in the following quantities: 2 kg day<sup>-1</sup> from 0 to 7 days and 2.4 kg day<sup>-1</sup> from 8 to 73 days of gestation.

From 74 to 114 days of gestation, sows were subjected to one of the dietary treatments (Table 1). Rations were given in one meal per day at 08.00 h. Diets during gestation were formulated to meet the minimum requirements of daily intake of digestible amino acids, total nitrogen, and energy suggested by NRC (2012). The daily ration intake (Table 1) was adjusted based on the amounts of energy and lysine in the diets, so that sows would consume the same quantity of nutrients per day. To increase the amount of fiber in the diet, rice grain and soybean meal were partially substituted for defatted rice bran (DRB) and soybean hulls (SH). Lactation diet was also formulated in accordance with NRC (2012). In this phase, ration leftovers were collected to determine feed intake of individual sows. Piglets did not receive any supplementary food during the entire lactation period. Water was available *ad libitum* for sows and piglets throughout the experimental period.

The chemical composition of the diets was determined using the techniques described by AOAC (1990), except fiber (total, insoluble, and soluble), which was determined according to the enzymatic method described by Lee et al. (1992) using the enzymes alpha-amylase, glucoamylase, and protease, at 240 KNU-T/g, 300 AGU/mL, and 2.4 AU-A/g, respectively.

From 74 days of gestation, 0.35% of the indicator chromium oxide (Cr<sub>2</sub>O<sub>3</sub>) was included in all the diets, and a partial collection of feces was performed daily from 82 to 87 days of gestation. Feces were analyzed to measure the levels of chromium oxide, ash, CP, ether extract (EE), neutral detergent fiber (NDF), gross energy (GE), and dry matter (DM). To determine the apparent total

Table 1 - Ingredients, chemical composition, and daily intake of gestation and lactation diets of sows

| Item  | Total dietary fiber level (g kg <sup>-1</sup> ) <sup>1</sup> |       |       | Lactation      |
|---|--|-------|-------|----------------|
|   | 156  | 223   | 282   |                |
| <b>Ingredient (g kg<sup>-1</sup>)</b>                       |  |       |       |                |
| Defatted rice bran  | 320  | 348   | 376   | 100            |
| Rice grain  | 570  | 442   | 314   | 611            |
| Blood and bone meal   | 40   | 40    | 40    | 45             |
| Soybean meal  | 42   | 21    | -     | 216            |
| Soybean hulls   | -  | 122   | 244   | -              |
| Limestone   | 12.9   | 11.7  | 10.5  | 5.1            |
| Salt  | 2.2  | 2.3   | 2.4   | 3.55           |
| Rice oil  | 10   | 10    | 10    | 15             |
| Vitamin and mineral premix <sup>2</sup>                     | 2.74   | 2.74  | 2.74  | 3.61           |
| Copper sulfate  | 0.24   | 0.24  | 0.24  | 0.2            |
| <b>Analyzed composition (g kg<sup>-1</sup>)<sup>3</sup></b> |  |       |       |                |
| Crude protein   | 156  | 139   | 129   | 202            |
| Ashes   | 66   | 81    | 96    | 63             |
| Ether extract   | 12.8   | 20.6  | 22.8  | 7.6            |
| Crude fiber   | 33   | 70    | 101   | 21             |
| Neutral detergent fiber                                     | 135  | 196   | 261   | -              |
| Acid detergent fiber  | 40   | 102   | 118   | -              |
| Non-fibrous carbohydrates <sup>4</sup>                      | 631  | 563   | 492   | -              |
| Insoluble food fiber  | 106  | 169   | 207   | -              |
| Soluble food fiber  | 50   | 54    | 75    | -              |
| Total dietary fiber   | 156  | 223   | 282   | -              |
| Dry matter  | 862  | 883   | 877   | 848            |
| Gross energy (MJ kg <sup>-1</sup> )                         | 14.36  | 15.06 | 15.47 | 16.27          |
| Digestible energy (MJ kg <sup>-1</sup> )                    | 12.54  | 12.24 | 11.92 | 14.4           |
| <b>Daily ration intake (kg)</b>                             |  |       |       |                |
| 74 to 90 days of gestation                                  | 2.10   | 2.21  | 2.40  | -              |
| 91 to 111 days of gestation                                 | 2.47   | 2.65  | 2.85  | -              |
| 112 days of gestation                                       | 1.70   | 1.82  | 1.96  | -              |
| 113 days of gestation                                       | 1.00   | 1.07  | 1.15  | -              |
| Day of birth  | 0.500  | 0.540 | 0.580 | -              |
| Lactation period  | -  | -     | -     | No restriction |

<sup>1</sup> Amounts of total dietary fiber level in gestation diets.

<sup>2</sup> Guaranteed levels: vitamin A, 4,750,000 IU/kg; vitamin D3, 950,000 IU/kg; vitamin E, 17,500 IU/kg; vitamin K3, 550 mg/kg; vitamin B1, 1,000 mg/kg; vitamin B2, 3,188 mg/kg; vitamin B6, 1,590.50 mg/kg; vitamin B12, 9,000 mcg/kg; niacin, 14,068 mg/kg; pantothenic acid, 8500 mg/kg; folic acid, 700 mg/kg; biotin, 300 mg/kg; choline chloride, 104.14 g/kg; B.H.T, 250 mg/kg; calcium, 60 g/kg; manganese, 45 g/kg; zinc, 170 g/kg; iron, 80 g/kg; copper, 12 g/kg; iodine, 750 mg/kg; selenium, 300 mg/kg.

<sup>3</sup> As fed.

<sup>4</sup> Calculated as per Weiss (1999).

tract digestibility (ATTD) of the nutrients, the following equation, described by Sun et al. (2014), was used:  $ATTD (\%) = 100 - \{100 \times [(\% \text{ of the indicator in the diet} / \% \text{ of the indicator in the feces}) \times (\% \text{ of the nutrient in the feces} / \% \text{ of the nutrient in the diet})]\}$ .

To determine the level of non-fibrous carbohydrates (NFC) in feed and feces, the following equation described by Weiss (1999) was used:  $NFC (\%) = 100 - CP (\%) - EE (\%) - NDF (\%) - Ash (\%)$ . The GE of feed and feces was determined with a bomb calorimeter. The DE of the feed, during gestation and lactation, was determined using a software that calculated the digestible fraction from the GE and the nutrients contained in the diets (EvaPig, 2014).

Sows were weighed at 107 days of gestation and at days 4, 11, 18, and 25 of lactation. The number and weight of all piglets was assessed at birth including live-born, stillborn, and mummified fetuses. Following standardization, the average daily weight gain (ADWG) of piglets and litters was calculated for the four periods. The total number of births is the sum of live-born, stillborn, and mummified piglets. The regression equation described by Noblet and Etienne (1989) was used to estimate milk production, based on the weight gain of the litter:  $\text{milk production (g/day)} = 2.50 \times \text{daily weight gain of the litter (g/day)} + 80.2 \times \text{litter weight after initial standardization (kg)} + 7$ . Milk production was estimated over four periods: from the day of standardization of the litter to day 4, days 5 to 11, days 12 to 18, and days 19 to 25. The piglets were weaned at 25 days of age.

To determine the interval between weaning and estrus manifestation, a boar was introduced into the pen containing the sows every morning and afternoon. Females that showed a positive behavior of tolerance to the back-pressure test, performed by a person in the presence of the boar, were considered to be in estrus.

Blood was collected at 105 and 112 days of gestation and at 4, 11, 18, and 25 days of lactation. Collections were always performed in the afternoon, starting at 14.00 h, using jugular venipuncture with a  $100 \times 10$  mm needle. Samples were collected using 50-mL Falcon tubes and a 4-mL tube of sodium fluoride to prevent glucose degradation. After collection, the blood samples were kept cool using a thermal box, and after 2 h, the samples were centrifuged for 15 min at 3,000 rotations per minute. After centrifugation, 13.5-mL aliquots of serum were divided among 1.5-mL microcentrifuge tubes using an automatic pipette. Concentrations of the following metabolites or hormones were measured: non-esterified fatty acids (NEFA), insulin, glucose, leptin, cholesterol, total protein, urea, and

albumin. Samples were assayed for leptin and insulin levels immediately. Blood samples were frozen before measuring all the other variables.

The level of serum leptin was determined using an ELISA kit (dbc – Diagnostic Biochem Canada Inc) and the level of serum insulin using an electrochemiluminescence kit (Roche Diagnostics). The NEFA was determined using the Randox commercial kit, and all the other analyses were performed using Bioclin commercial kits. We used the following Bioclin kits: Glucose Monoreagent, K082; Cholesterol Monoreagent, K083; Total Protein Monoreagent, K031; Urea Enzyme, K047; Creatinine, K016; Albumine Monoreagent, K040; Phosphorus, K020; Calcium, K007; and Magnesium, K027. Analyses were conducted using a semi-automated biochemical analysis apparatus (Mindray, model BA-88A). The analyses were performed in duplicate, and the intra-assay coefficient of variation values were 3.8% for glucose, 3.9% for protein, 5.1% for albumin, 3.3% for creatinine, 4.7% for urea, 3.7% for cholesterol, and 4.1% for NEFA. Globulin values were calculated from the difference between the serum values of total protein and albumin.

Data were analyzed using the MIXED procedure of SAS software (Statistical Analysis System, version 9.4), and LSmeans were compared using Fisher's (LSD) test. Fixed effect of fiber level was included in all the models of analysis. When the variables were repeatedly measured (metabolites and hormones, milk production, feed intake during lactation, ADWG of piglets, and litter weight), they were analyzed as repeated measures, and the day of evaluation and its interaction with the fiber level were also included in the models as fixed effects. Linear and quadratic effects of fiber level were also investigated. Some covariates were tested with all variables, but only those that were significant at the 5% probability level were retained in the models. The weight of sows at 74 days gestation was used as a covariate for sow weight at 107 days of gestation and for serum concentrations of protein and globulin. The parity order of the sows was used as a covariate for weight variation during gestation (kg and %), milk production, sow weight, and serum levels of protein, albumin, and globulin during lactation. The number of piglets was used as a covariate for the total weight and ADWG of the litters, and the weight of piglets at standardization was used as a covariate for the weight of the piglets during nursing. The concentrations of NEFA and numbers and percentages of stillborn piglets and mummified fetuses were subjected to non-parametric analysis, and treatments or days of sampling were compared using the Kruskal-Wallis test.

## Results

The ATTD of DM, GE, CP, NFC, organic matter, and DE significantly decreased ( $P < 0.05$ ) with a higher TDF level in the diet (Table 2). The ATTD of EE was not affected by the TDF level. The lowest ATTD of the NDF was observed in the treatment with 223 g kg<sup>-1</sup> of TDF. It can be observed that formulated DE (Table 1) was lower than DE obtained in the experiment (Table 2). This difference might be explained because the defatted rice bran used in the diets had a higher energy than the value defined in NRC (2012).

Variation of TDF in the diets did not affect ( $P > 0.05$ ) the weight or weight variation of sows between 74 and 107 days of gestation (Table 3). There were no differences in the number of total born, live-born, and mummified fetuses with increasing levels of dietary fiber ( $P > 0.05$ ). The weight of litters and mean birth weight of piglets were not affected by the level of TDF in the gestation diet ( $P > 0.05$ ) (Table 3).

There was an increase (quadratic  $P < 0.05$ ) in the concentration of protein and globulin, while cholesterol

showed a linear increase with the increase in TDF (Table 4). Serum concentrations of albumin, urea, glucose, leptin, and insulin were not affected ( $P > 0.05$ ) by the TDF in the diet, but were, in some cases, affected by the day of sampling ( $P < 0.05$ ) (Table 4). The concentrations of NEFA were not affected by the level of TDF in late gestation and at days 18 and 25 of lactation (Figure 1). The concentration of NEFA decreased at 112 days of gestation in sows fed the 282 g kg<sup>-1</sup> diet, but significantly at the third week in sows fed the 156 g kg<sup>-1</sup> TDF during lactation and from the second to fourth weeks in sows fed the 223 g kg<sup>-1</sup> TDF diet (Figure 1).

The other blood metabolites and hormones analyzed during lactation (Table 5) were not affected ( $P > 0.05$ ) by the TDF treatments, but were affected by the day of sampling ( $P < 0.05$ ) in almost all cases.

The weight of sows at weaning (overall 240.3±23.1 kg), change of weight (3.6, 2.0, and -5.4 kg), and the percentage of weight change (1.7, 1.3, and -2.2%) during lactation were not influenced ( $P > 0.05$ ) by the TDF level of diets (156 g kg<sup>-1</sup>, 223 g kg<sup>-1</sup>, and 282 g kg<sup>-1</sup>, respectively). The weaning-to-estrus interval was 4.6±1.4 days, with no difference ( $P > 0.05$ ) among the TDF levels. The amount of TDF in gestation diet

Table 2 - Effect of the amount of total dietary fiber in the diet of sows (74 to 114 days of gestation) on the apparent digestibility coefficients (g kg<sup>-1</sup>) and digestible energy (LSmeans)

| Variable                                 | Total dietary fiber level (g kg <sup>-1</sup> ) |       |       | SEM   | P-value |         |         |
|--|---|-------|-------|-------|---------|---------|---------|
|  | 156   | 223   | 282   |       | Diets   | L       | Q       |
| Dry matter                               | 859a  | 732b  | 684c  | 4.95  | <0.0001 | <0.0001 | <0.0001 |
| Gross energy                             | 887a  | 782b  | 725c  | 4.95  | <0.0001 | <0.0001 | 0.0003  |
| Crude protein                            | 890a  | 742b  | 635c  | 8.15  | <0.0001 | <0.0001 | 0.05    |
| Ether extract                            | 630   | 648   | 655   | 39.56 | 0.90    | 0.66    | 0.92    |
| Neutral detergent fiber                  | 694a  | 599c  | 636b  | 58.00 | <0.0001 | 0.003   | <0.0001 |
| Non-fibrous carbohydrates                | 978a  | 949b  | 917c  | 55.32 | <0.0001 | <0.0001 | 0.91    |
| Organic matter                           | 907a  | 813b  | 763c  | 41.85 | <0.0001 | <0.0001 | 0.0001  |
| Digestible energy (MJ kg <sup>-1</sup> ) | 14.8a   | 13.3b | 12.8c | 0.09  | <0.0001 | <0.0001 | 0.0002  |

LSmeans - least square means; SEM - standard error of mean; L and Q - linear and quadratic response, respectively, for the fiber level. Values in the row with different letters differ significantly at  $P < 0.05$ , after analysis of variance and comparison using the LSD test.

Table 3 - Effect of the amount of total dietary fiber in the diet of sows (74 to 114 days of gestation) on body weight and weight variation of sows during gestation and performance of the piglets at birth (LSmeans)

| Variable                     | Total dietary fiber level (g kg <sup>-1</sup> ) |       |       | SEM  | P-value |      |      |
|------------------------------|---|-------|-------|------|---------|------|------|
|                              | 156   | 223   | 282   |      | Diets   | L    | Q    |
| <b>Sows</b>                  |   |       |       |      |         |      |      |
| Weight at 107 days (kg)      | 244.2   | 245.7 | 248.0 | 7.14 | 0.49    | 0.24 | 0.88 |
| Weight gain 74-107 days (kg) | 12.4  | 13.5  | 15.8  | 2.05 | 0.50    | 0.25 | 0.81 |
| Weight gain 74-107 days (%)  | 5.5   | 5.8   | 7.0   | 0.87 | 0.43    | 0.22 | 0.68 |
| <b>Piglets</b>               |   |       |       |      |         |      |      |
| Total born                   | 13.7  | 13.2  | 12.5  | 1.43 | 0.82    | 0.54 | 0.94 |
| Live-born                    | 13.0  | 12.8  | 12.0  | 1.30 | 0.84    | 0.58 | 0.84 |
| Stillborn <sup>1</sup>       | 0.6   | 0.2   | 0.2   | 0.25 | 0.51    | -    | -    |
| Stillborn (%) <sup>1</sup>   | 4.2   | 1.0   | 1.1   | 1.38 | 0.42    | -    | -    |
| Mummified <sup>1</sup>       | 0.1   | 0.2   | 0.3   | 0.13 | 0.48    | -    | -    |
| Mummified (%) <sup>1</sup>   | 0.5   | 1.5   | 2.0   | 0.88 | 0.46    | -    | -    |
| Piglet weight (kg)           | 1.37  | 1.41  | 1.44  | 0.09 | 0.87    | 0.59 | 0.98 |
| Litter weight (kg)           | 17.5  | 17.2  | 16.1  | 1.26 | 0.68    | 0.41 | 0.78 |

LSmeans - least square means; L and Q - linear and quadratic response, respectively, for the fiber level; SEM - standard error of mean.

<sup>1</sup> Non-parametric analysis and diets compared using the Kruskal-Wallis test.

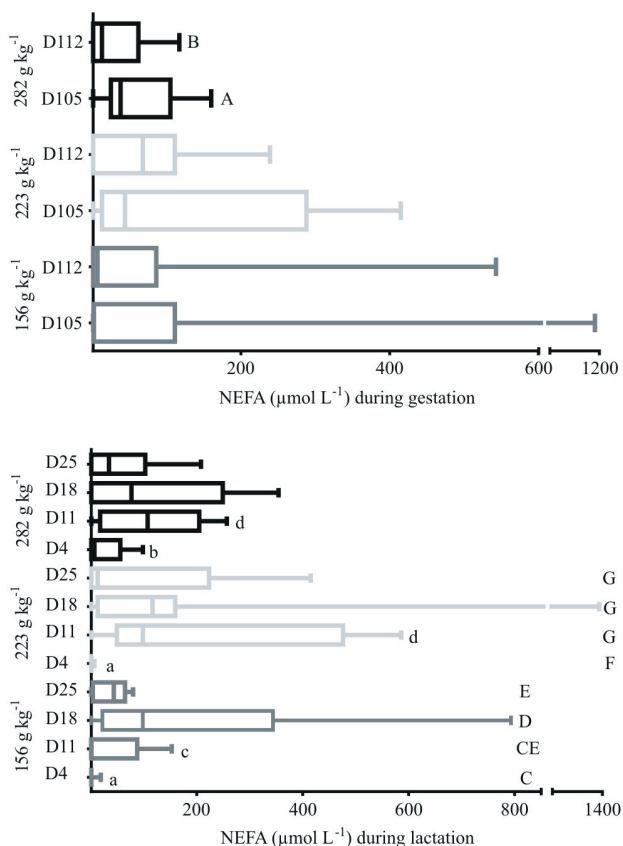
did not affect ( $P>0.05$ ) the average daily feed intake of sows and the weight of the litter (Table 6). The ADWG of the litter and piglets showed a linear increase ( $P<0.05$ ) with the increase in the TDF of the diet (Table 6). The

significant interaction ( $P<0.05$ ) between the treatment and day of evaluation was noted on the weight of piglets and milk production of sows (Figure 2). At 11 and 18 days of lactation, the piglets born from sows that received diets

Table 4 - Effect of the amount of total dietary fiber in the diet of sows (74 to 114 days of gestation) on blood and hormonal metabolites at 105 and 112 days of gestation (LSmeans)

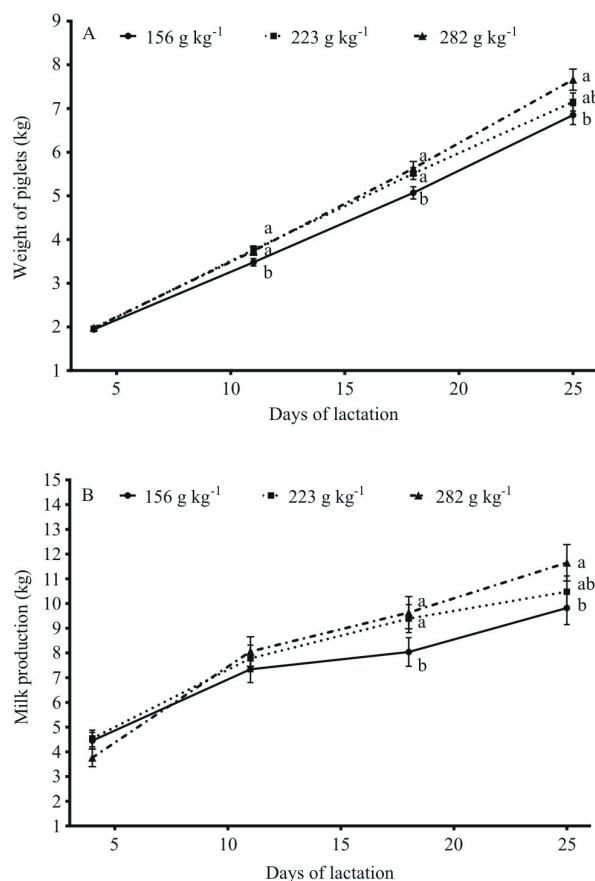
| Variable                             | Total dietary fiber level ( $\text{g kg}^{-1}$ ) |       |       | SEM  | Day of gestation |       |       | SEM  | P-value |       |       |  |
|--------------------------------------|--|-------|-------|------|------------------|-------|-------|------|---------|-------|-------|--|
|                                      | 156  | 223   | 282   |      | 105              | 112   | Diets |      | Day     | L     | Q     |  |
| Protein ( $\text{g L}^{-1}$ )        | 61.1b  | 64.0a | 60.1b | 1.01 | 62.1             | 61.5  | 0.72  | 0.03 | 0.34    | 0.48  | 0.009 |  |
| Albumin ( $\text{g L}^{-1}$ )        | 31.1   | 31.7  | 33.2  | 0.73 | 31.2b            | 32.8a | 0.55  | 0.12 | 0.03    | 0.05  | 0.63  |  |
| Globulin ( $\text{g L}^{-1}$ )       | 30.0ab   | 32.3a | 26.9b | 1.34 | 30.8a            | 28.7b | 0.84  | 0.03 | 0.003   | 0.11  | 0.03  |  |
| Urea ( $\text{mmol L}^{-1}$ )        | 4.5  | 4.6   | 4.5   | 0.12 | 4.4              | 4.7   | 0.10  | 0.69 | 0.07    | 0.82  | 0.41  |  |
| Glucose ( $\text{mmol L}^{-1}$ )     | 3.9  | 4.1   | 4.0   | 0.12 | 3.9              | 4.1   | 0.11  | 0.70 | 0.17    | 0.79  | 0.42  |  |
| Cholesterol ( $\text{mmol L}^{-1}$ ) | 1.6b   | 1.7b  | 1.9a  | 0.07 | 1.7              | 1.7   | 0.05  | 0.01 | 0.16    | 0.005 | 0.57  |  |
| Leptin ( $\text{ng mL}^{-1}$ )       | 1.0  | 0.8   | 1.0   | 0.10 | 1.1a             | 0.7b  | 0.09  | 0.46 | 0.001   | 0.78  | 0.23  |  |
| Insulin ( $\mu\text{U mL}^{-1}$ )    | 0.7  | 0.7   | 0.5   | 0.11 | 0.5b             | 0.8a  | 0.13  | 0.34 | 0.01    | 0.22  | 0.44  |  |

LSmeans - least square means; SEM - standard error of mean; L and Q - linear and quadratic response, respectively, for the fiber level. Values in the row, within fiber level of day, with different letters differ significantly at  $P<0.05$ , after analysis of variance and comparison using the LSD test. The interaction between fiber level and day of evaluation was not significant ( $P>0.05$ ).



NEFA - non-esterified fatty acids. From the left to the right, the minimum, 25% percentile, median, 75% percentile, and maximum values are represented in each box. Data were subjected to non-parametric analysis, and comparisons were performed using the Kruskal-Wallis test. a-b and c-d - Effect of diet on days 4 and 11, respectively ( $P<0.05$ ). A-B, C-E, and F-G - Effect of sampling day within 282, 156, and 223  $\text{g kg}^{-1}$  diets, respectively ( $P<0.05$ ).

Figure 1 - Concentrations of NEFA in late gestation (days 105 and 112) and during lactation (days 4, 11, 18, and 25) of sows fed gestation diets containing different levels of total dietary fiber (156, 223, or 282  $\text{g kg}^{-1}$ ).



There was a treatment  $\times$  day interaction ( $P<0.05$ ) for both variables. Lowercase letters, in the vertical, indicate differences (Panel A;  $P<0.05$ ) or tendency for difference (Panel B;  $P<0.10$ ) between the treatments on different days ( $P<0.05$ ).

Figure 2 - Average weight of piglets (A) and milk production of sows (B) according to the amount of total dietary fiber in the diet of sows during gestation (156, 223, and 282  $\text{g kg}^{-1}$ ).

with 223 g kg<sup>-1</sup> and 282 g kg<sup>-1</sup> of TDF during gestation showed an average weight greater ( $P < 0.05$ ) than those born from sows fed 156 g kg<sup>-1</sup> of TDF. At 25 days, the piglets of sows that received the diet with 282 g kg<sup>-1</sup> of TDF still remained heavier ( $P < 0.05$ ) than those from sows receiving 156 g kg<sup>-1</sup> of TDF (Figure 2A). At 18 days of lactation, sows fed 282 g kg<sup>-1</sup> and 223 g kg<sup>-1</sup> TDF tended ( $P < 0.10$ ) to have higher milk production than sows fed 156 g kg<sup>-1</sup> TDF (Figure 2). The sows fed 282 g kg<sup>-1</sup> TDF diet tended ( $P = 0.07$ ) to produce more milk than those fed 156 g kg<sup>-1</sup> TDF at 25 days of lactation (Figure 2B).

## Discussion

This study aimed to meet the nutritional requirements of sows, despite the variation in diet composition. The daily energy intake from 74 to 90 days of gestation was 26.8, 26.0, and 26.9 MJ kg<sup>-1</sup> of DE and 327, 306, and 308 g of CP, for the 156, 223, and 282 g kg<sup>-1</sup> TDF treatments, respectively. From 91 to 111 days of gestation, intake was 31.5, 31.2, and 32.0 MJ kg<sup>-1</sup> of DE and 385, 367, and 366 g of CP. Although many positive results have been observed with up to 110 g kg<sup>-1</sup> CF added to the feed (Quesnel et al., 2009; Veum

et al., 2009), amounts of CF over 130 g kg<sup>-1</sup> may reduce sow weight gain during gestation and the weight of piglets at birth (Gentilini et al., 2004). This occurs especially if the voluntary feed intake of sows is affected, as observed by van der Peet-Schwering et al. (2003) and Danielsen and Vestergaard (2001) in studies with diets containing 300 g kg<sup>-1</sup> of non-starch polysaccharides (NSP) and 446 g kg<sup>-1</sup> of total dietary fiber, respectively. Gentilini et al. (2004) evaluated a diet containing 350 g kg<sup>-1</sup> soybean hulls (131 g kg<sup>-1</sup> of CF in the diet), and even though the energy intake was not affected by CF level, the females that consumed less fiber (45 g kg<sup>-1</sup> of CF) weighed more at 110 days of gestation. In other studies (Holt et al., 2006; Darroch et al., 2008), sows also gained less weight during gestation when they received high-fiber diets. The reduced weight gain can be attributed to the increased rate of feed passage through the gastrointestinal tract (Jorgensen et al., 1996; Lattimer and Haub, 2010), which lowers the ATTD of nutrients and energy from the diet. In the present study, gestating sows consumed all the ration offered, showing that 282 g kg<sup>-1</sup> of TDF, corresponding to 101 g kg<sup>-1</sup> CF (376 g kg<sup>-1</sup> of defatted rice bran and 244 g kg<sup>-1</sup> of soybean hulls) did not limit the voluntary intake and, despite lowering the ATTD

Table 5 - Effect of the amount of total dietary fiber in the diet of sows (74 to 114 days of gestation) on blood and hormonal metabolites at 4, 11, 18, and 25 days of lactation (LSmeans)

| Variable                            | Total dietary fiber level (g kg <sup>-1</sup> ) |      |      | SEM  | Day of lactation |        |        |        | SEM  | P-value |         |      |      |
|-------------------------------------|---|------|------|------|------------------|--------|--------|--------|------|---------|---------|------|------|
|                                     | 156   | 223  | 282  |      | 4                | 11     | 18     | 25     |      | Diets   | Day     | L    | Q    |
| Protein (g L <sup>-1</sup> )        | 65.2  | 66.0 | 63.9 | 1.12 | 63.5b            | 64.9ab | 65.6a  | 66.2a  | 0.88 | 0.38    | 0.05    | 0.41 | 0.24 |
| Albumin (g L <sup>-1</sup> )        | 29.8  | 29.9 | 29.0 | 0.81 | 31.1a            | 28.4b  | 28.9bc | 29.9ac | 0.58 | 0.68    | <0.0001 | 0.46 | 0.59 |
| Globulin (g L <sup>-1</sup> )       | 35.4  | 36.1 | 34.7 | 1.51 | 32.4b            | 36.4a  | 36.8a  | 36.2a  | 1.12 | 0.79    | <0.0001 | 0.74 | 0.54 |
| Urea (mmol L <sup>-1</sup> )        | 7.85  | 7.90 | 7.92 | 0.29 | 6.99c            | 8.01b  | 8.07ab | 8.49a  | 0.21 | 0.98    | <0.0001 | 0.86 | 0.96 |
| Glucose (mmol L <sup>-1</sup> )     | 4.66  | 4.60 | 4.57 | 0.14 | 4.54             | 4.55   | 4.70   | 4.64   | 0.14 | 0.88    | 0.75    | 0.65 | 0.86 |
| Cholesterol (mmol L <sup>-1</sup> ) | 2.19  | 2.19 | 2.20 | 0.08 | 2.14b            | 2.16b  | 2.08b  | 2.39a  | 0.06 | 0.99    | <0.0001 | 0.97 | 0.92 |
| Leptin (ng mL <sup>-1</sup> )       | 1.23  | 1.27 | 1.04 | 0.14 | 1.14a            | 1.23a  | 1.65a  | 0.70b  | 0.12 | 0.44    | <0.0001 | 0.30 | 0.39 |
| Insulin (μU mL <sup>-1</sup> )      | 4.42  | 4.04 | 2.98 | 0.69 | 4.43             | 3.90   | 3.36   | 3.56   | 0.60 | 0.30    | 0.59    | 0.13 | 0.65 |

LSmeans - least square means; SEM - standard error of mean; L and Q - linear and quadratic response, respectively, for the fiber level.

Values in the row, within fiber level of day, with different letters differ significantly at  $P < 0.05$ , after analysis of variance and comparison using the LSD test.

The interaction between fiber level and day of evaluation was not significant ( $P > 0.05$ ).

Table 6 - Effect of the amount of total dietary fiber in the diet of sows (74 to 114 days of gestation) on average daily feed intake (ADFI) of sows and performance of piglets during lactation (LSmeans)

| Variable    | Total dietary fiber level (g kg <sup>-1</sup> ) |       |      | SEM  | Day of lactation |       |       |       | SEM  | P-value |         |      |      |
|-------------|---|-------|------|------|------------------|-------|-------|-------|------|---------|---------|------|------|
|             | 156   | 223   | 282  |      | 4                | 11    | 18    | 25    |      | Diets   | Day     | L    | Q    |
| Sows        |   |       |      |      |                  |       |       |       |      |         |         |      |      |
| ADFI (kg)   | 7.2   | 7.2   | 7.4  | 0.23 | 5.7d             | 7.3c  | 7.8b  | 8.2a  | 0.18 | 0.79    | <0.0001 | 0.52 | 0.78 |
| Litter      |   |       |      |      |                  |       |       |       |      |         |         |      |      |
| Weight (kg) | 44.3  | 47.8  | 48.1 | 1.93 | 20.8d            | 38.2c | 55.1b | 72.8a | 1.10 | 0.24    | <0.0001 | 0.14 | 0.45 |
| ADWG (kg)   | 1.9b  | 2.2a  | 2.3a | 0.10 | 1.1b             | 2.4a  | 2.4a  | 2.6a  | 0.09 | 0.03    | <0.0001 | 0.02 | 0.36 |
| Piglets     |   |       |      |      |                  |       |       |       |      |         |         |      |      |
| ADWG (g)    | 207b  | 217ab | 238a | 8.79 | 132b             | 243a  | 248a  | 260a  | 8.09 | 0.04    | <0.0001 | 0.02 | 0.61 |

LSmeans - least square means; SEM - standard error of mean; L and Q - linear and quadratic response, respectively, for the fiber level; ADWG - average daily weight gain.

Values in the row, within fiber level of day, with different letters differ significantly at  $P < 0.05$ , after analysis of variance and comparison using the LSD test.

The interaction between fiber level and day of evaluation was not significant ( $P > 0.05$ ).

of nutrients and energy, did not affect the weight gain of gestating sows.

As the levels of dietary fiber increased, a corresponding decrease in DE and ATTD of DM, GE, CP, NFC, and OM was observed, agreeing with results of Le Gall et al. (2009). The greater amount of fiber in the diet leads to important physiological changes, such as an increased viscosity of the diet (NSP in wheat) (Kim et al., 2005), but insoluble fiber, on the other hand, reduces time for the passage of chyme (Jorgensen et al., 1996; Lattimer and Haub, 2010), which decreases the fermentation time in the large intestine (Wilfart et al., 2007).

The greater quantity of fiber in the gestation diet might indirectly increase the energy available to the fetuses (Lee and Close, 1987) by improving the welfare of females and reducing the stereotypical behaviors and physical movement of the sows (Ramonet et al., 1999; Gentilini et al., 2003), which would explain the higher weight of piglets at birth (Veum et al., 2009). However, this response was not observed in the present study (Table 2). Ramonet et al. (2000) suggested that the greater energy availability that results from the lower physical activity of the females is lost, as part of the energy is converted into heat by the fermentation of the fiber. Thus, the weight of the piglets may not be affected by the amounts of fiber in the diet of gestating sows. Similarly, the number of live-born and stillborn piglets was not affected by the diet treatments, which is in agreement with other studies in which higher quantities of fiber were provided only during gestation (Gentilini et al., 2004; Renteria-Flores et al., 2008; Quesnel et al., 2009). In contrast to these results, van der Peet-Schwering et al. (2003) observed an increase of 0.5 piglets at birth, for the first cycle, and 0.7 piglets at birth, for the second cycle, in females that consumed NSP-rich diets. However, the authors attributed this improvement to greater embryonic survival, given that the NSP-rich diets were provided before confinement for gestation.

Several factors can apparently influence hematologic metabolites (Klem et al., 2010) including the level of crude protein of diet (Toledo et al., 2014). However, as the daily intake of CP was similar, there is currently no obvious explanation for the increase in protein and globulins in the diet with 223 g kg<sup>-1</sup> of TDF during gestation. In human species, serum cholesterol reduces with an increase in fiber consumption (Martensson et al., 2005), contrasting the increased cholesterol observed in sows that received diet with 282 g kg<sup>-1</sup> of TDF. The experimental diets presented increasing levels of EE as the fiber increased, and the difference in fat intake may have influenced the cholesterol level.

A higher amount of fiber in the diet increases glucose (Quesnel et al., 2009) and insulin (Quesnel et al., 2009;

Loisel et al., 2013) levels in the blood of gestating sows. However, this variation was observed up to 60 and 75 min after feeding for glucose and insulin, respectively. Probably, the influence of fiber in slowing glucose absorption (Lattimer and Haub, 2010), hence altering blood insulin and glucose levels, was more noticeable soon after intake. In this study, blood samples were collected at 6 h after intake of the experimental rations, and no effect was observed on either glucose or insulin levels.

The increased concentrations of urea observed as lactation progressed, irrespective of the CF level of gestation diet, may be partly explained by the increased catabolism of endogenous proteins due to the higher demands for milk production (Quesnel et al., 2009). The NEFA concentration has been used as an indicator of the energy status and fat catabolism of sows (Rojkittikhun et al., 1993; Valros et al., 2003). Serum concentrations of NEFA were not affected by the level of CF in gestation diet, at 18 and 25 days of lactation, as reported in other studies (Quesnel et al., 2009; Loisel et al., 2013). Although a significant increase in concentrations of NEFA as the lactation progressed was not observed for all the diets in the present study, it is common for NEFA to increase around the third week of lactation (Valros et al., 2003; Quesnel et al., 2009), due to the higher mobilization of lipids from fatty tissue to fulfill the demand for milk production (Valros et al., 2003). Nevertheless, the concentration of NEFA not always increases as lactation progresses; it can be low at 14 days of lactation if sows have high fat reserves in late gestation or if they lose less weight during lactation (Hultén et al., 1993). Furthermore, the large variation in NEFA concentration observed between individuals, irrespective of the diet consumed, makes its interpretation difficult, as already pointed out by Verheyen et al. (2007), who considered that only major changes may have a significant influence on the health status of animals. Although litter weight gain has been positively affected by NEFA concentration (Valros et al., 2003), piglet growth is not always related to higher mobilization of body reserves because Quesnel et al. (2009) reported that sows fed high-fiber diet mobilized similar body reserves and had similar NEFA concentrations to those fed the low-fiber diet, despite having piglets with increased growth rate.

Leptin is a hormone secreted by the adipose tissue and its release is negatively correlated with feed intake (Barb, 1999). Quesnel et al. (2009) verified that females that consumed a diet with more fiber presented a lower concentration of leptin in the blood at the end of gestation and greater ration intake during lactation. However, these responses were not observed in the present study.

In the present study, weight gain during gestation and leptin levels were not affected by the TDF level of gestation diet, thus reducing the expectation that a higher feed intake would occur during lactation. Higher feed intake during lactation can increase the weight gain of piglets as it was already reported for sows fed high-fiber diets during gestation (Veum et al., 2009; Quesnel et al., 2009). In the present study, however, there was only a numerical difference in feed intake in favor of sows fed 282 g kg<sup>-1</sup> compared with 156 g kg<sup>-1</sup> TDF. Despite that, milk production tended to be higher in sows fed 282 g kg<sup>-1</sup> TDF compared with those fed 156 g kg<sup>-1</sup> TDF, at 18 and 25 days of lactation, probably explaining the improved growth performance of piglets from the sows fed the high-fiber diet. Darroch et al. (2008) and Gentilini et al. (2004) observed that females receiving diets with 200 and 350 g kg<sup>-1</sup> of soybean hulls during gestation consumed 200 and 310 g more ration per day, respectively, during lactation. The increased feed intake during lactation could result from the increased extension and length of the gastrointestinal tract due to the high-fiber diet intake, as observed in young pigs (Jorgensen et al., 1996). Renteria-Flores et al. (2008) discussed the possibility that the higher feed intake during lactation elicited by soybean hulls could be related to the reduced energy intake and the lower weight gain during gestation. Also, high-fiber diets can reduce leptin levels before farrowing, which can be responsible for the increased feed intake during lactation (Quesnel et al., 2009).

### Conclusions

Even with a reduction in the apparent total tract digestibility of nutrients and energy, the 282 g kg<sup>-1</sup> of total dietary fiber diet may be used during gestation (376 g kg<sup>-1</sup> of defatted rice bran and 244 g kg<sup>-1</sup> of soybean hulls), as it does not impair the performance of sows during gestation and lactation or the birth weight of piglets. A greater total dietary fiber in the gestation diet improves the weight gain of piglets until weaning, even when there are no statistical differences in feed intake during lactation among sows fed different total dietary fiber levels during gestation.

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