Soybean meal particle size for pigs during the nursery phase

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ABSTRACT: This study evaluated the effect of soybean meal (SBM) particle size on nutrient digestibility and the growth performance of nursery piglets. Sixty-three piglets (BW = 6.86 kg ± 0.56; 23 d of age) were distributed in a randomized block design (by initial weight and sex) with 3 dietary treatments: diets with 1,017 µm (unground); 585 µm; and 411µm SBM, with 7 replicates of 3 piglets each. All diets were offered ad libitum in mash form, formulated differently according to three growing phases: (1) with 20% of SBM, from 23 to 32 d of age; (2) with 25% of SBM, from 32 to 44 d of age, and (3) with 30% of SBM, from 44 to 63 d of age. For the first 21 d, pigs fed diets with a medium particle size of SBM (585µm) had better average weight gain and feed/gain ratio (P<0.05). The average feed intake, average body weight gain, and feed/gain ratio from 44 to 63 d improved (P<0.05) with increasing SBM particle sizes, and the average live weight for the overall period increased with coarser SBM (P<0.05). There was a marginally improvement (P < 0.1) on digestible energy as particle size of SBM decreased; although, no differences (P > 0.05) in the coefficients of apparent digestibility of dry matter and crude protein for the assessed SBM particle sizes were observed. It was concluded that the grinding of dietary SBM is not required for piglets during the nursery phase.

Key words: particle size, growth performance, digestibility, Glycine max, piglets.

INTRODUCTION

Soybean meal (Glycine max; SBM) is the most widely utilized source of protein in pig diets because of its high-quality protein and relatively high concentrations of highly digestible limiting amino acids (lysine, threonine and tryptophan), compared to other plant ingredients; SBM also has high energy and low fiber contents. However, to be obtained and safely used in animal feeding and nutrition, the soybeans must undergo several processes, such as the use of solvents, different thermal treatments (e.g., toasting and extrusion), or recently developed enzymatic and fermentative treatments, in order to reduce the concentrations of oligosaccharides, trypsin inhibitors, and other antinutritional factors and mitigate their effects (STEIN et al., 2013).

Reducing the particle size (grinding) of the ingredients modifies their structure (ROJAS & STEIN, 2017), and is a commonly used option to...
maximize the availability of dietary nutrients, which is associated with an increase in digestibility of some dietary fractions and improves the feed efficiency in pigs (LANCHEROS et al., 2020). Feeding costs can be reduced; in addition, grinding facilitates further processing of the diets, such as the capacity/uniformity of mixing, transportation, pelleting, extrusion, and expansion (LUNDBLAD et al., 2011). Moreover, the use of diets with coarser particles (e.g., 23.8% of particles > 1000 µm or medium size > 700 µm) has been associated with improved intestinal health and broader microbial diversity in the gastrointestinal tract of pigs, providing an additional barrier against potentially harmful anaerobic bacteria (KIARIE & LAWRENCE, 2003; ALMEIDA et al., 2021). Therefore, selecting the ideal particle size will depend not only on the animal’s response, but also on the productive capacity of feed mills, as altering the particle size of ingredients and diets will affect the production rate (BAO et al., 2016).

Information on how SBM particle size affects piglets in the nursery phase is limited, despite SBM forming a large part of their diets. Based on these considerations, the objective of this study was to assess the effect of unground SBM or ground SBM with different particle sizes on nutrient digestibility and the growth performance of nursery piglets.

**MATERIALS AND METHODS**

This study included 42 barrows and 21 females piglets of commercial lineage (PIC®, Hendersonville, TN, USA), with a mean initial weight of 6.86 kg ± 0.56 and 23 d of age. They were housed in 2.8 m² pens with partially slatted flooring (approximately 65%) and supplied with a trough feeder, an automatic nipple drinker, and a brooder. Each pen contained three pigs of the same sex, resulting in five pens with males and two pens with females per treatment. Room temperature was initially set to 32 ºC at weaning and was reduced weekly to meet the comfort level of the piglets.

The piglets’ growth performance and nutrient digestibility during the nursery phase can be influenced by both the choice of ingredients used to reduce dietary particle size and the age of the animals (HEALY et al., 1994; ALBAR et al., 2000; LAWRENCE et al., 2003; ALMEIDA et al., 2021). Therefore, selecting the ideal particle size will depend not only on the animal’s response, but also on the productive capacity of feed mills, as altering the particle size of ingredients and diets will affect the production rate (BAO et al., 2016).

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The piglets were weighed individually at 23, 32, 44, and 63 days of age to evaluate their average body weight (BW) and average daily weight gain (DWG). Both the feed supplied and the leftovers were weighed to determine the average daily feed intake (DFI) and feed/gain ratio (F/G). Daily partial feces collection was conducted from 49 to 53 d of age, and the material was frozen until used. The fecal samples were thawed, homogenized, and dried in a forced-ventilation oven at 55 ºC until a constant weight was achieved. After drying, feces and feed samples were ground to 1 mm and analyzed for dry matter (DM) and crude protein (CP, method 954.01) according to the AOAC (1995). Gross energy (GE) levels were determined using a calorimetric bomb (Ika Werke C2000 Control Oxygen Bomb Calorimeter; Ika-Werke GmbH & Co, Staufen, Germany). Acid insoluble ash (AIA) was added to the initial diets and used as an insoluble marker compound to calculate the digestibility coefficients, and AIA content in feed and feces samples was determined using the adapted gravimetric method proposed by VAN KEULEN & YOUNG (1977).

The apparent digestibility coefficient (ADC) of nutrients was calculated using the following formula:

$$\text{ADC} = \frac{\text{Intake} - \text{Output}}{\text{Intake}}$$
ADC = \[\text{dietary nutrient} - (\text{feces nutrient} \times \text{IF})\]/\text{dietary nutrient}

where IF is the indigestibility factor, calculated as the ratio between AIA levels of diet and feces. The digestible energy (DE) was calculated using the following formula:

DE = GE of diet − (GE of fecal content × IF).

The data were analyzed as a randomized block design; the block (initial weight and gender) was considered a random effect and the pen was an experimental unit, with three treatments (SBM particle size) and seven replicates (five male and two female) of three pigs each. Orthogonal contrasts adjusted for unequal spacing between treatments (SBM particle size) were constructed to evaluate the linear and quadratic effects of reducing SBM particle size on performance and digestibility variables. All results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 \leq P \leq 0.1$. All statistical procedures were performed using the Linear Mixed-Effects Models package (BATES et al., 2015) in R (R CORE TEAM, 2018).

**Table 1 - Ingredients and calculated nutrient content of the diet (as-fed basis, g/kg).**

| Ingredients | Phase 1 | Phase 2 | Phase 3 |
|-------------|---------|---------|---------|
| Corn        | 385.00  | 490.00  | 634.00  |
| Soybean meal| 200.00  | 250.00  | 300.00  |
| Soybean oil | 15.00   | 10.00   | 15.00   |
| Basic mixture| 400.00$^1$ | 250.00$^2$ | 50.00$^3$ |
| Celite$^4$  | -       | -       | 1.0     |

**Calculated Composition**

| Metabolizable energy, Mcal/kg | 3.48 | 3.44 | 3.26 |
|-----------------------------|------|------|------|
| Lactose                     | 100.00 | 21.50 | -    |
| Crude protein               | 200.6 | 195.34 | 188.8 |
| Ether extract               | 37.01 | 33.66 | 42.55 |
| Crude Fiber                 | 23.11 | 29.16 | 34.76 |
| Lysine                      | 15.39 | 14.66 | 12.51 |
| Methionine                  | 5.69  | 5.63  | 3.45  |
| Methionine + cysteine       | 9.54  | 8.69  | 6.63  |
| Total calcium               | 6.99  | 7.45  | 8.69  |
| Total phosphorus            | 6.73  | 5.22  | 4.66  |
| Sodium                      | 3.09  | 2.28  | 2.24  |

$^1$Main ingredients: pregelatinized maize, dried whey, whole milk powder, soy protein concentrate, sugar, calcium formate, dicalcium phosphate, vanilla flavor, aspartame, dried blood plasma, spray-dried porcine blood, sodium chloride, lysine, methionine, tryptophan, and threonine. Provided per kilogram of diet: Fe, 57.3 mg; Cu, 8 mg; Mn, 25.48 mg; Zn, 475 mg; I, 0.496 mg; Se, 0.248 mg; vitamin A, 9,900 IU; vitamin D3, 1,980 IU; vitamin E, 49.88 IU; vitamin K3, 2.56 mg; vitamin B1, 1.96 mg; vitamin B2, 5 mg; vitamin B6, 3.96 mg; vitamin B12, 30 mcg; niacin, 40 mg; pantothenic acid, 19.6 mg; folic acid, 1.48 mg; biotin, 0.1 mg.

$^2$Main ingredients: soy protein concentrate, dried whey, pregelatinized maize, palm oil, dicalcium phosphate, calcitic limestone, vanilla flavor, aspartame, sugar, sodium chloride, lysine, methionine, tryptophan, and threonine. Provided per kilogram of diet: Fe, 68.5 mg; Cu, 8.12 mg; Mn, 28.27 mg; Zn, 1800 mg; I, 0.3 mg; Se, 0.25 mg; vitamin A, 9,900 IU; vitamin D3, 1,980 IU; vitamin E, 49.87 IU; vitamin K3, 2.55 mg; vitamin B1, 1.96 mg; vitamin B2, 5 mg; vitamin B6, 3.97 mg; vitamin B12, 30 mcg; niacin, 40.22 mg; pantothenic acid, 19.6 mg; folic acid, 1.5 mg; biotin, 0.1 mg.

$^3$Main ingredients: sodium chloride, sugar, dicalcium phosphate, calcitic limestone, vanilla flavor, aspartame, lysine, and methionine. Provided per kilogram of diet: Fe, 40.5 mg; Cu, 170 mg; Mn, 25.5 mg; Zn, 100 mg; I, 0.5 mg; Se, 0.25 mg; vitamin A, 6,000 IU; vitamin D3, 1,100 IU; vitamin E, 30 IU; vitamin K3, 1 mg; vitamin B1, 0.75 mg; vitamin B2, 4 mg; vitamin B6, 2 mg; vitamin B12, 30 mcg; niacin, 18 mg; pantothenic acid, 11 mg; folic acid, 1 mg; biotin, 0.15 mg.

$^4$Insoluble marker (Celite Hyflo; Imerys, Arica, Chile).

Ciência Rural, v.52, n.10, 2022.
Figure 1 - Particle size distribution of the complete diet, expressed as a percentage of the total sample, according to the soybean meal particle size in growth phases 1 (A), 2 (B) and 3 (C).
RESULTS AND DISCUSSION

During phase 1 (23 to 32 d of age), reducing SBM particle size from 1,017 to 411 µm did not affect (P > 0.05) DFI or BW (Table 3). However, as the SBM particle size increased it marginally increased DWG (linear, P < 0.1) and improved F/G (linear, P < 0.05). During the post-weaning period, piglets undergo radical social, environmental, and nutritional changes, usually leading to low voluntary feed intake and, consequently, morphological, enzymatic, and inflammatory alterations. It is possible to observe atrophy of the intestinal villi, followed by other issues such as hyperplasia of the crypts, increases in the permeability of the mucous membrane, difficulty with pH balance, and reduced enzymatic activity of pepsin, trypsin, carboxypeptidases A and B, chymotrypsin, amylase, and lipase (HEDEMANN & JENSEN, 2004; MONTAGNE et al., 2007; BARSZCZ & SKOMIAŁ, 2011; MODINA et al., 2019). Even though the difference in average particle size of the complete diet of phase 1 was small only 37 µm - it influenced the piglet’s consumption and, consequently, their digestive and absorption capacity could have been depressed.

In the next phase (32 to 44 d of age), a quadratic response was observed (P < 0.05) for DFI, DWG, and F/G as the best results were obtained with piglets fed diets with the medium (585 µm) SBM particle size (Table 3). In a similar age period, LAWRENCE et al. (2003) did not detect any difference in performance variables between pigs fed diets containing 444 to 1,226 µm SBM. According to the authors, SBM had little effect on the average diet particle size (maximum difference of 103 µm between diets) due to its low dietary inclusion. In the present study, the distinct SBM particle sizes led to a difference of 195 µm between phase 2 diets, and both the coarser and finer SBM negatively affected performance. Other studies assessed different ingredients to change dietary particle size for pigs: HEALY et al. (1994) reported a linear reduction on DFI and DWG when corn and sorghum particle sizes were reduced from 900 to 300 µm; MAVROMICHALIS et al. (2000) observed lower DFI when wheat particle size was reduced from 1300 to 400 µm; ALMEIDA et al. (2021) reported a quadratic response on F/G when the particle size of the whole diet was varied between 394 to 695 µm, as the best results were obtained with 534 µm. According to the current study, when looking at the overall pre-initial period (Phase 1 + 2; 23 to 44 d of age), the best results for DWG and F/G (quadratic, P < 0.05), and BW (quadratic, P < 0.1) were observed in piglets fed the medium particle size of SBM, although, DFI was not affected by particle size (Table 3).

In phase 3 (44 to 63 d of age), the alteration of SBM particle size did not influence DFI (P > 0.05), but there was a marginally increased (quadratic, P < 0.1) on DWG and a linear improvement (P < 0.05) on F/G when increasing SBM particle size. When analyzing the overall period (23 to 63 d) DFI, DWG, F/G, and BW were affected (linear, P<0.1), as every 100 µm increase in SBM particle sizes led to an increased feed intake of 5.1 g and an average live weight gain of 189 g, and a 0.009 improvement on F/G. ALMEIDA et al. (2021) evaluated distinct particle sizes of pelleted feed for pigs and reported a notable impact on feed intake, where higher particle size linearly increased DFI; and consequently DWG. Similar results were observed by HEALY et al. (1994), who suggested that the ideal particle size for piglets increases as the pigs grow older.

Reducing the particle size of a feed or ingredient will increase the surface area exposed to digestive enzymes (HEALY et al., 1994), thus improving the digestibility of some dietary fractions (WONDRA et al., 1995; ALBAR et al., 2000; GUILLOU & LANDEAU, 2000; ROJAS & STEIN, 2015). In the current study, reducing SBM particle size marginally increased (linear, P < 0.1) DE; however, feeding diets containing different particle sizes did not affect DFI and BW.

### Table 2 - Geometric mean diameter (GMD), and geometric standard deviation (GSD) of the complete diet according to SBM particle size in each growth phase.

| Phase 1 (20% SBM) | Phase 2 (25% SBM) | Phase 3 (30% SBM) |
|-------------------|-------------------|-------------------|
| GMD, µm | 1,017 | 585 | 411 |
| GSD, % | 543 | 2.02 | 522 | 1.74 | 506 | 1.70 |
| GSD, % | 730 | 1.86 | 591 | 1.71 | 535 | 1.83 |
| GSD, % | 864 | 1.82 | 717 | 1.67 | 694 | 1.69 |
not influence \( (P > 0.05) \) the apparent digestibility coefficients of the DM and CP (Table 4).

The extent of the pigs’ response to different dietary particle sizes on either performance or nutrient digestibility seems to depend on the raw materials selected as a tool to establish these different sizes. ALBAR et al. (2000) verified distinct responses in DM digestibility and energy when comparing two particle sizes of barley meal, corn, and pea; ALMEIDA et al. (2021) reported linear responses for DM and CP digestibility and a quadratic response for DE when working with different corn particle sizes. KAMPHUES et al. (2007) found that coarse particle size did not affect DM digestibility but had a positive effect on gut microbiota and gut health.

The use of diets with coarser particles (23.8\% of particles >1000 \( \mu \text{m} \) or with a medium size >700 \( \mu \text{m} \)) will likely increase the amount of DM in the stomach and reduce transit time, eventually increasing the number of anaerobic bacteria and the production of short-chain fatty acids, mainly lactic acid (MIKKELSEN et al., 2004; CANIBE et al., 2005). Lactic acid bacteria can compete with other

Table 3 - Effect of soybean meal particle size on average daily feed intake (DFI), average daily weight gain (DWG), feed/gain ratio (F/G) and average body weight of piglets in the nursery phase.

| Item                    | Soybean meal particle size\(^1\) | SE  | L\(^2\) | Q\(^2\) |
|-------------------------|-------------------------------|-----|---------|---------|
|                         | 1,017 \( \mu \text{m} \)          | 585 \( \mu \text{m} \)          | 411 \( \mu \text{m} \)          |
|                         | Phase 1, 23 to 32 days of age\(^2\) |     |         |         |
| DFI, g                  | 229                           | 218 | 214     | 6.6     | 0.149 | 0.412 |
| DWG, g                  | 165                           | 155 | 139     | 10.0    | 0.059 | 0.852 |
| F/G                     | 1.424                         | 1.446| 1.566   | 0.081   | 0.018 | 0.849 |
|                         | Phase 2, 32 to 44 days of age\(^3\) |     |         |         |
| DFI, g                  | 615                           | 647 | 624     | 11.9    | 0.934 | 0.022 |
| DWG, g                  | 326                           | 380 | 357     | 13.3    | 0.185 | 0.003 |
| F/G                     | 2.094                         | 1.989| 2.054   | 0.067   | 0.144 | 0.026 |
|                         | Overall period of phase 1 and 2, 23 to 44 days of age\(^4\) |     |         |         |
| DFI, g                  | 457                           | 461 | 443     | 9.1     | 0.218 | 0.504 |
| DWG, g                  | 243                           | 263 | 246     | 6.9     | 0.768 | 0.041 |
| F/G                     | 1.876                         | 1.763| 1.803   | 0.033   | 0.308 | 0.041 |
|                         | Phase 3, 44 to 63 days of age\(^5\) |     |         |         |
| DFI, g                  | 1004                          | 960 | 964     | 16.1    | 0.180 | 0.134 |
| DWG, g                  | 639                           | 593 | 573     | 11.0    | 0.001 | 0.071 |
| F/G                     | 1.731                         | 1.781| 1.841   | 0.040   | 0.027 | 0.638 |
|                         | Overall period, 23 to 63 days of age\(^6\) |     |         |         |
| DFI, g                  | 715                           | 698 | 684     | 9.4     | 0.036 | 0.496 |
| DWG, g                  | 430                           | 420 | 401     | 8.3     | 0.011 | 0.855 |
| F/G                     | 1.662                         | 1.662| 1.716   | 0.027   | 0.091 | 0.610 |
|                         | Average body weight, kg\(^7\) |     |         |         |
| 32 days old             | 8.33                          | 8.21 | 8.05    | 0.235   | 0.123 | 0.787 |
| 44 days old             | 11.90                         | 12.42 | 12.00   | 0.283   | 0.895 | 0.052 |
| 63 days old             | 24.10                         | 23.76| 22.95   | 0.450   | 0.017 | 0.966 |

\(^1\) Each treatment had seven replicates (five male and two female) of three pigs each.
\(^2\) Linear (L) and quadratic (Q) effect for soybean particle size.
\(^3\) Geometric mean diameter of the complete diets Phase 1 were: 543, 522 and 506 \( \mu \text{m} \), respectively.
\(^4\) Geometric mean diameter of the complete diets Phase 2 were: 730, 591 and 535 \( \mu \text{m} \), respectively.
\(^5\) Geometric mean diameter of the complete diets Phase 3 were: 864, 717 and 694 \( \mu \text{m} \), respectively.

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bacteria for nutrients and binding sites in the gut, and may increase the intestinal production of mucins and antioxidants and influence the immune system (YANG et al. 2015). The undissociated form of these acids can pass through the membrane of these bacteria; although, they dissociate inside them and reduce intracellular pH, resulting in cell death (RUSSELL & DIEZ-GONZALEZ, 1998). In other words, the gastric and intestinal conditions established by feeding coarse particles can be seen as an additional protective barrier against the transmission of undesirable anaerobic bacteria, such as Salmonella and Escherichia coli (KIARIE & MILLS, 2019). Therefore, diets with coarser SBM may have contributed to improved gut health of the piglets, which resulted in improved growth performance.

CONCLUSION

The results obtained in this study demonstrated that the particle size of soybean meal influences the growth of nursery piglets. Diets containing soybean meal with 585 µm particles were ideal during the first half of the nursery period, from 23 to 44 d of age. During the following period, from 44 to 63 d of age, diets containing unground soybean meal (average particle size of 1,017 µm) were optimal. However, considering the overall evaluation period, the grinding of soybean meal is not required for piglets during the nursery phase.

ACKNOWLEDGMENTS

This study was carried out with the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Funding Code 001.

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Table 4 - Effect of soybean meal particle size on the apparent digestibility coefficients (ADC) of dry matter (DM) and crude protein (CP), and the digestible energy (DE) of piglets aged 49 to 53 days.  

| Item       | Soybean meal particle size1 | SE  | L2   | Q2   |
|------------|-----------------------------|-----|------|------|
| ADC of DM, % | 1,017 µm                    | 76.13 | 77.17 | 0.60  | 0.151 | 0.414 |
| ADC of DM, % | 585 µm                      | 76.89 |       | 0.414 |      |      |
| ADC of DM, % | 411 µm                      | 77.17 | 0.60  |       | 0.151 |      |
| ADC of CP, % | 1,017 µm                    | 69.51 | 69.30 | 0.83  | 0.810 | 0.917 |
| ADC of CP, % | 585 µm                      | 69.55 |       | 1.012 |      |      |
| ADC of CP, % | 411 µm                      | 69.30 | 0.83  |       | 0.810 |      |
| ADC of CP, % | 1,017 µm                    | 411  |      |      |      |      |
| ADC of CP, % | 585 µm                      | 411  |      |      |      |      |
| ADC of CP, % | 411 µm                      | 411  |      |      |      |      |
| DE, kcal    | 1,017 µm                    | 3266 | 3344 | 30.66 | 0.097 | 0.293 |
| DE, kcal    | 585 µm                      | 3326 |       | 0.414 |      |      |
| DE, kcal    | 411 µm                      | 3344 | 30.66 |       | 0.097 |      |

1 Each treatment had seven replicates (five male and two female) of three pigs each.  
2 Linear (L) and quadratic (Q) effect for soybean particle size.  
3 Geometric mean diameter of the complete diets Phase 3 were: 864, 717 and 694 µm, respectively.

BIOETHICS AND BIOSECURITY COMMITTEE APPROVAL

The experimental procedures involving animals were approved by the Animal Ethics Committee of the Universidade Federal do Paraná, Curitiba, Brazil.

DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. Funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

AUTHORS’ CONTRIBUTIONS

All the authors contributed equally to designing and preparing the manuscript. All the authors critically reviewed and approved the final version of the manuscript.
