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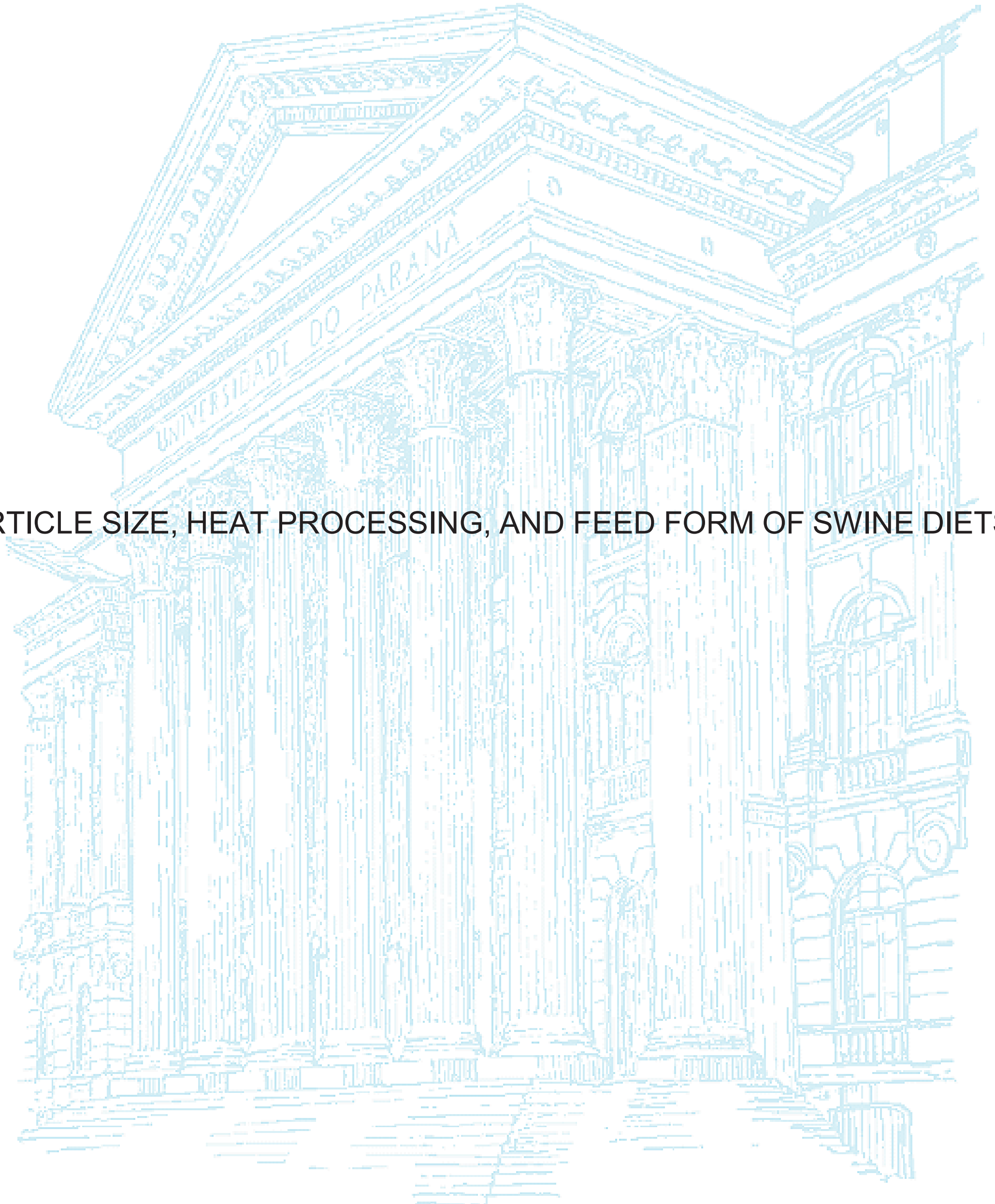

PARTICLE SIZE, HEAT PROCESSING, AND FEED FORM OF SWINE DIETS

CURITIBA

2022

LEOPOLDO MALCORRA DE ALMEIDA

PARTICLE SIZE, HEAT PROCESSING, AND FEED FORM OF SWINE DIETS

Tese apresentada ao curso de Pós-Graduação em Ciências Veterinárias, Setor de Ciências Agrárias, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Doutor em Ciências Veterinárias.

Orientador: Prof. Dr. Alex Maiorka
Co-orientador: Dr. Uislei Antônio Dias Orlando

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Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação CIÊNCIAS VETERINÁRIAS da Universidade Federal do Paraná foram convocados para realizar a arguição da tese de Doutorado de **LEOPOLDO MALCORRA DE ALMEIDA** intitulada: **PARTICLE SIZE, HEAT PROCESSING, AND FEED FORM OF SWINE DIETS**, sob orientação do Prof. Dr. ALEX MAIORKA, que após terem inquirido o aluno e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

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Assinatura Eletrônica
21/07/2022 14:48:52.0
ALEX MAIORKA
Presidente da Banca Examinadora

Assinatura Eletrônica
25/07/2022 14:25:53.0
EVERTON LUIS KRABBE
Avaliador Externo (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA)

Assinatura Eletrônica
21/07/2022 08:22:52.0
KEYSUKE MURAMATSU
Avaliador Externo (DSM PRODUTOS NUTRICIONAIS)

Assinatura Eletrônica
21/07/2022 13:24:38.0
CHAYANE DA ROCHA
Avaliador Externo (UNIVERSIDADE FEDERAL DO PARANÁ)

Assinatura Eletrônica
21/07/2022 17:33:40.0
ANANDA PORTELLA FÉLIX
Avaliador Interno (UNIVERSIDADE FEDERAL DO PARANÁ)

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RESUMO

Os processos de produção de ração (moagem, expansão e peletização) poderão alterar tanto características químicas como físicas das matérias primas, o que resultará em diferentes respostas dos suínos. Podem influenciar o consumo e o desperdício de ração, a digestibilidade, a saúde intestinal, e consequentemente o desempenho e o custo de produção. Apesar desses processos serem muito utilizados na fabricação de rações para suínos, ainda existem dúvidas sobre a efetividade dos resultados esperados. Dessa forma o objetivo dessa tese foi verificar o efeito que esses processamentos têm sobre os suínos. Foram realizados experimentos avaliando a influência do tamanho médio das partículas do farelo de soja (FS) (capítulo II) e da dieta peletizada (capítulo III) sobre o desempenho e digestibilidade da dieta em leitões no período de creche, e o efeito de diferentes formas físicas e processamentos térmicos (expansão e peletização) fornecidos de acordo com distintos programas alimentares sobre o desempenho de suínos em crescimento e terminação (capítulo IV e V). No primeiro estudo três tamanhos médios das partículas do FS foram avaliadas: 1.017 µm (sem moer), 585 µm, e 411 µm. Nos primeiros 21 dias os animais apresentaram melhor desempenho com o tamanho médio das partículas de 585 µm, porém ao analisar o período total (21 a 63 dias de idade) os melhores resultados de desempenho foram dos animais recebendo o FS mais grosso, ou seja, não se faz necessário a moagem do FS para leitões no período de creche. No estudo seguinte, quatro tamanhos médios das partículas foram avaliados de dietas peletizadas em leitões. Novamente na fase inicial o tamanho ideal das partículas foi menor, de 534 µm para os leitões de 28 a 42 dias de idade; e maior conforme o crescimento dos animais, de 943 µm (43 a 63 dias de idade). Em ambos os estudos a digestibilidade foi melhor nos animais consumindo as dietas finas. Nos experimentos dos suínos em crescimento e terminação foi demonstrado que a peletização pode melhorar o aproveitamento do alimento pelos suínos, pois ao restringir o consumo de dieta peletizada os animais apresentaram resultados similares aos animais recebendo ração farelada à vontade. Entretanto, no último experimento, o processamento da ração (expansão ou peletização) melhorou o desempenho dos suínos alimentados de forma controlada quantitativamente apenas na fase de crescimento, dos 63 aos 128 dias de idade. Em conclusão, esses processamentos de ração (moagem, peletização

e expansão) influenciaram na resposta do animal. Nos leitões o consumo de ração foi essencial para atingir o melhor desempenho; com o aumento da idade do leitão, melhor foi há resposta no desempenho conforme o aumento do tamanho das partículas da dieta peletizada. Nos suínos em crescimento e terminação houve melhora do aproveitamento das dietas processadas termicamente. Entretanto, a magnitude dessa resposta, que pode ser tanto negativa como positiva, depende de uma serie de fatores, principalmente relacionados ao processamento da matéria prima e/ou ração (equipamento, temperatura, tempo de retenção, matéria prima utilizada, entre outros), mas também do animal (idade/peso) que está sendo avaliado.
Palavras-chave: digestibilidade, desempenho, expansão, farelo de soja, tamanho de partícula, leitões, milho, peletização.

ABTRACT

The processing (grinding, expansion, and pelleting) of the feed and feed ingredients may alter both the chemical and physical characteristics of the ingredients/feed, leading to various responses in the animal. They can influence feed intake and waste, digestibility, gut health, and consequently performance and production cost. Although these processes have become widely used for the manufacture of animal diets, there are some uncertainties regarding the expected outcomes in swine production. Thus, the objective of this thesis was to verify the effect of these feed and ingredients processes on pigs. Experiments were conducted to evaluate the influence of the soybean meal (SBM) particle size (Chapter II) and pelleted diet (Chapter III) particle size on performance and digestibility of nursery piglets, and the effect of different physical forms and thermal processing (expansion and pelleting) supplied according to different feeding programs on the performance of growing and finishing pigs (Chapters IV and V). In the first study three SBM particle sizes were evaluated: 1,017 μm (unground), 585 μm, and 411 μm. In the first 21 d, the piglets showed better performance with the particle size of 585 μm, but when analyzing the total period (21 to 63 d of age) the best performance results were from the animals receiving the coarser SBM. So, the grinding of dietary SBM is not required for piglets during the nursery phase. In the next study, four particle sizes of the pelleted diet were evaluated. Again, in the early phase the ideal particle size was a fine one, 534 μm for piglets from 28 to 42 d of age; and coarser as the piglets become older, 943 μm (43 to 63 d of age). In both studies, digestibility was better in the animals consuming the fine diets. In the growing and finishing pigs experiments it was demonstrated that pelleting can improve feed utilization by the animals, as by restricting the feed consumption of the pelleted diet the animals showed similar results as the animals receiving *ad libitum* mash feed. However, in the last experiment, feed processing (expansion or pelleting) improved the performance of pigs fed a quantitatively controlled diet only in the growth phase from 63 to 128 d of age. In conclusion, these feed processes (milling, pelleting and expansion) influenced the animal response. In piglets, feed intake was essential to achieve the best performance; as the animal become older, their growth performance response increases with increasing particle size of the diet. In growing and finishing pigs there was improved utilization of the thermally processed diets. However, the magnitude of this response, which can be either negative or positive,

depends on several factors, mainly related to the processing of feed/ingredients (equipment, temperature, retention time, raw material, among others) and the animal (age/weight) being evaluated.
Keywords: corn, digestibility, expansion, growth performance, particle size, piglets, pelleting, soybean meal.

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CHAPTER I - LITERATURE REVIEW

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SUMMARY

INTRODUCTION

Despite the sanitary challenges that occurred during 2020 and 2021, as per the Covid-19 pandemic and the African swine fever (ASF) which devastated swine farms in China, the production of feed for pigs in 2022 sustained an increase of 6.6% compared to the previous year, equating to 290.904 million tons of feed. Asia, while recovering from losses caused by ASF, was the major feed manufacturer, although Brazil was responsible for an expressive production of 19.9 million tons (ALLTECH, 2022; SINDIRAÇÕES, 2021). Feed manufacture in Brazil took place amid a rise in raw material costs, mainly corn and soybean meal, which correspond to approximately 85 to 90% of the cost of feed. In April 2021, corn and soybean meal prices were 97.15% and 68.1% above the April 2019 prices, respectively (CNA, 2021).

During the past decades, feed processing has evolved from a simple combination of drying, grinding, and mixing of raw materials to obtain a mash meal, to more advanced processes such as pelleting and expansion, which apply mechanical and thermal processing of the raw materials. Along with grinding, pelleting and expansion may change both chemical and physical characteristics of the ingredients/feed, leading to various responses in the animal. Parameters such as feed intake and waste, digestibility, gut health, and functionality can be influenced, thus impacting animal performance and production cost (ROURA and TEDÓ, 2009; LI et al., 2014; AMARAL et al., 2015; ROJAS et al., 2016a; KIARIE and MILLS, 2019; ALMEIDA et al., 2020).

Although these processes have become widely used for the manufacture of animal diets, there are some uncertainties regarding the expected outcomes in swine production, especially when grinding, pelleting, and expansion are applied together. During pellet formation, the feed is compacted/compressed through a matrix die, leading to a further reduction of the feed particles; during expansion, processing becomes more intense due to higher pressure and temperature. It is crucial to comprehend the impact these processes (grinding, pelleting, and expansion) can have on the quality of the diet, cost of production, as well as pig performance and health. For this purpose, this thesis has been divided into five chapters.

The first chapter is a literature review where, first, the factors related to feed processing that regulate feed intake will be addressed; understanding the factors involved in the determination of voluntary feed intake are prerequisites for designing feed management strategies that will affect the entire production system (NYACHOTI et al., 2004). Furthermore, the milling process and the main thermal processes of pig feed will be addressed, as well as: the means through which the efficiency of these process is evaluated; their possible impact on digestibility and performance of pigs; the effect of grinding during pelleting; and the effects of merged grinding and pelleting on gut health and functionality. Finally, some important production cost issues will be addressed.

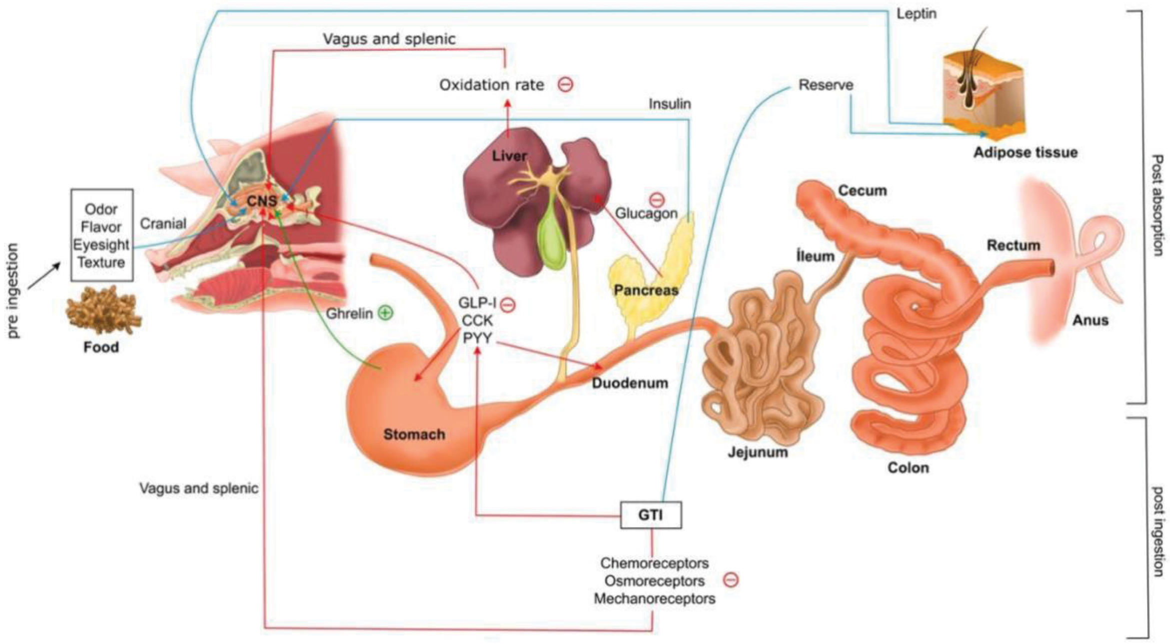
The remaining four chapters comprise the experiments conducted during the PhD period to assess the many aspects of feed processing on pig production. In chapter two, we evaluated the effect of soybean meal particle size on piglet performance and digestibility during the nursery period. In chapter three, the effect of pelleted diet particle size on nutrient digestibility and performance of piglets during the nursery period was evaluated; chapter four assessed the effect of different feeding programs and pelleting on the performance of growing and finishing pigs; and last, chapter five evaluated the effect of two dietary physical forms, submitted or not to thermal processing (pelleting and/or expansion), on the performance of growing and finishing pigs fed through a quantitative feeding control program.

CHAPTER I – LITERATURE REVIEW

1 FACTORS THAT REGULATE VOLUNTARY FEED INTAKE IN PIGS

The food intake regulatory mechanisms in swine work in a sort of cascading effect, where the changes caused by the presence of food in the gastrointestinal tract (GIT) will progressively trigger signals and neuron/hormonal responses that will act on the central nervous system (CNS) by either activating or inhibiting the consumption behavior at short (during meals) or long (in-between meals and days) terms (BLUNDELL and HALFORD, 1994, FORBES, 2009, GREGORY, 2002). This complex process can be divided into 3 steps: pre-ingestion, post-ingestion, and post-absorption (Figure 1).

FIGURE 1. INTERACTION BETWEEN PRE- AND POST-ABSORPTION FACTORS DURING FEED INTAKE REGULATION IN SWINES.



SOURCE: The author, 2022.

1.1 PRE-INGESTION

The chemical composition and structure of the feed entail a set of sensory characteristics (odor, taste, appearance, texture) that allow the pig to identify and then ingest or reject the food (Figure 1); according to Forbes (2009), the collective of these characteristics is usually referred to as palatability. The peripheral nervous system

(PNS) identifies these characteristics and carries the information to the CNS. Specifically in the oronasal cavity, the pairs of PNS nerves responsible for this identification are the cranial nerve I (olfactory), for odor; cranial nerves V (trigeminal) and X (vagus), which identify the somatic sensations; and nerves VII (facial), IX (glossopharyngeal) and X (vagus), related to taste (ROURA and TEDÓ, 2009).

The odor is generated by volatile components that reach the olfactory neuroepithelium, located in the upper nasal cavity and formed by three cell types: the sustaining cells, the basal cells and olfactory sensory neurons (ROURA and TEDÓ, 2009). The olfactory neuroepithelium of pigs has a broad surface area, close to 300 cm^2, and a large amount of sensory neurons (576 million), whereas in humans the surface area of this neuroepithelium is around 5 cm^2 with only 10 million sensory neurons (ROURA et al., 2008).

Feed also contains a variety of non-volatile components which are recognized by the taste buds, located in the papillae (fungiform, circumvallate, and foliaceous), thus forming the taste system. At least six different tastes can be detected by the buds: sweet, related to carbohydrates; fatty taste, related to fatty acids; umami, related to amino acids, peptides, and nucleotides; salty and sour, related to salts and acids, respectively; and bitter, which is related to toxic and anti-nutritional substances. In newborn pigs, this taste system is not yet fully developed, but has a rapid development and is closely related to the perception of food quality and diet selection/preference (ROURA and TEDÓ, 2009; KLASING and HUMPHREY, 2009).

Finally, somatic sensations refer to the mechanical, thermal, and chemical sensations of the food that are identified in the oral cavity. According to Szczesniak (2002), hardness, cohesion, viscosity, elasticity, and adhesiveness are the factors that define the mechanical characteristics of a food; the temperature, i.e. hot or cold is responsible for the thermal sensation; and the physical structure of the feed, as well as the changes it undergoes during processing, are responsible for the chemical sensation (ROURA and TEDÓ, 2009).

As previously stated, the feed undergoes different mechanical and thermal processes that lead to alterations in its physical-chemical characteristics of the feed, which in turn triggers different sensory responses in the animals during and/or after intake. For instance, feed with fine, smaller particle size can negatively impact feed intake in post-weaning piglets (MAVROMICHALIS et al., 2000; ALMEIDA et al., 2022). Bokelman et al. (2015) observed that post-weaning piglets preferred consuming the coarse diet when given the option to choose between diets with coarse or fine particles, as almost 80% of the daily feed intake corresponded to the diet produced with corn ground at 700 µm compared to only 20% for the diet produced with corn ground at 400 µm. This reduction of feed intake in piglets may be associated with the undesirable effect that the fine feed has on the dietary texture and, consequently, palatability (ZIJLSTRA et al., 2009).

The physical form of the diet also influences the intake preference of piglets, which seem to prefer pellets to mash diets (SOLÀ-ORIA et al., 2009a). However, some studies reported lower feed intake in pigs fed pelleted diets (MEDEL et al., 2004; NEMECHEK et al., 2015), although this difference can be partially related to a greater feed waste when feeding mash diets; when feed waste is considered or somehow controlled, the actual consumption of the thermally processed diet is then higher in both piglets (SUREK et al., 2017) and finishing sows (ALMEIDA et al., 2020).

To the day of publication of this thesis, there is no consensus on the optimal pellet size for pigs. Some studies show an increased feed intake of piglets when reducing pellet diameter from 2.0, 2.4, 5, or 9 mm to 1.8 mm (ZIJLSTRA et al., 2009), but there are other reports of animals properly adapting to different pellet sizes (EDGE et al., 2015); even during the lactational period, they seem to prefer larger (9-12 mm) to smaller (2-4 mm) pellets (VAN DEN BRAND et al. 2014; CRAIG et al., 2021). The provision of pellets with a larger diameter can also increase feed intake of finishing pigs. Traylor et al. (1996) observed a linear increase in feed intake and body weight gain of pigs fed pellets with increasing diameters, from 2.4 mm to 12.7 mm.

Regarding feed processing for pigs, the real challenge to be faced might lie in the production of small and resistant pellets that are at the same time not so hard, because the hardness of the feed and the effort used to chew the feed will influence feed preference; the harder the feed and the greater the effort needed to chew the feed, the lower the feed consumption (SOLÀ-ORIA et al. 2009b). There is scarce material evaluating the effect of pellet hardness on pig growth performance; it is believed that the older the animal the less sensitive it is to a harder material. However, feed hardness can be critical at weaning; Chen et al. (2021) evaluated the effect of pellets with two hardness characteristics, 0.505 kgf (soft) and 2.690 kgf (hard), for piglets in the pre- and post-weaning period, and found that during lactation, the piglets receiving the soft pellet consumed 2.35 times more feed than the piglets receiving the hard pellet, which in turn reduced the subsequent negative impacts of weaning (e.g.

undesirable intestinal modifications). No studies were found throughout literature that evaluated the effect of pellet hardness on feed intake of growing and/or finishing animals.

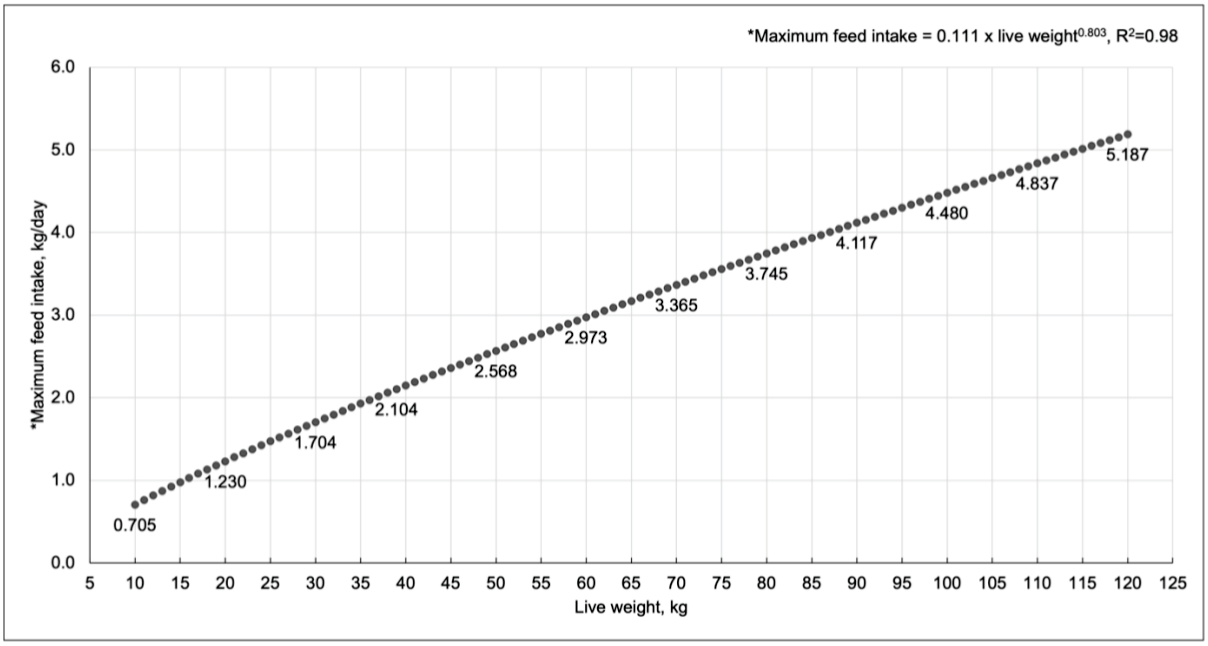
1.2 POST-INGESTION AND POST-ABSORPTION

1.2.1 Limitation of the gastrointestinal tract

The duration of a meal for pigs is rather short, between 10 and 20 minutes. After ingestion, both the presence of the feed and the products derived from its digestion may influence the short-term satiety response of the animal. As previously stated, the pig is capable of regulating feed intake based on certain characteristics of the feed, and that includes dietary energy concentration. BEAULIU et al. (2009) found a linear increase in feed intake when pigs were fed diets with reduced digestible energy from 3.57 to 3.09 Kcal/kg. As the concentration of available energy in the diet decreases, pigs will try to maintain a constant daily energy intake by consuming more feed, until intake is then limited by the physical capacity of the GIT. Inside both the stomach and intestine, mechanical receptors (Figure 1) are regulating feed intake through negative feedback according to the increasing sensation of filling (GREGORY, 2002).

To determine the maximum feed intake, BLACK et al. (1986) developed an equation based on the body weight of pigs and the physical limitation of the GIT (Figure 2), with maximum intake ranging from 705 g to more than 5 kg for animals weighting between 10 kg and 120 kg, respectively.

FIGURE 2. RELANTIONSHIP BETWEEN MAXIMUM FEED INTAKE AND PIG'S BODY WEIGHT.



SOURCE: Black et al., 1986

For Gregory (2002), physical GIT limitation may be an important factor on feed intake regulation, particularly for young pigs and when using feeds with high water holding capacity (WHC; g water retained per 1 g feed), a parameter that has been used to predict feed volume, i.e. the higher the WHC, the bulky is the diet being fed. Piglets up to 25 kg have a certain difficulty in maintaining a high feed intake in compensation for the diluted diet, which may reduce growth in these animals (KYRIAZAKIS and EMMANS, 1995; WHITTEMORE et al., 2003). However, when using diets with what is considered a very high WHC (~10.0 kg/kg), then even growing pigs have their consumption limited compared to those fed diets with high (4.6 kg/kg) and moderate (3.5 kg/kg) WHC (WHITTEMORE et al., 2002).

Short-term satiety response in pigs can also be affected by the physical form of the diet. According to Laitat et al. (2004), a reduction of the time spent at the trough can be observed, from 7.3 minutes per hour to 4.7 minutes per hour when feeding pelleted compared to mash diets. This difference of 2.6 minutes per hour is most likely related to a greater ease in orally apprehending the food, thus leading to a faster feed intake and consequent rapid feedback from the GIT filling.

The presence of metabolites resulting from feed digestion, i.e. glucose, amino acids, and fatty acids will also influence feed intake, namely decreasing intake as nutrient absorption increases. However, due to the complexity involved in the assessment of this response, it can be rather difficult to determine whether this feedback occurs due to either the stimulation of specific receptors, the osmolarity of the chyme (osmoreceptors), or even due to post-absorption mechanisms (Figure 1; FORBES, 2009).

1.2.2 Humoral response, oxidation rate in the liver, and metabolic status of the animal

Stimuli in the GIT caused by the presence of food, nutrients, and their absorption will result in the release of peptides/hormones, which can act either on local cells and tissues, or on distant organs and tissues (FORBES, 2009). This section is dedicated to briefly discussion of the major peptides/hormones involved in consumption regulation in pigs.

One of the most thoroughly investigated hormones is cholecystokinin, produced by I-cells in the small intestine and secreted during post-intake. Cholecystokinin is responsible for stimulating gastric emptying and small intestinal motility, acting via the vagus nerve to reduce feed intake (Figure 1). Additional peptides/hormones that act on the reduction of feed intake include apolipoprotein A-IV (apo A-IV), that is secreted by the intestinal mucosa during absorption and transport of lipids; glucagon-like-peptide 1 (GLP-1) and peptide tyrosine tyrosine (PYY), secreted by intestinal L-cells; and glucagon, secreted by the pancreas (FORBES, 2007; BLACK et al, 2009; SBARBATI et al., 2009).

After nutrient uptake, metabolites are directed to the liver, apart from triglycerides. The amount of substrate being oxidized in the liver will generate a signal that will be carried via the vagal and splenic nerve to the CNS, resulting in further regulation of food intake (Figure 1), which explains why glucose infusion into the hepatic portal vein, for instance, has been associated with reduced feed intake in animals (FORBES, 2009).

Another peptide that influences the regulation of feed intake is ghrelin. Produced and secreted mainly in the stomach, it plays an important role in stimulating the onset of a meal (ROMERO and ZANESCO, 2006). When applying intravenous human ghrelin in weaning piglets, Salfen et al. (2004) observed an increase in body weight gain and in the number of times the animals would eat, compared to piglets injected a saline solution. According to Dong et al. (2009), the dietary nutritional content is one of the most important factors for the secretion of ghrelin and regulation of ghrelin gene expression. For example, tryptophan infusions in weaning piglets increased ghrelin expression in the GIT mucosa and increased the plasma concentration of ghrelin (ZHANG et al., 2007).

In the pancreas, insulin is secreted in response to higher circulating glucose levels, which to some extent controls the ability of the liver to produce glucose or the ability of muscle, liver, and other tissues to absorb glucose. The plasma concentration of secreted insulin then triggers a signal to the hypothalamus regarding the adiposity status of the animal, exerting control over feed intake. Leptin, mainly produced by adipocytes, is also involved in the long-term energy reserve status of the animal, signaling the reduction of the animal's appetite (CARROLL et al., 2009).

1.3 OTHER FACTORS THAT CONTROL VOLUNTARY FEED INTAKE

Additional extrinsic and intrinsic factors take place on controlling the voluntary intake in pigs will be discussed next.

Animals grow optimally within a temperature range, often referred to as the thermoneutral zone. Within this zone of effective ambient temperature range, the heat generated from the normal maintenance and production functions of the animal during non-stressful situations is sufficient to compensate for the heat being constantly lost to the environment, without requiring an increase in the rate of metabolic heat production (NRC, 1981). Raising pigs in temperatures above or below the thermoneutral zone will have consequences on the voluntary intake and growth rate of the animals, such as a significant reduction in feed intake when pigs are under heat stress (RAUW et al., 2017). The impact of high and low temperatures on voluntary intake in pigs occurs mainly by changing the size of the meal rather than the number of meals consumed in a day, but alterations in environmental temperature also affects the feeding pattern; under high temperature, pigs will consume more during the night (cooler period) than during the day (QUINIOU ET AL., 2000).

Various physical and social factors, such as the square meter available per animal in the pen, group size, feeder space, and re-grouping management of pigs have been known to influence feed intake and growth performance by affecting their behavior. The introduction of electronic feeding equipment made it clear that voluntary feed intake of group-housed grower-finisher pigs is not the same trait as in individual housing (KNAP, 2009). While working with grower-finisher pigs, Nielsen et al. (1995) and Hyun and Ellis (2001) observed that larger groups of animals (20 males and 12 males and females, respectively) consumed more feed and more quickly when given access to only one feeder. Nielsen et al. (1995) pointed out that the factor of greatest relevance for group-housed pigs is not necessarily the number of animals, but the density per housing and per feeder, i.e. the higher the density, the greater the competition between animals and the worse the growth performance of the group. The authors further clarify that the number of animals does not seem to have adverse effects on performance when provide to them sufficient space and/or and adequate number of feeders available.

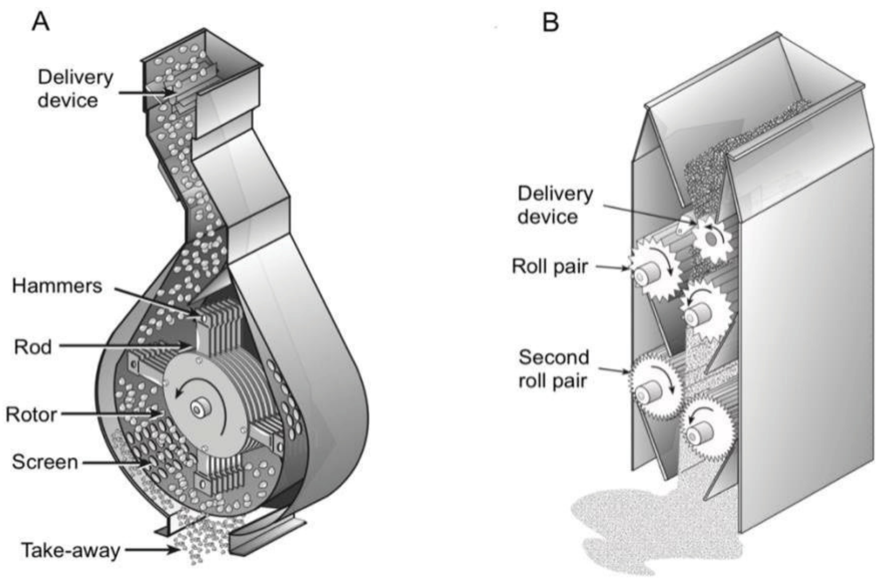
Finally, another important modulator of the feed intake response is the health status of the animal. When the immune system is activated as a reaction to an infectious disease, most often a reduction of feed intake is prompted (NYACHOTI et al., 2004).

2 GRINDING

Food grinding or milling is the process of reducing the particle size of an ingredient, performed by using different types of mills (ROJAS and STEIN, 2017); it is a regular process in a feed mill and has as main objective obtaining the ideal particle sizes for the animal's physiological needs, best use of the dietary nutrients (VUKMIROVIĆ et al., 2017a), and improving and facilitating future processes, such as mixing capacity/uniformity, transport, pelleting, extrusion, and expansion (LUNDBLAD et al., 2011). Hammer and roller mills are the most used types for grinding feed ingredients, and the choice between them is usually based on grinding capacity, electrical efficiency, and the variety of ingredients used in the formula (HANCOCK and BEHNKE, 2001).

The hammer mill (Figure 3A) corresponds to a set of hammers moving at high speed in a grinding chamber and reducing the size of grains until the particles can pass through a sieve of designated size (KOCH, 2002). The roller mill (Figure 3B), on the other hand, consists of one or more pairs of horizontal rollers set on a support structure, and the distance between pairs determines the desired particle size; as the feed passes between the rotating rollers, particle size is reduced, and a constant compression force is generated (AMERAH et al., 2007).

FIGURE 3. HAMMER MILL (A), AND A ROLLER MILL (B).



SOURCE: Koch, 2002.

When comparing both equipments, roller mills generate less noise, heat, and dust, and the material loses less moisture due to its slower operational speed. The particles ground in roller mills tends to be more uniform and have a lower proportion of fines than hammer mill grinding. However, hammer mills are more straightforward equipment and require a relatively low degree of skill in operation and maintenance. Additionally, hammer mills can be used to grind fibrous foods, unlike roller mills (KOCH, 2002; ROJAS and STEIN, 2017).

2.1 ANALYSES TO DETERMINE PARTICLE SIZE

To study and compare the effectiveness of grinding, it is essential to properly measure the average size of the particles at the end of the process. The average particle size is characterized by the geometric mean diameter (GMD) and the variation around it, described by the geometric standard deviation (GSD), both expressed in micrometers (μm) or millimeters (mm). For Fahrenholz et al. (2010) the best analysis of average particle size is the one capable of appointing the lowest GMD value and the highest GSD value.

Several techniques can be used to calculate these two variables. The most widely used one in Brazil was published in 1996 by Zanotto and Bellaver, and later updated in 2016 by Zanotto et al. In essence, this analysis uses sub-samples (after quartering) between 90 and 140 g, a set of 6 ABNT sieves with a plate (Figure 4A and B), and an electromagnetic vibration equipment (Figure 4C). After weighing, a sub-sample is transferred to the top sieve and the vibration equipment is activated with a vibration intensity of 80% for 10 minutes, which prompts part of the sample to drop down to the lower sieves. Then, the data of the retained weight of the sub-sample in each sieve plus the plate (Figure 4B) are inserted in the Granucalc® software (EMBRAPA, 2013) to calculate the GMD and GSD of the particles.

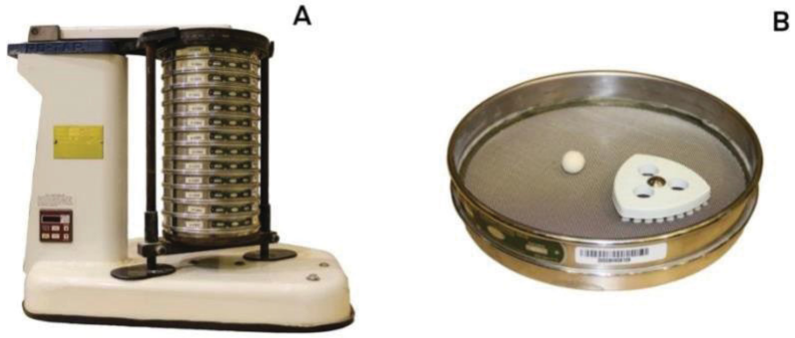
FIGURE 4. SIEVES AND PLATE (A), SIEVES CONTAINING CORN SAMPLES (B), SET OF SIEVES AND AGITATOR (C).

SOURCE: Lucas S. Cardos/EMBRAPA

The American Society of Agricultural and Biological Engineers (ASABE) also has a published method for determining GMD and GSD entitled Method of Determining and Expressing Fineness of Feed Material by Sieving (ANSI/ASAE S319.4 FEB 2008 R2012). In this procedure, 13 U.S sieve MODELS (no. 6, 8, 12, 16, 20, 30, 40, 50, 70, 100, 140, 200, and 270) plus the plate and a vibration equipment (Figure 5A) driven for 10 to 15 minutes are used; sieve agitators (rubber balls and bristle sieve cleaner, Figure 5B) can be added to help move the fine particles through the sieves as well as a flow agent to prevent them from clumping together. When comparing the sieving time (10 vs. 15 min) and the use or not of sieve agitators and flow agents, Kalivoda et al. (2015) found that these parameters influence the outcome of the analysis, with a longer vibration time showing lower GMD results. However, if sieve agitators and flow agents are applied, 10 min of sieving is sufficient to obtain similar results. There are also some alternative methods for particle size analysis, such as the three-sieve method (1700 µm, 600 µm and 300 µm mesh diameter) plus plate developed at Kansas State

University, and the single-sieve method (1400 μm mesh diameter), which allow us to quickly assess GMD (BALDRIDGE et al., 2001).

FIGURE 5. AGITATOR WITH SIEVE STACK (A), AND EXAMPLES OF A RUBBER BALL AND A BRISTLE SIEVE CLEANER (B).



SOURCE: Stark and Kalivoda, 2016.

When evaluating the particle size of a diet with a different physical form, such as pelleted feeds, the wet sieving method can be indicated. In this analysis, the first step is to soak the pelleted sample in water for about 2 hours. Then the sample is sieved on a set of at least 6 sieves with constant water flow during the process. At the end, the sample on each sieve is dried at 105 ºC to obtain the total dry matter content retained on each sieve, and consequently the particle distribution of the pelleted sample (MILADINOVIC, 2009).

2.2 DIGESTIBILITY OF DIETARY NUTRITIONAL FRACTIONS

When reducing the average particle size of a diet, its contact surface increases, and so is the area potentially being exposed to the digestive enzymes. Healy et al. (1994) found an increase in surface area from 61 to 141 cm^2/g by gradually reducing the average size of corn particles from 900 to 300 μm, and Blasel et al. (2006) reported through an in vitro test that for each 100 μm decrease (from 4000 to 370 μm) in the GMD of corn, there is an increase in the degree of starch accessed by amylase and amyloglucosidase by up to 26.8 g/kg. So, because of this possible improved action of the enzymes secreted by the pigs, a better utilization of the food by the animal could be expected.

Table 1 shows the influence of reducing feed particle size on the digestibility of dry matter (DM), nitrogen (N) and energy in pigs, although this response may differ when comparing different ingredients and animals at different growing phases; this may occur because of the distinct composition, physicochemical properties, and the amount of antinutritional factors between ingredients and their varieties within the same feed (VAN BARNEVELD et al., 1999; LI et al., 2014). Intense heat treatments applied to the ingredients may also interfere with diet utilization by the pigs, as high drying temperatures (± 100ºC) can impair the digestibility of amino acids (BARRIER-GUILLOT et al., 1993). Regarding growing phases, the structural and functional maturation of the gastrointestinal tract of pigs progresses gradually with age (EVERAERTA et al., 2017), and weaning is, for example, a moment that calls for extra attention: during this phase transition, the piglet undergoes important morphological, enzymatic, and inflammatory changes that will influence the animal's feed utilization response (HEDEMANN and JENSEN, 2004; MONTAGNE et al., 2007; BARSZCZ and SKOMIAŁ, 2011; MODINA et al., 2019).

The method chosen for grinding the ingredient can also affect nutrient digestibility. Both hammer mills and roller mills can achieve a very similar GMD, but the product from grinding will not necessarily be the same. Hammer mills will often result in feed particles with inconsistent shapes and a greater size variation when compared to the roller mills, which can interfere with enzyme access and action upon the diet, and in turn, digestibility. Acosta et al. (2020) evaluated the digestibility of growing and finishing pigs fed corn with three average particle sizes (700, 500 and 300 µm) obtained from hammer and roller mills. The apparent tract total digestibility of DM, gross energy (GE) and N were equal in pigs fed with corn ground in hammer mills, whereas for animals fed corn ground in roller mills they observed an increase on digestibility when reducing particle size.

TABLE 1. EFFECT OF REDUCING PARTICLE SIZE (GMD) OF RAW MATERIALS ON THE DIGESTIBILITY OF DRY MATTER (DM), NITROGEN (N) AND ENERGY OF MASH DIETS FOR PIGS ON DIFFERENT GROWING PHASES.

Ingredient	Phase	GMD, µm	Digestibility			Reference
			DM	N	Energy	
Corn	Nursery (13.5 kg)	1210	86.30 b		85.20 b	Albar et al., 2000
		490	88.00 a		87.70 a	
Soybean meal	Nursery (49 to 53 days)	1017	76.13	69.51	73.79	Almeida et al., 2022
		585	76.89	69.55	75.08	
		411	77.17	69.30	75.11	
Corn	Growing (Initial body weight of 30 kg)	865			^{L} 66.10	Rojas and Stein, 2015
		677			69.20	
		485			71.60	
		339			74.30	
Wheat	Growing (Initial body weight of 21.2 kg)	670	87.16	^{Q} 84.79	86.98	Bao et al., 2016
		580	87.46	85.87	87.17	
		470	87.43	87.07	87.37	
		450	87.77	87.65	87.93	
		430	88.30	88.01	88.77	
		330	86.69	86.90	87.66	
Distiller's dried grains with solubles	Growing (Initial body weight of 40 kg)	818	82.81 a	80.78	80.81 a	Liu et al., 2012
		594	83.88ab	80.69	81.92 ab	
		308	84.32 b	81.40	82.65 b	
Rice	Growing (Initial body weight of 35.6 kg)	800	88.00 b	86.10 b	87.70 b	Li et al., 2019
		600	90.60 a	88.70 a	90.90 a	
		400	91.00 a	89.90 a	92.20 a	
Corn	Finishing (± 94 kg)	1000	^{L} 79.90	^{L} 72.60	^{L} 77.60	Wondra et al., 1995
		800	78.90	70.80	75.80	
		600	81.70	76.30	79.60	
		400	84.80	79.50	84.10	

Means in the same column followed by distinct lowercase letters differ.
^{L} linear effect; ^{Q} quadratic effect.

2.3 GROWTH PERFORMANCE

As a result of a better feed utilization with the reduction of particle size, an improvement in the pigs' growth performance is also expected. Table 2 summarizes the results of some studies that evaluated the effect of reduced particle size of mash diets on the performance of pigs at different growth phases.

These studies have shown that reducing the particle size of ingredients from coarse (> 1017 µm) to medium (± 500 µm) may lead to average improvements of 7% and 9.5% in daily weight gain (DWG) and feed conversion ratio (FC)/feed efficiency (FE), respectively, in post-weaning piglets. However, overly fine grindings (< 490 µm) may cause a reduction in daily feed intake (DFI) and weight gain (ALBAR et al, 2000; MAVROMICHALIS et al., 2000; ALMEIDA et al., 2022).

The study by Almeida et al. (2022) reports that the optimal particle size for piglet performance increases as the animal grows (Table 2). In the total evaluated period (23 to 63 days of age) a linear effect of soybean meal particle size was observed on DFI, DWG, FC, and live weight: for each 100 µm increase in the particle size (from 411 to 1017 µm) there was a 5.1 g increase in DFI, a 189 g gain in live weight, and a 0.009 improvement in FC. As much as the digestibility of some dietary fractions may be improved with the use of finer particles, DFI still has a big impact on the animal's DWG, and the use of coarser particles brought better results in this matter.

Studies show that during the growing and finishing phases, there is an important effect of reducing particle size on FC/FE for pigs, which can be improved with lower diet GMD (Table 2) - often associated with a lower feed consumption by the animals. The application of the milling process also increases dietary energy utilization (WONDRA et al., 1995), and as previously discussed, animals may regulate their DFI based on the energy provided by the diet (QUINIOU and NOBLET, 2012).

TABLE 2. EFFECT OF REDUCING PARTICLE SIZE (GMD) OF RAW MATERIALS IN MASH DIETS ON DAILY FEED INTAKE (DFI), DAILY WEIGHT GAIN (DWG) AND FEED CONVERSION (FC) OR FEED EFFICIENCY (FE) OF PIGS AT DIFFERENT GROWTH STAGES.

Ingredient	Phase	GMD, µm	DFI (g)	DWG (g)	FC or FE	Reference
Barley	Nursery (8 a 26 kg)	1210	729	474 b	1.53	Albar et al., 2000
		970	753	498 a	1.51	
		710	742	501 a	1.49	
		650	748	498 a	1.50	
Wheat	Nursery (5.7 to 20.75 kg)	1300	^{L}550	^{Q}410	^{Q}0.75	Mavromichalis et al., 2000
		600	520	450	0.87	
		400	510	430	0.84	
Corn	Nursery (13.5 kg)	1210	805	518 b	1.56 b	Albar et al., 2000
		700	815	541 a	1.51 ab	
		640	810	545 a	1.50 ab	
		490	776	534 ab	1.46 a	
Soybean meal	Nursery (6.86 to 12.10 kg)	1017	457	^{Q}243	^{Q}1.87	Almeida et al., 2022
		585	461	263	1.76	
		411	443	246	1.80	
Soybean meal	Nursery (12.10 to 23.60 kg)	1017	1004	^{L}639	^{L}1.73	Almeida et al., 2022
		585	960	593	1.78	
		411	964	573	1.84	
Corn	Growing-Finishing (34 a 120kg)	650	2410	^{L}900	^{L}0.372	Nemechek et al., 2016
		650:350	2370	890	0.375	
		350	2260	860	0.382	
Wheat	Growing (10.4 a 21.8 kg)	670	660	^{Q}411	1.63	Bao et al., 2016
		580	675	437	1.59	
		470	682	448	1.58	
		450	663	455	1.59	
		430	659	454	1.65	
		330	694	442	1.57	
Corn	Growing (30.5 a 56.0 kg)	850	1880	850	2.21 b	Amaral et al., 2015
		700	1900	860	2.22 b	
		550	1810	860	2.11 a	
Corn	Finishing (55.2 to 114.8 kg)	1000	^{L}3250	960	^{L}0.295	Wondra et al., 1995
		800	3210	940	0.293	
		600	3260	950	0.291	
		400	3160	980	0.310	
Wheat	Finishing (67 to 114 kg)	1300	3110 b	880	0.28	Mavromichalis et al., 2000 (Exp. 2)
		600	3050 a	890	0.29	
Wheat	Finishing (63 to 115 kg)	600	2910 b	900	0.31 b	Mavromichalis et al., 2000 (Exp. 3)
		400	2840 a	910	0.32 a	

Means in the same column followed by distinct lowercase letters differ.
^{L} linear effect; ^{Q} quadratic effect.

3 PELLETING AND EXPANSION

3.1 PELLETING

Pelleting is a feed thermal processing in which the ingredients or feed mixture are agglomerated by mechanical action in combination with moisture, pressure, and temperature, resulting in the formation of larger structures called pellets (ZIGGERS, 2003). This process is carried out by a set of equipment consisting of a screw feeder, conditioner, retainer (or hygieniser) and pelleting press.

The screw feeder regulates the amount of feed directed to the conditioner and prevents the flow of steam from the conditioner to the press silo (STEIDINGER et al., 2000). The heat treatment starts in the conditioner: saturated steam is constantly adding moisture and heat to the feed mixture as it passes through the conditioner, until it reaches a physical state favorable for compaction (FROETSCHNER, 2006; COLOVIC et al., 2010). A wide range of temperature and moisture can be employed during conditioning, commonly varying from 60 to 100°C and 12 to 18% humidity (HANCOCK, 1992). After conditioning, a retainer (or hygieniser) can be installed to increase the retention time of the feed and thus prolong the exposure time of the feed mixture to steam as a means of promoting greater starch gelatinization and reduction of microbiological pathogens (LARA, 2013). Finally, the mixture is taken to the pelleting mill, composed basically of the press matrix and the roller. Inside the press, the deflectors direct the flow of feed to the rollers, which force the mixture through the matrix holes, giving shape to the feed pellets (KULIG and LASKOWSKI, 2008).

The main advantages of pelleting diets for pigs includes reduced feed waste, reduced segregation of ingredients, reduced microbiological load, greater nutrient digestibility and, therefore, improvements in growth and production performances (BEHNKE, 1994; COCHRANE et al., 2015). However, this heat process can reduce vitamin levels due to the application of high moisture and temperature, especially in diets lacking an adequate amount of antioxidant that would otherwise prevent an accelerated oxidation, or if the vitamin products are not manufactured with encapsulated protection for pelleting (ENSMINGER, 1985). Also, depending on the intensity of the process and the type of diet being produced, pelleting can promote undesirable changes in the structure of ingredients, such as complexation reactions between proteins and carbohydrates (DELGADO-ANDRADE et al., 2010), formation of resistant starch (VORAGEN et al., 1995; ABDOLLAHI et al., 2010), and impaired stability of exogenous enzymes (CAMPBELL and BEDFORD, 1992).

3.1.1 Pellet quality

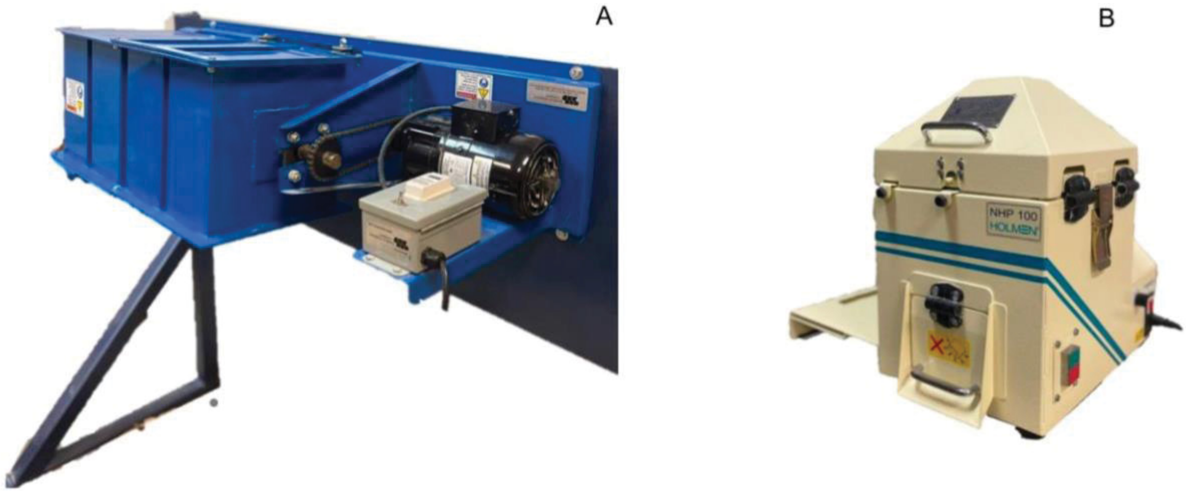
Pellet quality can be synonymous to its resistance: from the moment of its production, transportation, and distribution in farm feeders, a strong pellet must reach the feeders intact and not generate a high proportion of fines (AMERAH et al., 2007); good pellet quality is critical to achieve the benefits of pelleting (STARK et al., 1993; NEMECHEK et al., 2015). Two methods can be used to determine pellet quality: the durability index (PDI) and pellet hardness.

The PDI method was first developed in 1962 (PFOST et al., 1962), standardized in 1969 (YOUNG et al., 1969; ASAE Standard S269.1), and later revised in 2012; it is defined by ASAE as ASAE Standard S269.5 (2012). The durability of pellets or crumbles are determined on a tumbler by tumbling the sample. Typically, the feed is tested immediately after the material is cooled; 500g of sieved pellets or crumbles are placed in the tumbling box (Figure 6A) for 10 minutes at 50 revolutions per minute (rpm), then the sample is sieved, and the percentage of intact pellets or crumbles is calculated. To have a more representative sample of the number of fines found in the animal feeder, the standard method of determining PDI is often modified by adding hex-nuts or ball bearings to the tumbling chamber to create a more abrasive test.

The PDI can also be calculated by the Holmen method, which instead of tumbling, uses air force to create the abrasion on the pellets. 100g of intact pellets are added to the Holmen NHP 100 (TekPro Ltd, Norfolk, UK) test chamber (Figure 6B) and shaken with air for 30, 60, 90, or 120 seconds. After the test, the sample is removed, weighed, and the percentage of intact pellets or crumbles is calculated. The following formula is used to calculate the PDI by both the ASABE and Holmen methods:

$$\text{Pellet durability index (\%)} = \frac{\text{Weight of pellets or crumbles after test}}{\text{Weight of pellets or crumbles before test (500 or 100g)}} \times 100$$

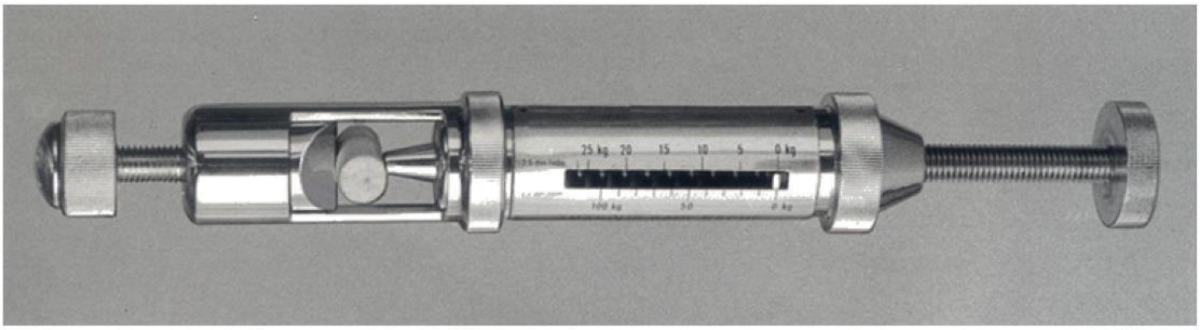
FIGURE 6. TUMBLER (A) AND HOLMEN NHP 100 (B).



FONTE: Auburn University, Poultry Department.

Pellet hardness is measured by a hardness tester (Figure 7), which applies mechanical force to the pellet through a piston until it breaks, then taking the hardness measurement in kilograms.

FIGURE 7. PELLET HARDNESS TESTER.

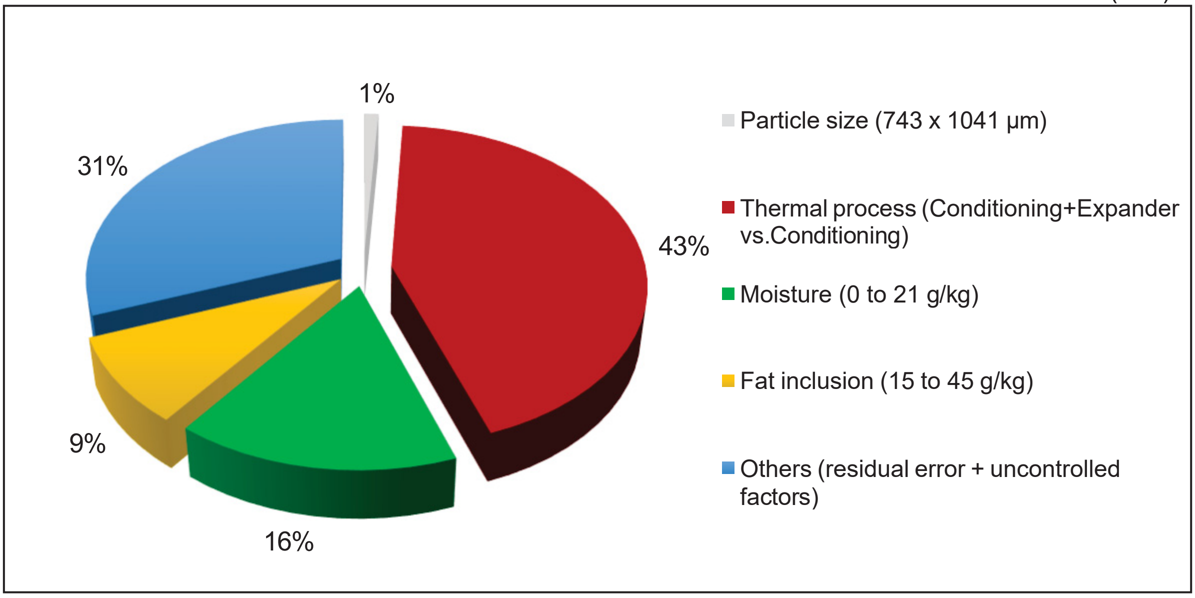


FONTE: Amandus Kahl Gmbh & CO.

Pellet durability/hardness tests will ultimately indicate the effectiveness of the pelleting process, and the quality of the product. Each feed mill can create their own model to estimate the percentage of fines in the feed that will be consumed by the animals. A well-designed model entails continuous feedback on the effect of formulation and other process variables on pellet quality (STARK and FAHRENHOLZ et al., 2015).

Several factors can interfere with pellet integrity and all of them can act individually or combined, and it is crucial to understand what the participation of each factor on the quality of pelleted diets. Reimer (1992) proposed the following division based on the importance of each factor on pellet durability: 5% related to the cooling/drying process; 15% related to press matrix specifications; 20% related to thermal conditioning; 20% related to the particle size of raw materials; and 40% attributed to the feed formulation. However, Muramatsu et al. (2015) evaluated the interactions between different factors on the PDI of corn and soybean meal-based diets, including feed particle size (743 and 1041 m), thermal processing (conditioning-pelleting or conditioning-expansion-pelleting), moisture addition (0, 7, 14 and 21 g/kg feed) and fat inclusion (15, 25, 35 and 45 g/kg feed); the authors observed that thermal processing was the factor with most influence, accounting for 44% of the variability observed for PDI, whereas particle size was the least influencing, corresponding to only 1% (Figure 8). Arguably, the difference between both studies regarding the influence of particle size on pellet quality may be related to the range of the analyzed GMD.

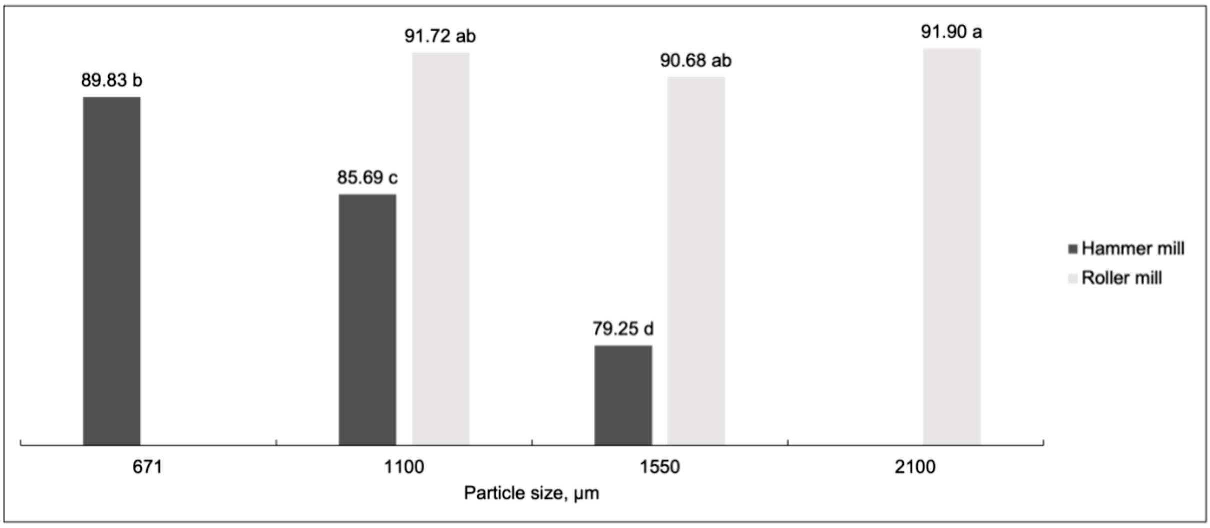
FIGURE 8. INFLUENCE OF DIFFERENT FACTORS ON THE PELLET DURABILITY INDEX (PDI).



SOURCE: Muramatsu et al., 2015.

During the pelleting process, the molecular structure of proteins is broken down (protein denaturation), but they reassemble during cooling to form new bonds (covalent bonds, electrostatic interactions, Van Der Waals interactions or hydrogen bonds) that act as binders between the particles (SALAS-BRINGAS et al., 2011). The coarser particles cause more fractures in the pellets, possibly because they have less contact surface area and consequently less bond strength between them. Due to the large variability (high GSD) on particle size when grinding with the hammer mill, pellet quality may be influenced differently compared to the roller mill, as shown in Figure 9 (VUKMORIVIC et al., 2016).

FIGURE 9. INFLUENCE OF MILL TYPE AND GRINDING SEVERITY ON PELLET DURABILITY



SOURCE: Vukmorivic et al., 2016.

3.2 EXPANSION

Expansion is another type of thermal processing that applies high pressure with high temperature to the feed mixture for a short time, mainly used as an intermediate process or an intensification of the conditioning process in pelleting lines (ZIJLSTRA et al., 2009). Expansion is implemented by turning mechanical energy into thermal energy with the addition of steam, which allows to reach high temperatures above 120°C, and pressure values higher than 1200 PSI (FANCHER et al., 1996). In the expander, the feed mixture is forced by a screw to flow through a hollow cylinder that has a hydraulically controlled cone partially preventing the feed from coming off the equipment, generating intense frictional force, pressure, and heat production; the release of pressure and spontaneous evaporation of the water causes the temperature to drop rapidly, and the feed material to expand in volume.

Expansion can be used on either the total diet or individual ingredients (ROJAS and STEIN, 2017). Expanded pelleted feed can have better pellet quality, a greater degree of starch gelatinization, increased metabolizable energy and metabolizability coefficient of crude protein compared to traditional pelleting. In addition, other expected benefits include greater reduction of bacteria and fungi in the feed (due to the higher temperatures) and greater flexibility in formulation, granting, for example, the possibility to add more oil without compromising pellet quality (LOPEZ et al., 2007; LUNDBLAD et al., 2011; MURAMATSU et al., 2014). Traylor et al. (1999) demonstrated that expansion increases pellet quality in corn, sorghum, wheat bran, and wheat-based diets by 39, 20, 6, and 3%, respectively. However, as discussed earlier, the high temperatures employed during thermal processing can compromise the nutritional quality of the diet – a probable downside for the expansion process.

3.3 DIGESTIBILITY OF DIETARY NUTRIENT FRACTIONS

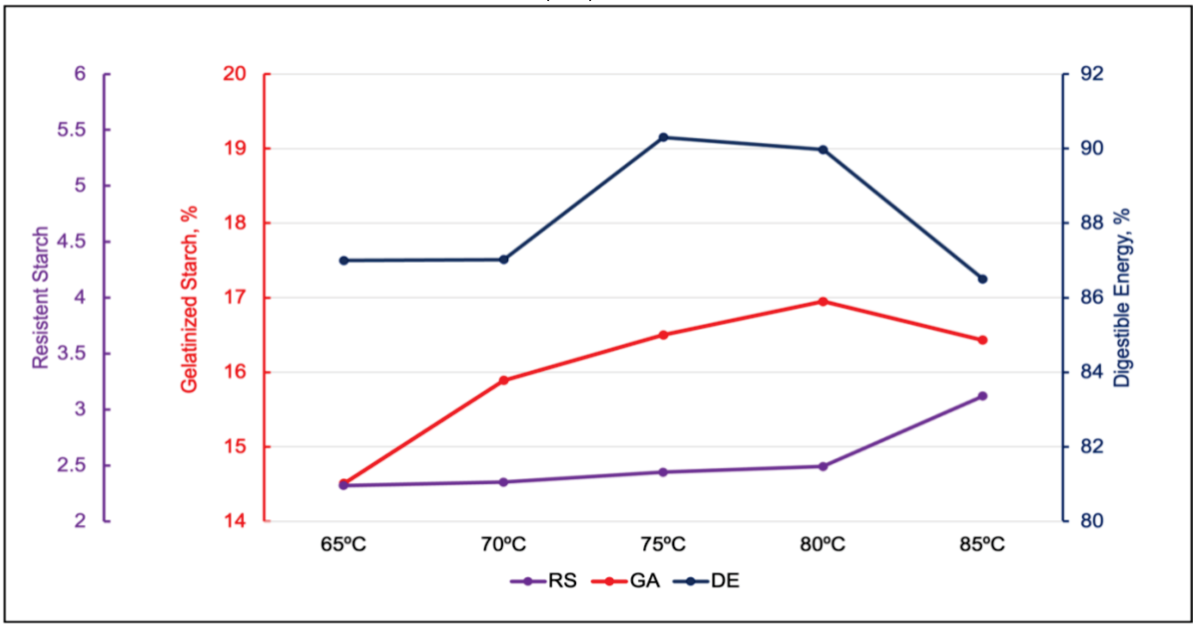
3.3.1 Starch

Starch is the main energy source in animal nutrition and its quantification in cereals can be used as an indirect indication of nutritional value (SILVA, 2002). It is a homopolysaccharide composed of two main macromolecules: amylose and amylopectin; amylose is formed by glucose units joined by α(1→4) glycosidic bonds, originating a linear chain; amylopectin, on the other hand, is formed by glucose units joined by α(1→4) and α(1→6) glycosidic bonds, constituting a branched structure (WANG and WHITE, 1994). The linear part of the amylopectin molecules forms double helical structures stabilized by hydrogen bridges between the hydroxyl groups, giving shape to the crystalline region of the starch granule. The amorphous region of the granule is composed of the chains of amylose and branches of amylopectin (VAN SOEST et al., 1996), and it is in this last portion where the starch gelatinization process begins due to its lesser structural organization (LUND and LORENZ, 1984).

Starch gelatinization can be defined as the irreversible destruction of the crystalline region of the starch granule, thus exposing its surface to reagents, solvents and enzymes (LUND and LORENZ, 1984; MORITZ et al., 2005). Lundblad et al. (2011) assessed the gelatinization degree in diets for pigs with different physical forms, and reported that mash diets, pelleted diets with low (47ºC) and high (90ºC) temperature, expanded, and extruded diets had a gelatinization of 9, 14, 15, 24 and 77%, respectively (LUNDBLAD et al., 2011). According to Svihus et al. (2005), pelleting exerts little effect on starch availability, whereas more intense processing promotes a higher degree of gelatinization, e.g. extrusion, in which more water is added and the temperature is higher.

Englyst et al. (1992) classified the in vitro starch digestibility into three types: rapidly digested starch, slowly digested starch, and resistant starch (RS). The RS represents the fraction of starch that leaves the small intestine undigested, and it can be classified into other 3 subtypes: physically inaccessible starch (type 1); granular resistant starch (type 2); and retrograde starch (type 3). Type 3 RS occurs when thermal processes are employed followed by cooling, making the linear segments of amylose align themselves into condensed structures based on doubles helices after having been gelatinized, which renders the α(1→4) glycosidic bonds inaccessible to amylase enzymes (HTOON et al., 2009). Hydrothermal processing (expansion and pelleting) has shown to improve the ileal digestibility coefficient of starch in growing pigs when compared to mash diets (LUNDBLAD et al., 2011). However, the improvements in starch digestibility provided by the gelatinization process may be impaired if large amounts of retrograde starch are formed. The negative impact of RS formation on energy utilization by pigs was demonstrated by Wang et al. (2019) when working with conditioning temperatures from 65 to 85ºC and observing a quadratic response for gelatinization degree and a linear increase in RS formation in the pellet with higher conditioning temperature, with a consequent quadratic response in digestible energy for growing pigs (Figure 10).

FIGURE 10. EFFECT OF INCREASING PELLETING TEMPERATURE ON THE AMOUNT (%) OF GELATINIZED STARCH (GA) AND RESISTANT STARCH (RS) ON PELLETS, AND ON ENERGY DIGESTIBILITY (DE) OF GROWING PIGS.



SOURCE: Wang et al., 2019.

3.3.2 Protein

Proteins have complex spatial structures that can be organized in four levels: a) primary: the sequence of amino acids in the polypeptide chain, b) secondary: provided by hydrogen bonds between the radical amine and carboxyl groups, between adjacent amino acids, c) tertiary: the final three-dimensional shape of a polypeptide chain, resulting from the association of organized parts of the molecule, and d) quaternary: composed of more than one polypeptide chain, which may be associated by disulfide bonds (NELSON and COX, 2011).

The action of temperature and moisture during feed processing can result in protein denaturation. Protein denaturation refers to physical changes on protein structures, causing disruption of the secondary, tertiary, and quaternary structures, modifying their spatial structure, and forming disordered arrangements through intramolecular bonds. The primary structure is not affected by denaturing agents, so the peptide bonds are not affected (ARAÚJO et al., 2009). Nutritionally, the changes caused by the partial denaturation of protein facilitates their subsequent digestion (DOZIER, 2001), resulting in improved digestibility of protein and most amino acids (VANDE GINSTE and DE SCHRIJVER, 1998; O'DOHERTY et al., 2000; ROJAS et al., 2016b). However, very intense thermal processing can lead to undesirable reactions between food components, such as the complexation between amino acids and carbohydrates that makes these compounds partially unavailable and impairs the solubility and digestibility of proteins (DELGADO-ANDRADE et al. 2010).

Pre- and post-weaning diets are more susceptible to these feed alterations due to their high amount of dairy products. A well-known reaction of such kind is the Maillard reaction, which occurs between a reducing carbohydrate carbonyl group and the amino group of the amino acid, in a preferentially alkaline environment, in the presence of water and temperature. This reaction may unwantedly block or reduce the bioavailability of essential amino acids and the activity of enzymes; it also triggers the production of melanoidins, responsible for giving a brown coloration to the food (BOEKEL, 1998). At the beginning of the Maillard reaction, the feed is not yet with the characteristic brownish coloration, but the amino acids are already going through changes, as the bioavailability of lysine is the most affected with increasing temperatures. Delgado-Andrade et al. (2010) have observed deleterious effects of temperature on the amount of free lysine when pelleting complex diets (containing 11.5% whey powder) at not so high temperatures (around 60-65ºC).

Veloso et al. (2005) reported that soybean meal had its protein solubility in KOH reduced from 805.7 to 641.2 g/kg protein after being subjected to processing at 130-136°C. The authors mentioned the possibility that the expansion could cause the soybean meal protein to bond with starch, making it insoluble. A linear reduction of protein solubility (reduction from 73.74 to 65.30%) is observed even in less severe processes (conditioning + pelleting), when increasing temperature from 65 to 85°C (WANG et al., 2019).

3.4 GROWTH PERFORMANCE

The positive effect of thermal processing on nutrient digestibility and feed preference may have influence in pig performance. Table 3 shows the comparison of piglets in the nursery phase receiving either mash or pelleted diets and their effects on FC or FE. Most of the studies cited in the table found differences in DWG, but a marked effect on feed utilization efficiency as well. Even though the studies used animals of different weights and genetics, as well as different raw materials and feed GMD, the FC/FE was on average 9.5% better for piglets receiving the pelleted diet during the nursery period.

Feed wastage is another factor that interferes with animal performance and is deeply related to the feed form. Pigs receiving pelleted feed waste less than animals receiving mash feeds (PATRIDGE, 1989; HANCOCK and BEHNKE, 2001, SENGER et al., unpublished data), and this may consequently impact FC/FE. Furthermore, if feed wastage is considered, the consumption of pelleted feed may be higher compared to animals receiving mash feed, as observed by Surek et al. (2017) when correcting piglet consumption in the first week post-weaning (wastage of 9.15% for mash vs. 1.68% for pelleted).

TABLE 3. COMPARISON OF FEED CONVERSION (FC) OR FEED EFFICIENCY (FE) OF POST-WEANING PIGLETS FED MASH OR PELLETED DIETS AND THE % OF IMPROVEMENT BETWEEN DIETS.

References	Body weight, kg		Main ingredients	FC or FE[1]		
	Initial	Final		Mash	Pelleted	%
Medel et al., 2004	6.10	16.65	Barley and corn	1.450	1.330	8.3
Surek et al., 2017	6.07	12.30	Corn and SBM[2]	1.470	1.140	22.4
Mazutti et al., 2017	7.18	12.16	Corn and SBM	1.310	1.170	10.7
Neta et al., 2019	6.65	17.30	Corn and SBM	1.241	1.145	7.7
Senger et al.[3]	6.06	23.46	Corn and SBM	1.708	1.554	9.0
Lundblad et al.,2011	5.60	16.00	Wheat and fishmeal	0.759	0.810	6.7
Ohh et al., 2002	7.60	14.30	Corn and SBM	1.480	1.310	11.5
Nemechek et al., 2015	11.90	24.50	Corn and SBM	0.672	0.702	4.5
Nemechek et al., 2015	14.00	34.00	Corn and SBM	0.630	0.663	5.2

[1]FC – feed conversion ratio; FE – feed efficiency
[2]SBM – soybean meal
[3]Unpublished data.

Growing and finishing pigs also show a better growth when fed pelleted diets in comparison to mash diets. The effect on feed intake of animals receiving the pelleted diet is quite varied among the studies presented in Table 4; in most studies there is either a reduction or a lack of effect on feed intake between the different dietary feed forms, but in the work of Almeida et al., 2020 an increase of feed intake was observed on female pigs receiving pelleted diet. Weight gain increased with pelleted diets in most studies, but just as in the nursery period, there is a marked effect on the FC/FE of the animals. Regardless of genetics, initial/final weight, raw material and/or average feed particle size, there was a 6.0% improvement on feed utilization in growing and finishing pigs consuming pellets (Table 4).

However, to fully achieve the benefits of pelleting on pig performance, it is necessary to produce high quality pellets, with high PDI and low presence of fines. It has been observed that with the gradual increase of the percentage of fines in the diet, there is a linear worsening of feed efficiency in finished pigs (STARK et al., 1993), and loss of efficiency may occur from 33% of fines in the diet of nursery piglets (NEMECHEK et al., 2015).

TABLE 4. COMPARISON OF FEED CONVERSION (FC) OR FEED EFFICIENCY (FE) OF GROWING AND FINISHING PIGS FED MASH OR PELLETED DIETS AND THE % OF IMPROVEMENT BETWEEN DIETS.

References	Body weight, kg		Main ingredients	FC or FE[1]		
	Initial	Final		Mash	Pelleted	%
Williams et al., 2021	53.0	87.5	Corn and SBM[2]	0.423	0.452	6.9
Williams et al., 2021	53.0	136.2	Corn and SBM	0.371	0.389	4.9
Almeida et al., 2021	22.0	76.5	Corn and SBM	1.993	1.944	2.5
Almeida et al., 2021	22.0	135.2	Corn and SBM	2.252	2.229	1.0
Senger et al.[3]	23.4	93.9	Corn and SBM	2.047	2.013	1.7
Almeida et al.[3]	24.0	71.5	Corn and SBM	1.744	1.683	3.5
Ball et al., 2015	44.8	105.0	Bearly and wheat	2.680	2.550	4.9
Park et al., 2003	49.5	111.8	Wheat	0.354	0.363	2.5
De Jong et al., 2016	31.5	136.0	Corn and SBM	2.590	2.460	5.0
Nemechek et al., 2016	34.4	120.7	Corn and SBM	0.372	0.399	7.3
Nemechek et al., 2016	34.4	120.7	Corn and SBM	0.376	0.394	4.8
Paulk and Hancock, 2016	60.0	127.5	Corn and SBM	0.363	0.393	8.3
Nemechek et al., 2015	56.8	78.0	Corn and SBM	0.415	0.457	10.1
Nemechek et al., 2015	56.8	125.0	Corn and SBM	0.343	0.390	13.7
Jo et al., 2021	22.6	100.0	Corn and wheat	0.435	0.463	6.4
Almeida et al., 2020	96.7	118.7	Corn and SBM	2.816	2.439	13.4
Almeida et al.[3]	98.0	118.0	Corn and SBM	3.000	2.840	5.3

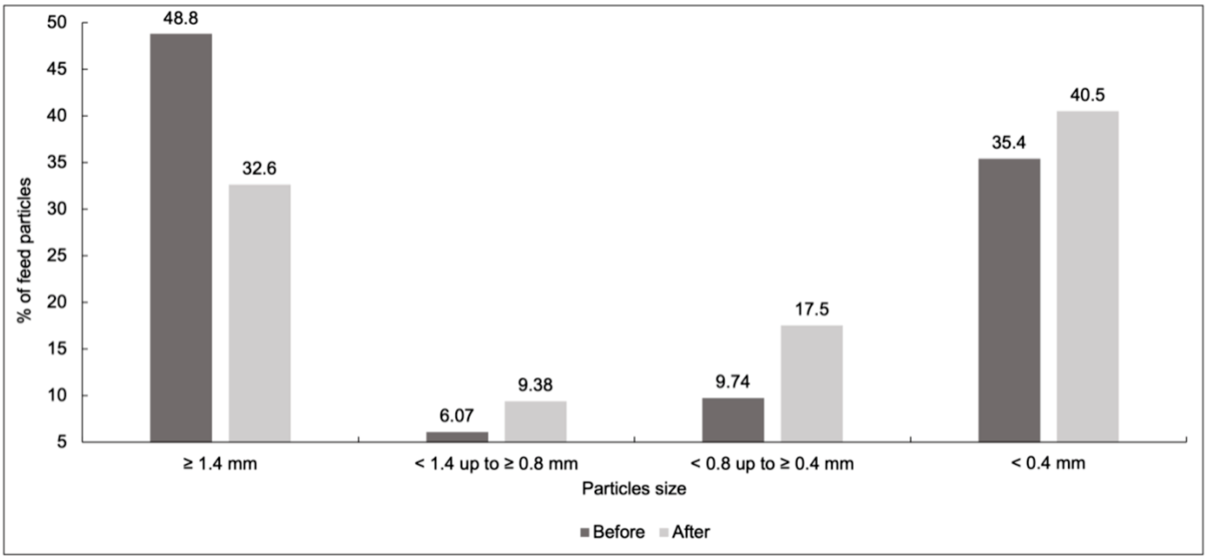
[1]FC – feed conversion ratio; FE – feed efficiency
[2]SBM – soybean meal
[3]Unpublished data.

3.5 REDUCTION OF PARTICLE SIZE DURING PELLETING

As previously discussed, reducing the particle size of ingredients improves the utilization of some nutritional fractions of the diet and consequently can positively influence the performance of pigs. However, when comparing the effect of reducing the GMD of corn (650 to 350 μm) in either mash or pelleted diets, Nemechek et al. (2016) observed different responses according to the feed form; there was a linear improvement in FE with the reduction of corn GMD for pigs receiving a mash diet, whereas no additional benefit was verified with the pelleted diet. A possible explanation for the FE interaction found in this study may be the additional reduction in feed particle size that occurs with pelleting, as during this processing there are shear and compression forces acting on the particles (roll-friction-die and between the particles themselves) and reducing their average size (RUHLE, 2019). In Figure 11, it is possible to observe the impact of pelleting on the feed particles, especially on the coarser particles (≥1.4 mm). Bonilla et al. (2022) founded a reduction of 198, 532 and 505 μm when comparing a mash diet before (914, 1311, 1590 µm) and after (716, 779, 1085 µm) pelleting.

The degree of grinding that occurs during pelleting is influenced by several factors, including: the initial particle size, the compression ratio, the distance between matrix and rolls, the temperature, and the conditioning retention time. To some extent, the effect of grinding is intensified as particle size, compression rate, and die-to-roller gap increase - and reduced with increasing temperature and use of a retainer (for longer conditioning time). The temperature is regulated by the addition of steam, and with higher temperatures comes higher moisture, with consequently more elastic and moldable particles, and less grinding intensity during pelleting. In this perspective, the retainer will also influence the effect of friction between the feed and the equipment, as it ensures greater uniformity of moisture absorption by the feed (RUHLE, 2019; VUKMIROVIC et al., 2017b).

FIGURE 11. COMPARISON OF PARTICLE SIZE BEFORE AND AFTER PELLETING.



SOURCE: Wolf et al., 2010.

4 INTESTINAL HEALTH AND FUNCTIONALITY

Feed structure - both particle size and feed form - can influence the intestinal functionality of pigs by altering the fluidity of the stomach contents and regulating the microbial diversity of the GIT. The use of diets with coarser particles (23.8% of particles >1000 μm or with a medium size >700 μm) 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 bacteria for nutrients and binding sites in the GIT and may increase the intestinal production of mucins and antioxidants, affecting the immune system (YANG et al. 2015). The undissociated form of these acids can pass through the membrane of these bacteria, dissociate inside them and reduce intracellular pH, resulting in cell death (RUSSELL and 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 and MILLS, 2019).

Particle size will not only affect the gastric region, but also other parts of the GIT, namely the large intestine. Increasing the GMD of the diet can result in a greater amount of undigested starch reaching the final portion of the GIT and being used by gram positive bacteria as substrate to produce butyric and propionic acids (KAMPHUES et al., 2007). The alteration of this fermentative pattern may stimulate the growth of epithelial cells, as described by Hedemann et al. (2005) who observed an increase in crypt depth in pigs fed with coarse diets (>16% particles larger than 1000 mm). Additionally, it may also hinder the colonization of some bacteria, including the pathogenic *Salmonella* (LAWHON et al., 2002).

The occurrence of gastric ulcers in pigs is not yet fully understood, but the severe grinding process of the diet seems to be one of the risk factors that contributes to the development of this pathology. Feeding piglets and growing pigs diets containing fine particles (less than 400 μm) leads to higher keratinization scores and stomach ulcers, compared to animals fed coarse diets with GMD greater than 700 μm (HEALY et al., 1994; MOREL and COTTAM, 2007). Potentially, the more fluid stomach contents and the low stomach pH resulting from consuming a diet with fine particles will affect the structure of the non-glandular region of the stomach, with the least mucoid protection (CAPPAI et al., 2013).

In pelleted diets, the grinding caused by pelleting must be considered. Wondra et al. (1995) fed pigs a corn-based diet, which was milled to four mean particle sizes (1,000, 800, 600 and 400 μm) and fed in either mash or pelleted form; stomach lesions and keratinization increased with lower particle size ($P<0.003$) along with the pelleting process ($P<0.02$) for finishing pigs, but performance was significantly better with these processes. However, feeding pelleted diets with fine particle size to grower and finishing pigs can increase the number of animals removed (DE JONG et al., 2016)

Grosse Liesner et al. (2009) and Cappai et al. (2013) discuss the importance of considering the distribution of the particles in a diet rather than their average size alone, when assessing stomach morphology. In diets containing 29% of very fine particles, microscopic lesions are observed in the non-glandular region of the stomach of pigs and increasing fine particles to 36% starts provoking macroscopic lesions. Based on this, the ulcerogenic risk was classified by Cappai et al. (2013) into 3 classes according to the amount of very fine particles (< 400 μm), into: Class 1, high risk (> 36% particles smaller than 400 μm); Class 2, moderate risk (29 to 36% particles smaller than 400 μm); and Class 3, low risk (< 29% particles smaller than 400 μm).

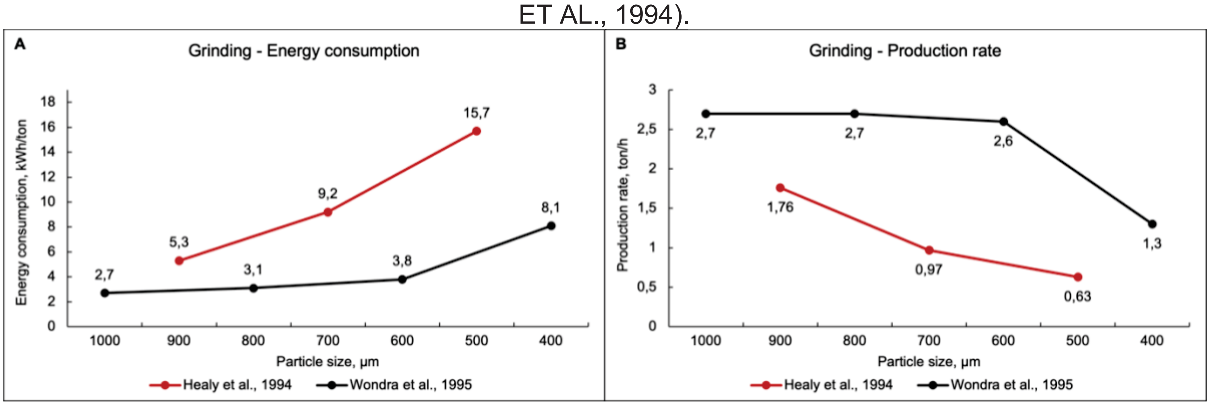
5 PRODUCTION COSTS: GRINDING AND PELLETING

The cost of food grinding and pelleting can be divided into three broad categories: equipment cost, maintenance cost and energy cost. The equipment cost is the initial investment which will be influenced mainly by the type of equipment chosen and the installation costs; for example, roller mills generally have a higher initial cost than hammer mills.

The maintenance costs depend not only on the value of replaced items, but also on the time and labor (qualified or not) required to perform this operation. When comparing the two types of mills, roller mills need less frequent maintenance, but when needed, it is often more expensive (KOCH, 2002). The roller and hammer mill manufacturer CPM (California Pellet Mill) reports that the maintenance costs of hammer mills are lower, but it is influenced by the size of the equipment and the particle size of the ground ingredient.

As discussed, the average size of the particles ground in the mills will also impact the energy used and the production rate (HEALY et al., 1994; WONDRA et al., 1995). Figure 12 exemplifies that as the particle size is reduced from 1000 to 400 µm, there is a considerable increase in the power consumption by the mills and a decrease in the production rate.

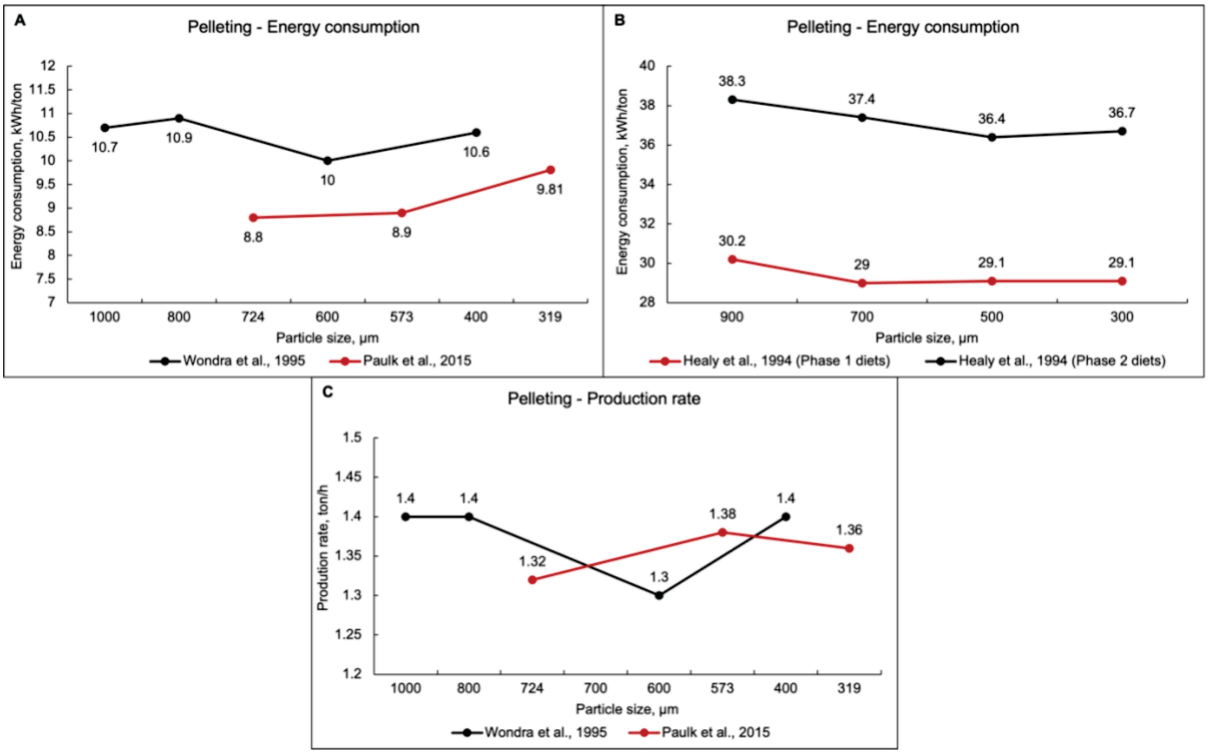
FIGURE 12. EFFECT OF REDUZING PARTICLE SIZE ON ENERGY USAGE (A) AND PRODUCTION RATE (B) OF HAMMER MILL (WONDRA ET AL., 1995) AND ROLLER MILL (HEALY ET AL., 1994).



FONTE: Healy et al., 1994; and Wondra et al., 1995.

The use of coarser particles can negatively affect pellet durability (VUKMIROVIC et al., 2016). This is one of the reasons why companies tend to grind the ingredients finer when producing pelleted diets compared to mash diets, although this technique does not seem to be advantageous from the standpoint of electricity consumption and production rate for both the grinding mills and the pellet mill, (Figure 12 and 13).

FIGURE 13. EFFECT OF REDUZING PARTICLE SIZE ON ENERGY USAGE (A) AND PRODUCTION RATE (B) OF THE PELLET MILL.



SOURCE: Healy et al., 1994; Wondra et al., 1995; and Paulk et al., 2015.

In Figure 13, with the reduction of the particle size from 1000 to 300 µm there were small variations in the electricity consumption and production rate of the pellet mill. This suggests that when pelleting diets for pigs, the use of fine grinds (<600 µm) dramatically increases electricity costs and reduces the grinding rate of ingredients per hour, although there is no benefit of this finer grind on pellet mill costs. The Brazilian industrial electricity tariff went from 38.62 $/MWh (R$5.53 = $1.00) in 2008 to 86.40 $/MWh in 2020 (nominal values; ANEEL, 2020), and this 55.29% increase naturally has a huge impact on the feed production cost. Therefore, it is important to stablish the particle size within the company that will bring the most profitability. For example, Wondra et al. (1995) suggested a GMD for corn of 600 µm or slightly less for finishing pigs, considering the energy required to grind this ingredient, the growth performance, stomach morphology, and nutrient utilization by the pigs.

6 CONSIDERATIONS

Reducing the average particle size of some cereals and grains added to the feed can improve feed utilization and optimize growth performance of nursery, growing, and finishing pigs, although particle size may also affect dietary palatability, functionality, and the intestinal health of the animals.

Pelleting may increase the digestibility of some dietary nutritional fractions and, as a result, improve animal performance. It will also modify the feed form, adhering to a better preference by the pig, and reduce feed wastage when compared to mash diets. Because this process is a compression/compaction of the feed through a matrix die, the particle size of the diet can be reduced during pellet production, which can influence both the functionality and intestinal health as well as performance outcomes. However, a proper pellet quality is crucial to achieve the goals set for when choosing to feed a pelleted diet to the animals.

More intense feed processing, such as expansion, can further alter to the feed structure and consequently improve its utilization. Moreover, due to the increase of heat, the expansion process can improve pellet quality, or even allow for a greater flexibility in diet formulation when performed together with pelleting.

Regarding milling and pelleting costs, the largest cost is associated to the energy expenditure in the feed mill to conduct these processes. Therefore, the understanding of how these processes interact with each other is critical to optimize production costs as a fruit of producing a diet with desirable quality.

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CHAPTER II - SOYBEAN MEAL PARTICLE SIZE FOR PIGS DURING THE NURSERY PHASE

ABSTRACT

The objective of this study was to evaluate 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 gender) with 3 dietary treatments: diets with 1,017 µm (unground), 585 µm (10 mm screen), or 411 µm (3 mm screen) 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 (585 µm) 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 consequently 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. In conclusion, the results obtained in this study demonstrate that the grinding of dietary SBM is not required for piglets during the nursery phase.

Keywords: digestibility, *Glycine max*, growth performance, particle size, piglets.

CAPITÚLO II - TAMANHO DAS PARTÍCULAS DO FARELO DE SOJA EM SUÍNOS NO PERÍODO DE CRECHE

RESUMO

O objetivo deste estudo foi avaliar o efeito do tamanho das partículas do farelo de soja (FS) sobre o desempenho e digestibilidade de leitões no período de creche. 63 leitões (6,86 kg ± 0,56; 23 dias de idade) foram distribuídos aleatoriamente em um delineamento de blocos casualizados (peso inicial e sexo) entre os tratamentos. As dietas experimentais foram produzidas a partir de diferentes tamanhos médios de partículas do FS moídos ou não: 1.017 μm (sem moer), 585 μm (moído em peneira de 10 mm), e 411μm (moído em peneira de 3 mm), totalizando três tratamentos com sete repetições de três animais cada. Todas as dietas foram fornecidas na forma farelada e *ad libitum*, sendo divididas em três fases: (1) com 20% de FS, dos 23 a 32 dias de idade; (2) com 25% de FS, dos 32 a 44 dias de idade; e (3) com 30% de FS, dos 44 a 62 dias de idade. Nos primeiros 21 dias de experimento, os animais consumindo a dieta com o tamanho médio (585 μm) das partículas do FS apresentaram melhor resultados para o ganho de peso médio e conversão alimentar. No período seguinte (44 a 63 d), houve ($P<0,05$) aumento do consumo de ração médio, do ganho do peso médio e melhor conversão alimentar dos leitões conforme o aumento do tamanho da partícula de FS incluída na ração. Consequentemente, ao final do experimento houve melhora linear do peso vivo médio dos animais com o aumento do tamanho do FS consumido. Foi observado melhora marginalmente significativa ($P<0,1$) da energia digestível conforme a redução no tamanho do FS, entretanto, não houve diferença ($P>0,05$) no coeficiente de digestibilidade aparente da matéria seca e da proteína bruta dos animais entre os diferentes tamanhos do FS. Em conclusão, de acordo com as condições deste estudo, não se faz necessária a moagem do farelo de soja para leitões no período de creche.

Palavras-chave: desempenho, digestibilidade, *Glycine max*, tamanho das partículas, leitões.

1 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 AND 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 AND MILLS, 2019).

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).

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.

2 MATERIALS AND METHODS

The experimental procedures involving animals were approved by the Animal Ethics Committee of the Federal University of Paraná, Curitiba, Brazil (Annex 1).

This study included 42 barrows and 21 females piglets of commercial lineage (Genus 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 m^2 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°C at weaning and was reduced weekly to meet the comfort level of the piglets.

The experimental diets were formulated to meet the requirements of nursery pigs, which were divided into three growing phases: pre-initial 1, from 23 to 32 d of age; pre-initial 2, from 32 to 44 d of age; and initial, from 44 to 63 d of age (Table 1). Diets were offered in mash form and contained soybean meal (SBM) with different particle sizes. A single lot of solvent-extracted SBM was ground using a hammer mill (TN-8, Nogueira S/A Máquinas Agrícolas, Itapira, SP, Brazil) driven by a 30 HP electric motor with a rotation speed of 3,500 rpm to achieve three different particle sizes: 1,017 µm (unground), 585 µm (10 mm screen), or 411 µm (3 mm screen) with a geometric standard deviation (GSD) of 1.86, 1.85, and 1.87, respectively. Feed and water were offered *ad libitum*. The corresponding whole-diet distributions and mean particle sizes for each growth phase are presented in Figure 1 and Table 2, respectively.

The particle size distribution of SBM and of each complete diet was determined using a dry sieving method described by Zanotto and Bellaver (1996). Initially, a 200 g sample of SBM or feed was dried in a forced-air ventilation oven at 105ºC for 24 h, equilibrated to room temperature, and weighed. Afterwards, the samples were passed through a sieve stack (Bertel Ind. Metalúrgica Ltda., Caieiras, SP, Brazil) with a set of six sieves (4.0, 2.0, 1.2, 0.6, 0.3, 0.15, and 0.0 mm) and shaken for 10 min. The amount of sample retained on each sieve was weighed, and the geometric mean diameter (GMD) and GSD were calculated for each sample.

TABLE 1. INGREDIENTS AND CALCULATED NUTRIENT CONTENT OF THE DIET (AS-FED BASIS, G/KG).

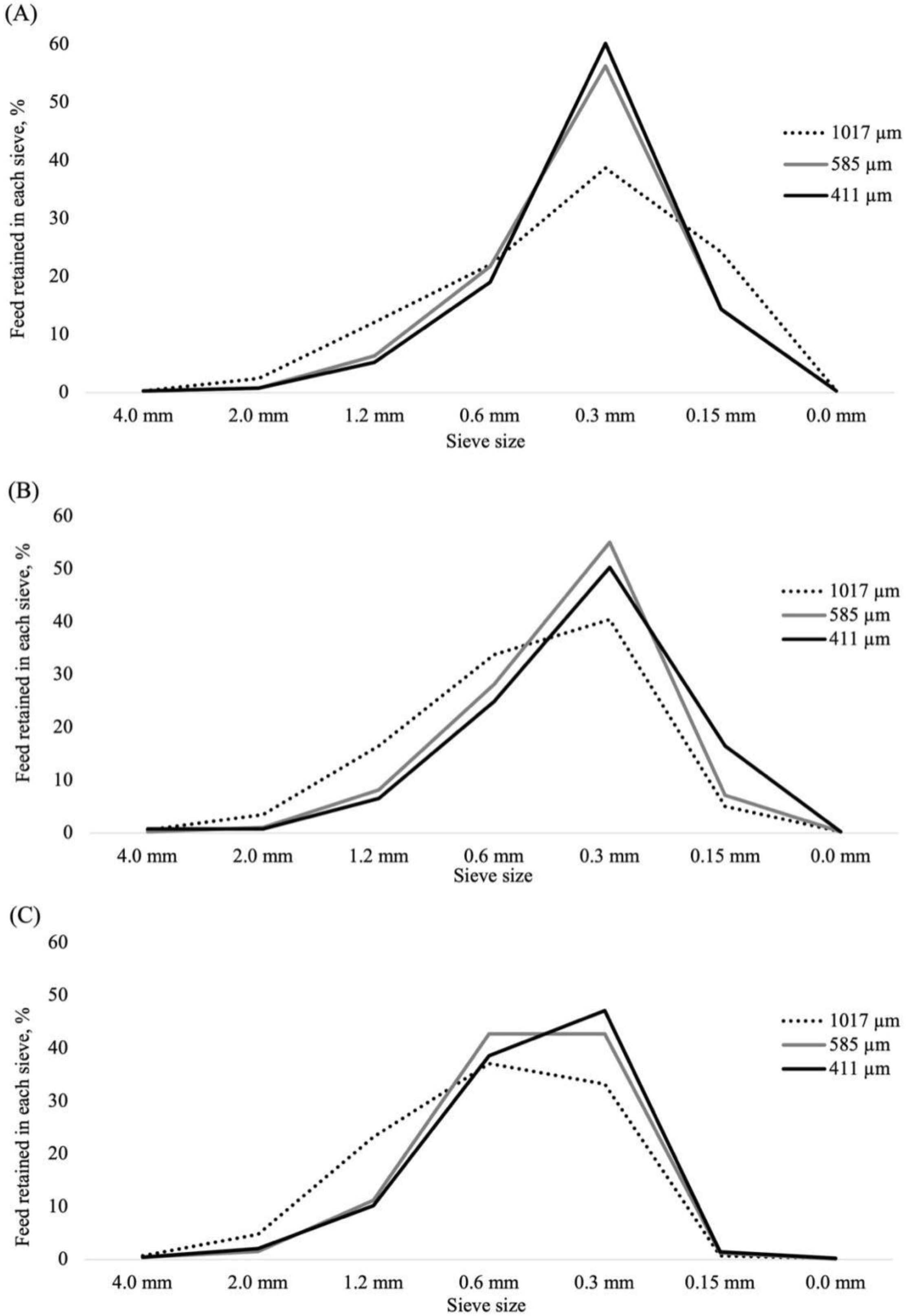
Ingredients	Phase 1	Phase 2	Phase 3
Corn	385.00	490.00	634.00
Soybean meal	200.00	250.00	300.00
Soybean oil	15.00	10.00	15.00
Basic mixture	400.00[1]	250.00[2]	50.00[3]
Celite[4]	-	-	1.00
Calculated Composition			
Metabolizable energy, Mcal/kg	3.48	3.44	3.26
Lactose	100.00	21.50	-
Crude protein	200.60	195.34	188.80
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).

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)		
	1,017	585	411	1,017	585	411	1,017	585	411
GMD, μm	543	522	506	730	591	535	864	717	694
GSD, %	2.02	1.74	1.70	1.86	1.71	1.83	1.82	1.67	1.69

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).



SOURCE: The author, 2022.

The piglets were weighed individually at 23, 32, 44, and 63 d 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°C 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 (IkaWerke 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 and Young (1977).

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

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

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:

$$\text{DE} = \text{GE of diet} - (\text{GE of fecal content} \times \text{IF}).$$

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).

3 RESULTS AND DISCUSSIONS

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 AND JENSEN, 2004; MONTAGNE et al., 2007; BARSZCZ AND 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).

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 µm	585 µm	411 µm			
Phase 1, 23 to 32 days of age[3]						
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[4]						
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						
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						
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						
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 µm, respectively.
[4]Geometric mean diameter of the complete diets phase 2 were: 730, 591 and 535 µm, respectively.
[5]Geometric mean diameter of the complete diets phase 3 were: 864, 717 and 694 µm, respectively.

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 AND LANDEAU, 2000; ROJAS AND 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 influence (P>0.05) the apparent digestibility coefficients of the DM and CP (Table 4).

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 DAYS3.

Item	Soybean meal particle size[1]			SE	L[2]	Q[2]
	1,017 µm	585 µm	411 µm			
ADC of DM, %	76.13	76.89	77.17	0.60	0.151	0.414
ADC of CP, %	69.51	69.55	69.30	0.83	0.810	0.917
DE, kcal	3266	3326	3344	30.66	0.097	0.293

[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.

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) found 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 µm or with a medium size >700 µm) 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 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 AND 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 AND MILLS, 2019). Therefore, diets with coarser SBM may have contributed to improved gut health of the piglets, which resulted in improved growth performance.

4 CONCLUSIONS

The results obtained in this study demonstrate 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.

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CHAPTER III - EFFECT OF FEED PARTICLE SIZE IN PELLETED DIETS ON GROWTH PERFORMANCE AND DIGESTIBILITY OF WEANING PIGLETS

ABSTRACT

The objective of this study was to evaluate the effect of particle size in pelleted diet on nutrient digestibility and growth performance of weaning piglets. 352 uncastrated males with 28 d old were distributed in a randomized block design (initial weight) according to treatments. The experimental feeds were divided into two phases, pre-initial (28 to 42 d) and initial (43 to 63 d) and produced with different corn particle sizes ground in a hammer mill, which provided a geometric mean diameter (GMD) of 394 μm, 534 μm, 647 μm, and 695 μm respectively, to the pre-initial phase diets. In the initial phase the GMD were 587 μm, 625 μm, 798 μm, and 943 μm. All feeds were pelleted (pellet diameter 2.5 mm) and supplied *ad libitum*. After an analysis of variance ($P<0.05$), orthogonal contrasts were constructed to evaluate the linear and quadratic effect of increasing feed particle size on digestibility and growth performance. In the pre-initial phase, there was no difference in daily feed intake and daily weight gain between treatments; however, there was a quadratic response ($P<0.05$) in feed/gain ratio, and the reduction of GMD to 534 μm was positively correlated with feed/gain ratio. In the initial phase, feed intake increased linearly ($P<0.05$) with increasing GMD in the pelleted diet. GMD had no effect on feed/gain ratio, but there was a linear correlation ($P<0.05$) between GMD and weight gain in this phase, owing to greater feed consumption. There was a linear response ($P<0.05$) in dry matter and ether extract digestibility coefficients, with the highest values determined in pigs consuming the finest diets (587 μm). GMD had no effect on crude protein digestibility, but there was a quadratic correlation ($P<0.05$) between particle size and digestible energy, as digestible energy reduced when GMD increased up to 798 μm, followed by a slight increase at 943 μm. In conclusion, as the weaning pigs become older, their growth performance response increases with increasing particle size of the pelleted diet. The GMD for an optimal pelleted feed is 534 μm for pre-initial and 943 μm for initial phase. Additionally, during the initial phase, fine particle sizes results in better efficiency of feed utilization.

Keywords: digestibility, performance, pigs.

CAPÍTULO III – EFEITO DO TAMANHO DAS PARTÍCULAS EM DIETAS PELETIZADAS SOBRE O DESEMPENHO E DIGESTIBILIDADE DE LEITÕES DESMAMADOS

RESUMO

O objetivo deste estudo foi avaliar o efeito do tamanho das partículas da dieta peletizada na digestibilidade dos nutrientes e no desempenho de leitões desmamados. 352 machos não castrados com 28 dias de idade foram distribuídos em blocos casualizados (peso inicial) de acordo com os tratamentos. As rações experimentais foram divididas em duas fases, pré-inicial (28 a 42 d) e inicial (43 a 63 d) e produzidas com diferentes tamanhos de partículas de milho moídas em moinho de martelos, o que proporcionou diâmetro geométrico médio (DGM) de 394 µm, 534 µm, 647 µm e 695 µm nas dietas da fase pré-inicial. Na fase inicial, os DMG eram 587 µm, 625 µm, 798 µm e 943 µm. Todas as rações foram peletizadas (diâmetro do pellet 2,5 mm) e fornecidas *ad libitum*. Após análise de variância ($P<0,05$), contrastes ortogonais foram construídos para avaliar o efeito linear e quadrático do aumento do tamanho das partículas da ração na digestibilidade e desempenho dos animais. Na fase pré-inicial não houve diferença no consumo diário de ração e ganho de peso diário entre os tratamentos; entretanto, houve uma resposta quadrática ($P<0,05$) na conversão alimentar, sendo a melhor reposta dos animais consumindo a dieta com o DGM de 534 µm. Na fase inicial, o consumo de ração aumentou linearmente ($P<0,05$) com o aumento do DGM da dieta peletizada. O DGM não teve efeito sobre a conversão alimentar, mas houve correlação linear ($P<0,05$) entre DGM e ganho de peso nesta fase, devido ao maior consumo de ração. Houve resposta linear ($P<0,05$) nos coeficientes de digestibilidade da matéria seca e do extrato etéreo, sendo os maiores valores determinados em suínos que consumiram as dietas mais finas (587 µm). O DGM não teve efeito sobre a digestibilidade da proteína bruta, mas houve uma correlação quadrática ($P<0,05$) entre o tamanho das partículas e a energia digestível. Em conclusão, com o aumento da idade do leitão, melhor a resposta no desempenho conforme o aumento do tamanho das partículas da dieta peletizada. O DGM ideal foi 534 µm na fase pré-inicial e 943 µm na inicial. Além disso, na fase inicial, o aproveitamento da dieta foi melhor para os animais consumindo as dietas finas.

Palavras-chave: desempenho, digestibilidade, suíno.

1 INTRODUCTION

Feed milling is the step of feed processing in which the particle size of an ingredient is reduced. The main objective of this regular feed factory process is to reduce particle size in order to facilitate the intake and improve the nutritional availability of dietary fractions. This, in turn, increases the contact surface of the feed, which then becomes more accessible to digestive enzymes, consequently affecting the feed efficiency of the animal. Feed milling also provides other benefits such as mixing capacity/uniformity, decreases separation during bulk feed transport, increases the degree of starch gelatinization during pelletizing, and improves pellet quality. In contrast, very fine feeds can lead to increased production costs, factory generated dust, and functional changes in the gastrointestinal tract of pigs.

The particle size will depend on the type of grain used in the feed, the growth phase of the pigs, and the physical form of the feed. For weaning piglets, reducing wheat size from 1,300 to 400 μm had a quadratic effect on daily weight gain (DWG) and feed efficiency, and better results were obtained with diets containing wheat with 680 μm particle size (MAVROMICHALIS et al., 2000), whereas corn size reduction from 900 to 300 μm improved feed efficiency linearly in the first two weeks after weaning (HEALY et al., 1991). However, regarding the effect of physical form of the feed, particle size reduction in pelleted feeds showed no effect on growth performance compared to mashed feeds; Nemechek et al. (2016) reported improved feed efficiency with corn size reduction in mashed feeds (from 650 to 360 μm), this reduction was not extended to animals consuming pelleted feeds.

Thus, the objective of this study was to evaluate the effect of feed particle size, produced with different corn particle size, in pelleted diets on total nutrient digestibility, digestible energy, and growth performance of weaning piglets (28 to 63 d).

2 MATERIAL AND METHODS

The experimental procedures involving animals were approved by the Animal Ethics Committee of the Federal University of Paraná, Curitiba, Brazil (Annex 2).

2.1 ANIMALS AND HOUSING

This study included 352 uncastrated male pigs of commercial lineage (Genus PIC®, Hendersonville, TN, USA), with a mean initial weight of 7.10 ± 1.11 kg and 28 d of age (28 to 42 d in the pre-initial phase and 43 to 63 d in the initial phase), were housed in 2.8 m^2 pens with partially slatted flooring (approximately 65%) and supplied with trough feeder and automatic nipple drinker. The mean weaning age of the pigs was 21 d (5.94 ± 0.94 kg), and the first week of weaning was set as a period of adaptation to the new environment and diet. During this period all pigs received a single pelleted feed (pellet diameter 2.5 mm), before receiving the experimental diets starting at aged of 28 d.

2.2 EXPERIMENTAL DIETS

The diet was formulated to meet the requirements of uncastrated weaning pigs, which were divided into two growing phases: pre-initial, from 28 to 42 d; and initial, from 43 to 63 d (Table 1). The experimental diets were produced with different corn particle sizes, ground in a hammer mill (KW 350 with two screens; Kepler Weber, São Paulo, Brazil) with different screens (2.5 x 2.5 mm, 2.8 x 2.8 mm, 2.8 x 8.0 mm and 8.0 x 8.0 mm) used to achieve four different particle sizes of the feed in each growing phase. The particle size of the feed in the pre-initial phase were 394 µm, 534 µm, 647 µm, and 695 µm; and for the initial phase were 587 µm, 625 µm, 798 µm, and 943 µm (Table 2).

All experimental feeds were pelleted and produced in a steam pellet mill (DFPC-L; Bühler AG, Uzwill, Switzerland) with a 200 HP motor and a die with 2.5:15 mm diameter:effective thickness ratio (pre-initial and initial). The conditioning time was 12 s at a temperature of 50 to 60°C and pressure of 117.68 kPa. After the pelletizing process, the feeds were dried and cooled until reaching a temperature of 32 °C.

Before pelletizing, particle size distribution of each pre-initial and initial experimental feeds were determined using a dry sieving method described by Zanotto and Bellaver (1996). Ground feed samples (200 g; 4 replicates per particle size) were passed through a screen stack with a set of 7 sieves (4.0, 2.0, 1.2, 0.6, 0.3, 0.15 and 0.0 mm) on shakers for 10 minutes. The amount of sample retained on each screen was determined and the geometric mean diameter (GMD) and geometric standard deviation (GSD) was calculated for each sample.

To determine the percentage of fines, 500 g of the pelleted feeds for each phase were weighed and sieved for approximately 30 s using 2 mm screens (Tyler no. 10; Telastem Peneiras para Análises Ltda., São Paulo, Brazil). The percentage of fines was expressed as the percentage of pelleted feed retained on the sieve in relation to the initial weight (Table 2).

The pellet durability index (PDI) was evaluated using a PDI testing equipment (Durabilimetro; RA Eletromecânica, Santa Helena, Brazil). Approximately 500 g of the pellet retained on the sieves during the determination of fines percentages was used in the PDI testing equipment. All samples were processed at 50 rpm for 10 min and thereafter sieved (2 mm) for approximately 30 s to remove fines and broken pellets. PDI was calculated by dividing the weight of the sample after sieving by the weight before sieving and expressed as percentages according to the method described by Ensminger (1985) (Table 2).

TABLE 1. COMPOSITION AND FORMULATION OF THE EXPERIMENTAL DIETS (G/KG, AS FED BASIS).

Ingredients	Pre-initial	Initial
Corn	299.60	555.70
Soybean meal	190.00	255.00
Milk whey	137.70	-
Broken rice	120.00	-
Cracked bran	70.00	50.00
Viscera and bone meal	50.00	50.00
Chicken fat	35.90	25.30
Blood plasma	30.0	-
Soy protein concentrate	20.3	-
Mono-dicalcium phosphate	14.5	4.0
Premix[a]	8.0	11.09
Lysine sulfate	6.13	6.34
Calcitic limestone	4.62	8.25
Organic acid	3.84	3.85
Methionine	2.23	1.87
Iodized granulated salt	2.18	3.94
Threonine	1.56	1.72
Mineral mix	1.25	1.10
Copper sulfate	0.80	0.80
Tryptophan	0.61	0.57
Choline chloride	0.52	0.39
Ronozyme Histarch[c]	0.133	0.133
Soy Fatty Acid	-	15.00
Celite[b]	-	5.0
Calculated Composition		
Metabolizable energy, Mcal/kg	3.45	3.4
Ether extract	69.80	73.70
Crude protein	220.2	202.9
Lactose	100.0	-
Lysine	16.11	13.88
Methionine	5.49	4.93
Methionine + cysteine	9.50	8.15
Threonine	10.59	9.13
Tryptophan	3.29	2.82
Total calcium	7.50	7.20
Total phosphorus	7.10	5.40

[a]Premix provided the following quantities per kilogram of complete diet: Fe, 77.6 mg; Cu, 11.6 mg; Mn, 67.9 mg; Zn, 97.0 mg; I, 0.97 mg; Se, 0.31 mg; vitamin A, 11,250 UI; vitamin D3, 2250 UI; vitamin E, 22.5 UI; vitamin K3, 2.0 mg; vitamin B1, 1.75 mg; vitamin B2, 5.0 mg; vitamin B6, 1.75 mg; vitamin B12, 22.5 mcg; niacin, 37.5 mg; pantothenic acid, 20.0 mg; folic acid, 0.5 mg; biotin, 0.125 mg.
[b]Indigestible external indicator (Celite Hyflo; Imerys, Arica, Chile).
[c]Amylase was added in diets at 80 KNU/kg.

TABLE 2. GEOMETRIC MEAN DIAMETER (GMD), GEOMETRIC STANDARD DEVIATION (GSD), PELLET DURABILITY INDEX (PDI), AND PERCENTAGE OF FINE (% FINE) OF EXPERIMENTAL PIGLET FEEDS IN THE PRE-INITIAL (28 TO 42 D) AND INITIAL (43 TO 63 D) GROWING PHASES.

Feed GMD, µm	GSD, %	PDI, %	% Fine
Pre-initial			
394	2.07	98.33	0.38
534	1.70	98.50	0.27
647	1.96	97.72	3.69
695	2.04	95.96	11.22
Initial			
587	1.85	85.42	1.74
625	1.81	76.28	2.90
798	2.19	82.57	2.64
943	2.18	77.60	3.87

2.3 PERFORMANCE AND DIGESTIBILITY

The animals were weighed individually at 28, 42, and 63 d to evaluate their DWG. Both the feed supplied and the leftover were weighed to determine daily feed intake (DFI) and feed/gain ratio (F/G).

Daily partial feces collection was conducted from animals at 49 to 53 d, and the material was frozen until use. An indigestible external indicator (Celite Hyflo; Imerys, Arica, Chile) was added to all experimental initial phase feeds to evaluate nutrient digestibility. The feces samples were thawed, homogenized, and dried in a forced-ventilation oven at 55°C until constant weight. After drying, feces and feed samples were ground to 1 mm and analyzed for dry matter (DM), crude protein (CP, method 954.01), and ether extract (EE, method 945.16) according to the AOAC (1995). Gross energy (GE) levels were determined using a calorimetric bomb (IkaWerke C2000 Control Oxygen Bomb Calorimeter; Ika-Werke GmbH & Co, Staufen, Germany). To quantify the external indicator, acid insoluble ash (AIA) was determined using the adapted gravimetric method proposed by Van Keulen and Young (1977). The apparent digestibility coefficient (ADC) of nutrients was calculated using the following formula:

$$ADC = (\text{dietary nutrient}) - (\text{feces nutrient} \times IF)/\text{dietary nutrient},$$

where IF is the indigestibility factor calculated as the ratio between AIA levels of diet and feces.

Digestible energy (DE) was calculated using the following formula:

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

2.4 EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

The data were analyzed as a randomized block design; the block (initial weight) was considered a randomized effect and the pen an experimental unit, with four treatments, each with eight replicates and 11 pigs per replicate. After the analysis of variance ($P<0.05$), orthogonal contrasts adjusted for unequal spacing between treatments were constructed to evaluate the linear and quadratic effect of increased feed particle size on digestibility and animal performance. The data were analyzed using the Linear Mixed-Effects Models package (BATES et al., 2015) in R (R CORE TEAM, 2009).

3 RESULTS AND DISCUSSIONS

In the present study, there was no difference (P>0.05) among the treatments in DFI and DWG of piglets aged between 28 and 42 d; however, there was a quadratic response (P<0.05) for F/G, which decreased in pigs receiving diets with GMD reducing to 534 μm (Table 3). Nemechek et al. (2016), using corn feed with different GMD (650 to 360 μm) and two physical forms (pelleted or mash), reported a linear reduction in DFI and a linear decreased in F/G when reducing GMD in growing and finishing pigs fed mash diet, but observed no effect of particle size on the performance of pigs consuming pelleted diets. According to these authors, there is no need for a very fine milling of this cereal if pelleted feed is used because of the particle grinding during this thermal process. During the pre-initial phase, the GSD of 534 μm complete diet was better than others, which can be associated with higher quality pellets, as reflected by the PDI greater than 98% and percentage of fines lesser than 0.3% (Table 2). Additionally, there was an increasing percentage of fines in the diet with the coarsest particles size (695 μm), which is in according to Reimer (1992), who reported that pellet quality is influenced in 20% by particle size.

TABLE 3. EFFECT OF THE GEOMETRIC MEAN DIAMETER (GMD) OF PELLETED FEEDS ON DAILY FEED INTAKE (DFI), DAILY WEIGHT GAIN (DWG) AND FEED/GAIN RATIO (F/G) OF UNCASTRATED MALE PIGLETS AGED 28 TO 42 D.

Item	Feed GMD				SEM	*P*-value[1]	
	394 μm	534 μm	647 μm	695 μm		L	Q
DFI, g	429	408	418	429	32	-	-
DWG, g	354	339	341	346	28	-	-
F/G	1.213	1.204	1.227	1.245	0.009	0.005	0.017

[1]Linear (L) and quadratic (Q) effect for feed particle size.

There was a linear increase (P<0.05) in DFI in the period between 43 and 63 d with increasing GMD of the feed from 587 to 943 μm, which was similarly reported by Wondra et al. (1995) in growing pigs. GMD had no effect on F/G of the animals, but there was a linear correlation (P<0.05) between GMD and DWG in this phase as consequence of higher feed consumption (Table 4). These results suggest that the response to GMD reduction is greater in the first weeks after weaning and the optimal particle size of the feed increases with the age of weaning pigs, thus corroborating Healy et al. (1994) who evaluated the effect of feed with particle size between 300 and 900 µm. Regarding the diet quality in the initial phase, there was a reduction on PDI and percentage of fines as the greater inclusion of corn resulted in a coarser feed when compared to the pre-initial diets.

TABLE 4. EFFECT OF THE GEOMETRIC MEAN DIAMETER (GMD) OF PELLETED FEEDS ON DAILY FEED INTAKE (DFI), DAILY WEIGHT GAIN (DWG) AND FEED/GAIN RATIO (F/G) OF UNCASTRATED MALE PIGLETS AGED 43 TO 63 D.

Item	Feed GMD				SEM	*P*-value[1]	
	587 µm	625 µm	798 µm	943 µm		L	Q
DFI, g	797	800	820	845	25	0.001	0.722
DWG, g	631	633	648	670	19	0.001	0.534
F/G	1.264	1.265	1.267	1.262	0.007	-	-

[1]Linear (L) and quadratic (Q) effect for feed particle size.

The reduced GMD of the feed translates to larger surface area exposed to digestive enzymes, which promotes the digestibility of dietary fractions and may consequently improve animal performance. Guillou and Landeau (2000) studied the effect of different GMD and raw materials on CP digestibility and energy in pigs for each 100 µm reduction between 1,500 and 200 µm, and showed a 0.847% and 0.629% improvement in the ADC of nitrogen and energy digestibility, respectively. Although, the authors concluded that this result was influenced by the main raw material used in the diet. Diets with different corn particle sizes showed a 3.4% improvement of DE in weaned piglets consuming finer feeds (430 µm) compared with coarser GMD diets (840 µm) (ALBAR et al., 2000), and a linear increase in apparent ileal digestibility of starch when decreasing particle size from 865 to 339 µm in growing pigs (ROJAS and STEIN, 2015). Corroborating the data on improved diet fraction digestibility, Steinhart (2012) summarized the effect of GMD reduction from 900 µm to 500 µm on feed efficiency (FE) and reported an improvement of approximately 1 to 1.2% in FE for every 100 µm reduction.

However an interaction between feed GMD and the pelletizing process is also potential. Wondra et al. (1995) evaluated the interaction between corn GMD (1,000 to 400 µm) and the physical form of the feed (pelleted and mash). They observed a linear increase in GE digestibility with corn particle reduction from 1,000 to 400 µm in animals consuming pelleted feed, but a quadratic response in animals consuming mash feed; GE digestibility was improved at particle size less than 800 µm. This positive effect on GE digestibility with coarser particles in pelleted diets may have occurred due to a decreased GMD caused by milling during the pelleting process. Feed milling in the pelleting process takes place due to both the narrow space between the rollers and the die and the frictional force in the die holes (VUKMIROVIĆ et al., 2017).

Digestibility based on partial feces collection revealed a linear response ($P<0.05$) in ADC of DM and EE, with increased values obtained when reducing the particle size from 943 to 587 µm (Table 5). In addition, GMD had no effect ($P>0.05$) on ADC of CP, but there was a quadratic correlation ($P<0.05$) between particle size and DE, as DE reduced when GMD was increased up to 798 µm, followed by a slight increase at 943 µm (Table 5). The reduced particle size of the diet increased the exposed surface area, allowing better contact with digestive enzymes, thereby improving digestion in the small intestine of animals consuming finer feeds. However, coarse feed may intensify fermentation in the large intestine due to larger amounts of the undigested substrate reaching the lower gut, as observed by Morel and Cottam (2007) when reporting similar results for DE when comparing fine (±400 µm) and coarse (±1000 µm) feeds.

TABLE 5. EFFECT OF THE GEOMETRIC MEAN DIAMETER (GMD) OF PELLETED FEEDS ON THE APPARENT DIGESTIBILITY COEFFICIENT (ADC) OF DRY MATTER (DM), CRUDE PROTEIN (CP), AND ETHER EXTRACT (EE), AND THE DIGESTIBLE ENERGY (DE) OF UNCASTRATED MALE PIGLETS AGED 49 TO 53 D..

Item	Feed GMD				SEM	*P*-value[1]	
	587 µm	625 µm	798 µm	943 µm		L	Q
ADC of DM, %	85.59	85.68	85.43	84.39	0.372	0.033	0.285
ADC of CP, %	81.31	81.56	81.67	80.51	0.440	-	-
ADC of EE, %	77.60	76.36	72.76	72.08	0.960	<0.001	0.237
DE, kcal	4390	4268	3956	4002	31.55	<0.001	<0.001

[1]Linear (L) and quadratic (Q) effect for feed particle size.

Feed structure, both particle size and physical form, can influence the fluidity of stomach content and microbial diversity of the gastrointestinal tract in pigs. The stomach content of pigs fed coarse particles (>700 µm) shows a higher amount of DM, higher water binding capacity, firmer consistency, and consequently decreased passage rate (REGINA et al., 1999; MIKKELSEN et al., 2004; CANIBE et al., 2005). These changes can bestow two benefits, a reduced keratinization score and a decreased number of ulcers in the stomach of piglets and growing pigs consuming feeds with GMD greater than 700 μm when compared with those consuming finer feeds with GMD less than 400 μm (HEALY et al., 1994; MOREL and COTTAM, 2007). In addition, the total number of anaerobic bacteria present in the stomach increases as does the production and the changes in the profile of short-chain fatty acids, whereas stomach pH decreases (MIKKELSEN et al., 2004; CANIBE et al., 2005). The association between lower stomach pH and high concentration of short-chain fatty acids, mainly lactic acid, creates an additional protective barrier (KIARIE and MILLS, 2019).

The GMD affects not only the gastric region of pigs, but also other parts of the gastrointestinal tract, particularly the large intestine. An increased GMD may result in more undigested starch reaching this final portion of the tract, favoring gram-positive bacteria and increasing the production of butyric acid (KAMPHUES et al., 2007). This is considered to stimulate the growth of epithelial cells, as described by Hedemann et al. (2005), who observed increased crypt depth in pigs consuming coarse diets (>16% of particles larger than 1,000 mm). The use of coarse feeds for piglets can improve the intestinal functionality of these animals by promoting intestinal morphology and decreasing proliferation of bacteria, including the harmful *Salmonella* and *E. coli* (KIARIE and MILLS, 2019). Therefore, diets with coarser particle sizes may also have improved the piglets' gut health and helped them achieve better growth performance results.

4 CONCLUSIONS

The older the piglets, the better the performance response to increased particle size of the pelleted feed. Under the conditions of this study, a particle size of 534 µm was ideal for animals aged 28 to 42 d, and a particle size of 943 µm was ideal for animals aged 43 to 63 d. Additionally, during the initial phase, fine particle sizes resulted in better efficiency of feed utilization.

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CHAPTER IV – EFFECT OF PELLETING AND DIFFERENT FEEDING PROGRAMS ON GROWTH PERFORMANCE OF GROWING AND FINISHING PIGS

ABSTRACT

The objective of this study was to evaluate the effect of pelleting on growth performance of growing and finishing pigs fed through different feeding programs. An experiment was conducted during the growing period, using uncastrated males (from 23 to 71.5 kg body weight), and two others during finishing period, one with castrated males and one with gilts (from 96 and 119 kg body weight). The dietary treatments on all three experiments consisted of a mash diet fed *ad libitum* and a pelleted diet fed either at 100% or restricted to 96 to 85% the amount consumed by pigs fed the mash diet. All data were analyzed by analysis of variance and, when significant ($P<0.05$), means were compared using Dunnett's test. Throughout all experiments, the animals that consumed pelleted diet equalized to the same amount as the mash diet presented higher daily body weight gain or final body weight. During the growing male experiment, the average body weight gain of pigs fed pelleted diets restricted at 96% was similar to pigs fed mash diets. The finishing gilts and castrated males were able to maintain their average body weight gain even when pelleted diet intake was restricted to 90 and 85%, respectively. As a result of higher body weight gain, all pigs consuming pelleted diet had lower feed conversion ratio, apart from finishing males under the highest level of restriction. In conclusion, equalized feeding of pelleted diets improved the growth performance of both growing and finishing pigs, whereas restricted feeding led to equal performance results as *ad libitum* mash feeding.
Keywords: conditioning, feeding program, pelleting, performance, processing.

CAPÍTULO IV - EFEITO DA PELETIZAÇÃO E DIFERENTES PROGRAMAS ALIMENTARES SOBRE O DESEMPENHO DE SUÍNOS EM CRESCIMENTO E TERMINAÇÃO

RESUMO

O objetivo desse estudo foi avaliar o efeito da peletização da ração sobre o desempenho produtivo de suínos em crescimento e terminação alimentados por meio de diferentes programas alimentares. Foi conduzido um experimento com machos inteiros durante a fase de crescimento (entre os 23 e 71,5 kg), e dois experimentos, um com machos castrados e outro com fêmeas, durante o período de terminação (96 e 119kg). Os tratamentos consistiram na oferta ração farelada à vontade ou ração peletizada fornecida na mesma proporção (100%) ou limitado (de 96% a 85%) com base na quantidade consumida pelos suínos alimentados com dieta farelada à vontade. Os dados foram submetidos à análise de variância e quando significativas ($P<0,05$), as médias foram comparadas pelo teste de Dunnett. Em todos os experimentos, os animais que consumiram ração peletizada em quantidade equalizada à farelada apresentaram maior ganho de peso diário ou peso final. No experimento com machos em fase de crescimento, o ganho de peso médio dos animais consumindo dieta peletizada limitada em 96% foi igual ao dos que receberam ração farelada à vontade. As fêmeas e machos castrados em terminação mantiveram o ganho de peso médio mesmo quando limitado o consumo de ração peletizada a 90 e 85%, respectivamente. Consequentemente, todos os suínos consumindo ração peletizada apresentaram menor conversão alimentar, com exceção dos machos em terminação sob o maior nível de redução. Em conclusão, a oferta equalizada de ração peletizada melhorou o desempenho produtivos dos suínos em crescimento e terminação, enquanto a alimentação com limitação resultou em desempenho similar aos tratamentos com ração farelada *ad libitum*.

Palavras-chave: condicionamento, desempenho, peletização, processamento, programa alimentar.

1 INTRODUCTION

Pelleting has become a widely used thermal process to maximize the performance of growing and finishing pigs, since it can result in up to 5% lower feed conversion (NEMECHEK et al., 2015 and 2016; DE JONG et al., 2016; JO et al., 2021, WILLIAMS et al., 2021). Basically, this feed processing consists of a heat treatment of the mash feed, through the addition of saturated steam (with high heat and moisture) for a certain time during the conditioning step, followed by forcing the mash through a matrix die, thus shaping the feed into pellets.

The gains obtained by pelleting the diet are connected by and large to the keen application of heat, moisture, and pressure during processing, which can decrease the microbiological load in the mash (BOLTZ et al., 2019) and lead to changes in the physical and chemical characteristics of the raw materials present in the feed, thereby increasing the digestibility of different dietary nutritional fractions (SVIHUS et al., 2005; LUNDBLAD et al., 2011). In addition, the new physical form (pellet) can be expected to increase feed consumption (SUREK et al., 2017) and decrease feed wastage by the animals (SUREK et a., 2017; SENGER et al., unpublished data).

Multiple factors resulting from pelleting may contribute to the improvement of growth performance. In growing and finishing pigs particularly, though, it is still not clear if the optimization of performance is related to feed wastage reduction, increase in nutrient digestibility, higher feed intake, or to a concurrent combination of all these factors. Therefore, the objective of this study was to evaluate the effect of equalization and reduction of pelleted feed consumed daily in relation to *ad libitum* mash consumption in growth performance of growing and finishing pigs.

2 MATERIAL AND METHODS

Three experiments were conducted under compliance with the Animal Ethics Committee of the Federal University of Paraná, Curitiba, Brazil (Annexes 3 and 4).

2.1 ANIMALS AND HOUSING

In the first experiment, a total of 240 uncastrated male PIC® (Genus PIC®, Hendersonville, TN, USA) pigs averaging 23.98 ± 0.06 kg and with 63 days of age were housed in groups of six for 52 days (3 days of adaptation + 49 days of experiment) in 9.12 m^2 pens, with compact flooring and equipped with trough feeders and duck-billed drinkers.

For the second and third experiments, 25 PIC® gilts with a mean initial body weight of 96.85 ± 3.52 kg and 130 days of age, and 24 PIC® castrated males with a mean initial body weight of 98.06 ± 4.63 kg and 145 days of age, respectively, were selected and housed individually for 18 days (4 days of adaptation + 14 days of experiment) in 4 m^2 pens, with partially trellised floors (26%), trough feeders and duck-billed drinkers.

During the experimental period, the room temperature was controlled by curtain management, and the animals had free access to water, whereas feed was provided according to the dietary treatments.

2.2 EXPERIMENTAL DIETS AND FEEDING PROGRAMS

Experimental diets were based on corn and soybean meal, formulated to meet the requirements of growing animals (Experiment 1) divided into three phases, as shown in Table 1, and finishing animals (Experiments 2 and 3, Table 2). Diets were offered in either mash or pelleted form as per each treatment.

TABLE 1. INGREDIENTS AND NUTRITIONAL COMPOSITION OF THE EXPERIMENTAL DIETS FOR GROWING PIGS (G/KG, AS FED BASIS).

	Phase 1	Phase 2	Phase 3
Corn	705.50	726.50	765.00
Soybean meal	156.94	164.71	106.07
Feather meal	-	-	30.00
Viscera and bone meal	82.00	55.0	46.50
Poultry fat	24.50	24.50	24.00
Premix	2.00[a]	1.60[b]	1.20[c]
Iodized granulated salt	4.95	5.02	4.67
Limestone	4.60	5.85	6.12
Copper sulfate 25%	0.34	0.35	0.36
Liquid Lysine	8.57	8.46	9.70
Liquid Methionine	2.23	2.14	1.36
L-Threonine	1.89	1.89	1.63
L-Tryptophan	0.40	0.38	0.53
L-Valine	0.43	0.46	-
Others	5.62	3.12	2.85
Calculated composition			
Metabolizable energy (kcal/kg)	3375	3375	3375
Crude protein	187.70	177.10	172.50
Digestible amino acid,			
Lysine	11.75	11.25	10.75
Methionine	4.51	4.27	3.43
Methionine + Cysteine	7.05	6.75	6.45
Threonine	7.64	7.31	6.99
Tryptophan	2.00	1.91	1.83
Arginine	10.41	9.78	9.15
Valine	7.64	7.31	7.10
Total Calcium, %	8.55	7.50	6.65
Available P (%)	4.50	3.75	3.50

[a]Premix provide the following per kilogram of diet in the phase 1: Fe, 120 mg; Cu, 100 mg; Mn, 75 mg; Zn, 175 mg; I, 1.0 mg; Se, 0.5 mg; vitamin A, 10,000 UI; vitamin D3, 2,000 UI; vitamin E, 100 UI; vitamin K3, 4.0 mg; vitamin B1, 3.0 mg; vitamin B2, 9.0 mg; vitamin B6, 4.5 mg; vitamin B12, 40.0 mcg; niacin, 40.0 mg; pantothenic acid, 30.0 mg; folic acid, 1.2 mg; biotin, 0.250 mg.

[b]Premix provide the following per kilogram of diet in the phase 2: Fe, 96 mg; Cu, 100 mg; Mn, 60 mg; Zn, 140 mg; I, 0.8 mg; Se, 0.4 mg; vitamin A, 8,000 UI; vitamin D3, 1,600 UI; vitamin E, 80 UI; vitamin K3, 3.2 mg; vitamin B1, 2.4 mg; vitamin B2, 7.2 mg; vitamin B6, 3.6 mg; vitamin B12, 32.0 mcg; niacin, 32.0 mg; pantothenic acid, 24.0 mg; folic acid, 0.96 mg; biotin, 0.200 mg.

[c]Premix provide the following per kilogram of diet in the phase 3: Fe, 72 mg; Cu, 100 mg; Mn, 45 mg; Zn, 105 mg; I, 0.6 mg; Se, 0.3 mg; vitamin A, 6,000 UI; vitamin D3, 1,200 UI; vitamin E, 60 UI; vitamin K3, 2.4 mg; vitamin B1, 1.8 mg; vitamin B2, 5.4 mg; vitamin B6, 2.7 mg; vitamin B12, 24.0 mcg; niacin, 24.0 mg; pantothenic acid, 18.0 mg; folic acid, 0.72 mg; biotin, 0.150 mg.

TABLE 2. INGREDIENTS AND NUTRITIONAL COMPOSITION OF EXPERIMENTAL DIETS FOR FINISHING PIGS.

Ingredients	g/kg as feed basis
Corn	837.95
Soybean meal	101.08
Viscera and bone meal	27.72
Poultry fat	12.94
Premix[1]	0.70
Iodized granulated salt	4.58
Limestone	7.63
Copper sulfate 25%	0.37
L-Lysine-HCL	3.56
DL-Methionine	0.85
L-Threonine	12.60
L-Tryptophan	0.29
Others	1.0
Calculated composition	
Metabolizable energy (kcal/kg)	3325
Crude protein	130.0
Digestible amino acid,	
Lysine	7.5
Methionine	2.75
Methionine + Cysteine	4.72
Threonine	5.25
Tryptophan	1.35
Arginine	6.83
Valine	5.11
Total Calcium (%)	6.00
Available P (%)	3.00

[1]Premix provide the following per kilogram of diet: vitamin A, 6,500 IU; vitamin D_3, 2,000 IU; vitamin E, 42 mg; vitamin K_3, 2.0 mg; vitamin B_2, 6.4 mg; vitamin B_6, 3.0 mg; vitamin B_{12}, 24 µg; D-biotin, 160 µg; D-calcium pantothenate, 20 mg; folic acid, 1.2 mg; niacina, 24 mg; Cu, 125 mg; potassium iodate, 0.5 mg; Fe, 100 mg; Mn, 50 mg; Zn, 100 mg; Se, 250 µg; and choline chloride, 250 mg.

Pelleted diets were manufactured using a steam pellet mill (Model MOGL - 450, Zheng Chang Calibras, Campinas - SP, Brazil) with a 64 mm thick ring die and a 4 mm diameter holes. Conditioning temperature was set to 80ºC for 20 seconds. Subsequently, the pellets were dried and cooled, when then samples of each diet were collected for physical analyses.

The different feeding programs adopted throughout the experiments are summarized in Table 3. In all the experiments, mash diet was considered the control group, and pigs allocated to this treatment had free access to feed. The feed intake of the control group was measured daily and then used to calculate the amount of feed given to the restricted groups, which only received pelleted feed.

TABLE 3. FEEDING PROGRAMS APPLIED FOR THE EXPERIMENTAL DIETS.

Feeding group	Exp. 1 – Growing whole males (23 to 71.5 kg body weight)	Exp. 2 – Finishing sows (96 to 119 kg body weight)	Exp. 3 – Castrated finishing males (98 to 118 kg body weight)
Control group		Mash *ad libitum*	
Amount of feed offered in relation to control group	Pelleted 100%	Pelleted 100%	-
	Pelleted 96%	Pelleted 95%	Pelleted 95%
	Pelleted 93%	Pelleted 90%	Pelleted 90%
	Pelleted 89%	-	Pelleted 85%

Pellet physical quality assessments were conducted. The percentage of fines was determined by sieving 500 g of sample through a 3.4 mm sieve (Tyler no.6, Telastem Peneiras para Análise LTDA, São Paulo, Brazil) for approximately 30 s, the determining the weight of fines passing through the sieve relative to the initial sample weight. The pellet durability index (PDI) was measured using a durability tester (Durabilimeter, RA Electromecânica, Santa Helena, Brazil); 500 g sample of pellets retained on the sieve after the determination of the percentage of fines was stirred at 50 rpm for 10 min and sieved (3.4 mm) for approximately 30 s to remove fines and broken pellets; the PDI was then calculated as the ratio between the weight of pellets retained on the sieve and the initial sample weight, expressed as a percentage according to the methodology of Ensminger (1985). Hardness was measured in a hardness tester (Nova Ética®, model 298DGP-Ethiktechnology, São Paulo, Brazil) using individual pellets (20 pellets).

The pelleted diets from experiment 1 (phase 1, 2, and 3) had a PDI of 82.84, 85.89, and 71.31%; percent fines of 13.20, 22.17, and 3.91%; and hardness of 3.0, 3.73, and 2.64 kgf/cm^2, respectively. The pelleted diets of experiments 2 and 3 had a PDI of 87.17 and 92.59%; percent fines of 2.6 and 1.75%; and hardness of 3.13 and 4.60 kgf/cm^2, respectively.

2.3 GROWTH PERFORMANCE

All animals were weighed at the beginning and end of each experiment to determine the average daily weight gain (AWG) in the period. The feeders in pens receiving the mash feed were weighed daily in the morning to calculate daily feed intake (DFI), then used to determine the amount of pelleted feed provided to the restricted treatments. Feed conversion ratio (FC) was calculated as the ratio between DFI by AWG. As a result of the different feeding programs, there was great variability in the average final weight of the pigs, thereby an adjusted feed conversion (AdjFC) was calculated in each experiment, according to the formula:

$$\text{AdjFC} = \{[\text{standardized final body weight} - \text{actual final body weight}] \text{ x slope estimate}\} + \text{observed feed conversion},$$

considering 70 kg as the standard final body weight in experiment 1, and 120 kg for experiments 2 and 3. The slope estimate was 0.011.

2.4 EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

The data from experiment 1 were analyzed as a randomized complete design with five treatments with eight replicates of six pigs each; data from experiments 2 and 3 were analyzed according to randomized block design where the block (initial weight) was considered a random effect. Experiment 2 had four treatments and five repetitions of one pig each, and experiment 3 had four treatments and six repetitions with one pig each. In all experiments, the repetition (pen) was considered the experimental unit. After submitting to analysis of variance, significant means were compared by Dunnett's multiple comparisons test, considering the treatments receiving *ad libitum* mash diet as a control group. All statistical procedures were performed using the software R (R CORE TEAM, 2018).

3 RESULTS

Throughout all three experiments, both the animals receiving mash diet at will (control group) and those receiving 100% of the control group's intake as pelleted diet had the highest DFI (P < 0.05). All other restrictively fed groups consumed less than the control group.

In experiment 1 (Table 4), the growing pigs supplied 100% pelleted feed had higher AWG, and lower FC and AdjFC than the control group (P<0.001). When restricting the offer of pelleted diets to 96%, AWG was similar to those consuming mash feed at will, but FC and AdjFC were reduced. When further restricting the offer of pelleted diet to 93%, there was a reduction in AWG (P<0.10) but still lower FC (P<0.05); the same was observed in animals that had the pelleted diet restricted to 89%, although for this group the final weight was lower compared to the control group.

TABLE 4. EFFECT OF DIFFERENT FEEDING PROGRAMS AND PELLETING ON DAILY FEED INTAKE (DFI), AVERAGE WEIGHT GAIN (AWG) FEED CONVERSION RATIO (FCR), ADJUSTED FEED CONVERSION RATIO (AdjFCR), AND FINAL AVERAGE BODY WEIGHT (ABW) OF PIGS FROM 23 TO 71.5 KG.

	Mash (control)	Pelleted diet supplied according to mash diet				SEM	*P*-value
		100%	96%	93%	89%		
DFI, kg	1.712	1.724	1.638 **	1.585 ***	1.521 ***	0.150	<0.001
AWG, kg	0.981	1.013 ·	0.983	0.950 ·	0.926 *	0.090	<0.001
FC	1.744	1.687 *	1.683 *	1.668 **	1.643 ***	0.015	<0.001
AdjFC-70kg	1.721	1.644 *	1.643 *	1.662	1.649 *	0.019	0.040
BW, kg	72.08	73.62	72.18	70.53	69.40 **	0.485	<0.001

Dunnet - *** <0.001; **<0.01; * <0.05; · <0.10
SEM = Standard error of the mean.

In experiment 2 (Table 5), there was no difference in AWG (P>0.05) between the gilts consuming mash feed or pelleted feed, regardless of the level of restriction, but lower FC and AdjFC-120kg was observed in all groups consuming pelleted diet (P<0.05). Additionally, gilts receiving 100% pelleted feed had higher final body weight compared to the control group (P>0.10).

TABLE 5. EFFECT OF DIFFERENT FEEDING PROGRAMS AND PELLETING ON DAILY FEED INTAKE (DFI), AVERAGE WEIGHT GAIN (AWG) FEED CONVERSION (FC), ADJUSTED FEED CONVERSION (AdjFC), AND FINAL AVERAGE BODY WEIGHT (ABW) OF SOWS FROM 96 TO 119 KG.

	Mash (control)	Pelleted diet supplied according to mash diet			SEM	*P*-value
		100%	95%	90%		
DFI, kg	4.286	4.284	4.072 ***	3.858 ***	0.116	<0.001
AWG, kg	1.536	1.706	1.660	1.590	0.077	0.182
FC	2.816	2.529 *	2.452 **	2.429 **	0.082	0.002
AdjFC-120kg	2.906	2.590 *	2.535 *	2.524 *	0.094	0.012
BW, kg	116.85	119.47 ˙	117.41	116.39	2.04	0.060

Dunnet - *** <0.001; **<0.01; * <0.05; ˙ <0.10
SEM = Standard error of the mean.

In experiment 3 (Table 6), restricting the offer of pelleted feed to 95% resulted in higher AWG and final live weight of castrated male pigs, as well as lower FC and AdjFC-120kg, compared to those in the control group. When restricting pelleted feed intake by 90%, though, no difference in AWG between treatments was observed, yet lower FC and AdjFC-120kg were observed for the pigs consuming pelleted diets. When the restriction was further increased to 85%, no differences between treatments were detected for AWG, FC, AdjFC-120kg or average final body weight.

TABLE 6. EFFECT OF DIFFERENT FEEDING PROGRAMS AND PELLETING ON DAILY FEED INTAKE (DFI), AVERAGE WEIGHT GAIN (AWG) FEED CONVERSION (FC), ADJUSTED FEED CONVERSION (AdjFC), AND FINAL AVERAGE BODY WEIGHT (ABW) OF CASTRADED PIGS FROM 98 TO 118 KG.

	Mash (control)	Pelleted diet supplied according to mash diet			SEM	*P*-value
		95%	90%	85%		
DFI, kg	4.003	3.816 *	3.595 ***	3.405 ***	0.079	<0.001
AWG, kg	1.333	1.578 ***	1.438	1.245	0.047	<0.001
FC	3.003	2.418 ***	2.526 ***	2.760	0.090	0.001
AdjFC-120kg	3.035	2.416 ***	2.552 ***	2.808	0.095	0.004
BW, kg	117.13	120.16*	117.60	115.7	2.00	<0.001

Dunnet - *** <0.001; **<0.01; * <0.05; ˙ <0.10
SEM = Standard error of the mean.

4 DISCUSSIONS

Heat processing the diet was shown to provide beneficial effects on growth performance of pigs. Even after restricting the consumption of pelleted feed by 4% and up to 15%, both growing male pigs and finishing castrated males and gilts were able to achieve the same AWG as those granted free access to mash feed. Moreover, when equalizing the intake of both physical forms, AWG was higher for growing pigs consuming the processed diets, which was also true for finishing male pigs in the 95% restriction group; such results suggest that pelleting may have had an impact on dietary nutrient utilization due to an exposure of the mash to elevated heat and pressure.

The gelatinization of starch and protein denaturation may be cited as the most perceived causes for physical and chemical changes occurring in the raw materials during pelleting. Gelatinization can be defined as the irreversible destruction of the crystalline condition of the starch granule, making the surface of the molecule accessible to reagents, solvents, and enzymes (LUND and LORENZ, 1984; MORITZ et al., 2005). Protein denaturation refers to the physical changes that causes a disruption of the secondary, tertiary, and quaternary protein structures, changing their spatial formation and disordering the arrangements between intermolecular bonds (ARAÚJO et al., 2009). These two reactions may facilitate the digestion of starch, protein, and most amino acids (ROJAS and STEIN, 2017), thus improving overall nutrient utilization, and as a result it is possible to observe reduced FC and/or higher weight gain in animals fed pelleted diets (BALL et al., 2015, NEMECHEK et al., 2016, SUREK et al., 2017; O'MEARA et al., 2020, SENGER et al., unpublished data). However, in the cited studies, the effect of pelleting cannot be attributed only to an optimized nutrient utilization, but also to a possible higher feed consumption or/and reduced waste due to the feed form effects.

According to Svihus et al. (2005), though, pelleting has little effect on starch availability, and the onset of starch gelatinization is in fact more imminent in more intense heat processes like extrusion, in which more water and higher temperatures are employed. However, this reaction can also be relevant to the pelleting process, as its degree of occurrence depends on the steam parameters (the temperature and moisture) and conditioning time. By increasing the temperature from 47ºC to 90ºC during the pelleting process, Lundblad et al. (2011) found an increase in the amount of gelatinized starch by 5 and 6%, respectively, compared to mash feed. Lewis et al. (2015) observed a 19% increase in gelatinized starch when raising the conditioning temperature from 77 to 88ºC, along with a 6% conditioning the mash for a longer time, from 15 to 60 seconds. There are still several other factors that can interfere in the extent of physical and chemical changes in raw materials caused by pelleting, namely the type, particle size, and level of inclusion of the main raw material used in the feed (ABDOLLAHI et al., 2010; MURAMATSU et al., 2014).

In the current study, the impact on growth performance generated by pelleting was less evident in the younger animals. Unlike finishing pigs, growing pigs were not able to maintain AWG when the offer of pelleted diet was restricted above 4%. Body weight is naturally related to the age of the animal, and it is a factor that also influences nutrient digestibility; heavier animals may present a longer retention time of the digesta along the gastrointestinal tract, as well as higher enzyme activity and secretion rate, higher absorptive efficiency, and higher microbial activity (NOBLET and VAN MILGEN, 2004; NITRAYOVÁ et al., 2006; ZHAO et al., 2020). Furthermore, even though the feed processing conditions were the same for growing and finishing experiments, the higher amount of corn (starch) in the finishing diets may have been an influencing factor in the animal’s response to the treatments.

The grinding of the diet that can occur during pelleting is another detail to be addressed. During heat processing, there are shear and compression forces acting upon the particles (roll-friction-die, and between-particles themselves) and grinding down the material particles to smaller sizes (RUHLE, 2019). In turn, reducing particle size will widen its contact surface, further exposing the feed to the digestive enzymes secreted in the tract, and thereby resulting in higher nutrient availability to potentialize the animal’s growth performance (HEALY et al., 1994; VUKMORIVIC et al., 2017).

5 CONCLUSION

The results of this study demonstrated that pelleting improved growth performance of growing and finishing pigs when not overly restricting feed consumption. When using equalized feeding, processed diets were superior to mash diets in increasing average body weight gain and reducing feed conversion ratio throughout all experiments. A restriction of pelleted feed intake up to 96% relative to the *ad libitum* mash feeding did not affect weight gain in whole male pigs from 23 to 71.5 kg, and animals consuming pelleted feed had lower feed conversion ratio regardless of the level of restriction; during the finishing period, pelleted feed intake was further restricted to 90% for gilts (96 to 119 kg) and 85% for castrated males (98 to 118 kg) without affecting average body weight gain, and both categories presented lower feed conversion ratio when fed pelleted diets.

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CHAPTER V - EFFECT OF FEED FORM AND HEAT PROCESSING ON THE GROWTH PERFORMANCE OF GROWING AND FINISHING PIGS

ABSTRACT

The objective of this study was to evaluate the effect of different feed processing methods (pelleting and/or expansion) and feed physical form on the growth performance of growing-finishing pigs submitted to quantitative feed control. Commercial hybrid boars (n=200), with 22 kg initial body weight were distributed in a randomized complete block design with five treatments and eight replicate pens of five pigs each. Treatments consisted of a mash feed, pelleted feed, expanded-pelleted feed, expanded-mash feed, and mash feed with previously expanded corn and soybean meal. Daily feed intake, average body weight, average daily gain, and feed conversion ratio were calculated at 63, 98, 128, 157, and 185 d of age. Data were submitted to analysis of variance, and when significant, treatment means were compared by orthogonal contrasts. No differences were detected for daily feed intake. However, from 63 to 128 d, the pigs fed processed diets showed improvements ($P<0.05$) for average daily gain (2.9%), body weight (1.9%), and feed conversion (2.9%) compared with those fed the unprocessed mash diet. Growth performance variables evaluated for the cumulative periods of 63 to 157 and 63 to 185 d were not influenced ($P>0.05$) by the treatments. It was concluded that feed processing positively influences growth performance of growing pigs (63 to 128 d) submitted to controlled feeding programs.

Keywords: expansion, feeding program, pelleting.

CAPÍTULO V – EFEITO DA FORMA FÍSICA E PROCESSAMENTO TÉRMICO SOBRE O DESEMPENHO DE SUÍNOS EM CRESCIMENTO E TERMINAÇÃO

RESUMO

O objetivo deste estudo foi avaliar o efeito de dietas com duas formas físicas e submetidas ou não a processamento térmico (peletização ou expansão) sobre o desempenho de suínos em crescimento e terminação com programa de controle alimentar quantitativo. Suínos machos inteiros (n=200) com 22kg de peso médio inicial foram distribuídos em um delineamento experimental de blocos casualizados (peso ao alojamento), totalizando 5 tratamentos, com 8 repetições de 5 animais cada. Os tratamentos consistiram em dieta farelada, dieta peletizada, dieta expandida-peletizada, dieta expandida-farelada e dieta farelada com a fração vegetal (milho e farelo de soja) expandida. O consumo diário de ração, ganho diário de peso, peso médio e conversão alimentar foram avaliados aos 63, 98, 128, 157 e 185 dias de idade. Os dados foram analisados pela análise de variância, e quando significativos, as médias dos tratamentos foram comparadas por contrastes ortogonais. Devido ao programa alimentar controlado, não foi verificado diferença ($P>0,05$) no consumo de ração médio. Entretanto, dos 63 aos 128 dias de idade, os animais consumindo as dietas submetidas ao processamento térmico apresentaram melhora ($P<0,05$) no ganho de peso diário (2,9%), peso médio (1,9%) e conversão alimentar (2,9%) em relação aos animais consumindo a dieta farelada. As variáveis de desempenho avaliadas para os períodos acumulados de 63 a 157 e 63 a 185 dias de idade não foram influenciadas ($P>0,05$) pelos tratamentos. Em conclusão, o efeito do processo térmico dos alimentos e/ou da ração melhorou o desempenho na fase de crescimento, dos 63 aos 128 dias de idade, de suínos alimentados de forma controlada quantitativamente.

Palavras-chaves: controle alimentar, expansão, peletização.

1 INTRODUCTION

In commercial pig production, diets are typically fed as pellets. Pelleting consists of applying heat, moisture, and pressure to agglomerate the diet mash mixture into larger particles. After mixing, the mash is submitted to conditioning, where different values of temperatures and moisture, generally ranging between 60-100ºC and 12-18%, respectively, are applied (HANCOCK, 1993).

Diet pelleting promotes several benefits. Some advantages of the physical form of pelleted feeds include easier handling, reduced feedstuff segregation, and reduced feed waste in the feeders compared with mash diets. In addition, conditioning of the mash before it is pressed in the pellet die improves protein and starch digestibility (WONDRA et al., 1995; MEDEL et al., 2004; LUNDBLAD et al., 2012). The application of high temperature and moisture can break the intermolecular bonds that maintain the crystalline structure of starch granules, which causes them to dilate and absorb water, thus increasing viscosity in a process called starch gelatinization. The gelatinized starch is more accessible to amylases, leading to greater starch digestibility (LUND and LORENZ, 1984; MORITZ et al., 2005). Pelleting also promotes that partial denaturation of proteins, increasing the access of proteases to the protein substrate (DOZIER, 2001).

Feed mash can be also submitted to expansion, which consists in the transfer of mechanical energy in thermal energy and the addition of steam for a short time (5 s), allowing the mash to reach temperatures above 100 ºC (MURAMATSU et al., 2014). Therefore, the expansion results in more intense modifications of the physical structures of the ingredients, improving the quality of the pellet and thus leading to improvements on growth performance (NEMECHEK et al., 2015; MURAMATSU et al., 2016). However, this process is more aggressive than pelleting, as the greater temperature and pressure may result in the formation of resistant starch through the retrogradation process, and reduce protein solubility through Maillard reaction, impairing the digestibility of these fractions (WANG et al., 2019).

Quantitative feed control or feed restriction programs applied during the growing and finishing phases have been used for decades in pig production, aiming at improving feed efficiency, reducing carcass fat deposition, and increasing lean yield relative to pigs fed *ad libitum*. In this context, the objective of this study was to evaluate the effect of different feed processing methods (pelleting and/or expansion) and feed physical form on the performance of growing-finishing pigs submitted to quantitative feed control.

2 MATERIAL AND METHODS

The experimental procedures involving animals were approved by the Animal Ethics Committee of the Federal University of Paraná, Curitiba, Brazil (Annex 5).

2.1 PIGS AND HOUSING

Commercial hybrid (Genus PIC®, Hendersonville, TN, USA) boars (n=200), with 22 kg ± 1.36 initial body weight (BW), were used from 63 to 185 days of age. Pigs were housed in 5.5 m^2 pens with partially slatted floor that were equipped with a trough feeder and a nipple drinker.

2.2 EXPERIMENTAL DIETS

Four experimental basal diets were formulated to meet the nutritional requirements of the boars, divided into 4 production phases (starter, grower, finisher 1, and finisher 2). Feedstuffs and calculated nutritional composition of the experimental diets are shown in Table 1. The experimental diets of each phase contained equal nutrient levels, and differed only as to feed processing method and physical form.

The following treatments were used: mash feed; pelleted feed; expanded-pelleted feed; expanded-mash feed; and mash feed with previously expanded corn and soybean meal. The main feedstuffs were ground through a 3 mm hammer mill screen. The mash feed was not subjected to any further processing. The pelleted diet consisted of the mash diet submitted to pelleting. The expanded-pelleted feed consisted of the mash feed submitted to the expansion process and then pelleted afterwards. The mash diet was also expanded and then ground through a 3 mm hammer mill screen to form the expanded-mash feed, and for the last dietary treatment, only corn and soybean meal were expanded and then ground through a 3 mm hammer mill screen before mixing. The equipment and process parameters are described below.

A steam pellet mill (model CPM 7000W, California Pellet Mill Co., Crawfordsville, USA) was used for pelleting, with a 250 hp motor and a die with 4:55 mm diameter:effective thickness ratio. The mash was conditioned for 7 s, at 75°C and 117.68 kPa pressure. After pelleting, the diets were dried and cooled.

Expanding was carried out in an expander (model OE38.2, Amandus Kahl GmbH & Co., Reinbek, Germany) at 105°C and 9414.4 kPa pressure for 4 s, and the expanded diets and expanded corn and soybean meal were dried and cooled.

TABLE 1. INGREDIENTS AND CALCULATED NUTRIENT CONTENT OF THE DIET (AS-FED BASIS, %).

Ingredients (%)	Starter 63 to 98 d	Grower 98 to 128 d	Finisher 1 128 to 157 d	Finisher 2 157 to 185 d
Corn	74.95	77.37	79.94	81.28
Soybean meal	18.19	16.53	14.75	13.96
Poultry fat	2.62	2.14	1.67	1.15
Bicalcium phosphate	1.71	1.52	1.33	1.33
Limestone	0.72	0.66	0.62	0.62
NaCl	0.500	0.501	0.501	0.501
L-Lysine-HCL	0.508	0.468	0.419	0.377
Premix [1]	0.420	0.420	0.420	0.420
DL-Methionine	0.151	0.134	0.119	0.105
L-Threonine	0.202	0.176	0.151	0.160
L-Tryptophan	0.092	0.082	0.073	0.079
Total	100.00	100.00	100.00	100.00
Calculated composition				
Metabolizable energy (kcal/kg)	3350	3340	3330	3300
Crude protein (%)	15.15	14.5	13.8	13.5
Digestible amino acid (%)				
Lysine	1.00	0.93	0.85	0.80
Methionine + Cysteine	0.580	0.551	0.523	0.504
Methionine	0.356	0.334	0.312	0.296
Threonine	0.649	0.605	0.561	0.560
Tryptophan	0.231	0.213	0.196	0.197
Available P (%)	0.400	0.363	0.325	0.325
Ca (%)	0.780	0.707	0.634	0.634
Na (%)	0.210	0.210	0.210	0.210

[1]Premix provide the following per kilogram of diet: vitamin A, 6,500 IU; vitamin D_3, 2,000 IU; vitamin E, 42 mg; vitamin K_3, 2.0 mg; vitamin B_2, 6.4 mg; vitamin B_6, 3.0 mg; vitamin B_{12}, 24 µg; D-biotin, 160 µg; D-calcium pantothenate, 20 mg; folic acid, 1.2 mg; niacina, 24 mg; Cu, 125 mg; potassium iodate, 0.5 mg; Fe, 100 mg; Mn, 50 mg; Zn, 100 mg; Se, 250 µg; and choline chloride, 250 mg.

2.3 FEEDING PROGRAM

The experimental diets were supplied twice daily, at 08:00 and 15:00 h. Feed allowance was adjusted weekly, according to the production phase: 1.150-1.700 kg/pig in the starter phase, 1.850-2.250 kg/pig in the grower phase, 2.250-2.550 kg/pig in the finisher 1 phase, and 2.550-2700 kg/pig in the finisher 2 phase.

2.4 PELLET QUALITY ANALYSES

The variables percentage of fines in the total diet and pellet durability index (PDI) were used to evaluate pellet quality (Table 2). The percentage of fines was determined by sieving 500 g of the pelleted diet treatments through a 3.4 mm sieve (Tyler no.6, Telastem Peneiras para Análise LTDA, São Paulo, Brazil) for approximately 30 s, and calculated as the weight of the fines passing through the sieve relative to initial sample weight.

The pellet durability index (PDI) was measured in a pellet durability tester (Durabilímetro, RA Electromecânica, Santa Helena, Brazil). A 500 g sample of the pellets retained in the sieve after the percentage of fines was determined was shaken at 50 rpm for 10 min and sieved (3.4 mm) for approximately 30 s to remove fines and broken pellets. PDI was calculated by dividing the weight of the pellets retained in the sieve by the initial sample weight, and expressed as a percentage according to the methodology of Ensminger (1985).

TABLE 2. PERCENTAGE OF FINES (%) AND PELLET DURABILITY INDEX (PDI) OF THE PELLETED AND EXPANDED-PELLETED DIETS OF EACH FEEDING PHASE.

Phases	Pelleted		Expanded-pelleted	
	PDI, %	% Fines	PDI, %	% Fines
Starter	93.96	39.03	93.68	2.87
Growing	90.86	32.33	91.23	10.90
Finishing 1	94.66	37.41	95.29	16.42
Finishing 2	87.13	39.50	89.10	3.66

2.5 GROWTH PERFORMANCE

Pigs were weighed at housing (initial body weight, 63 d) and at 98, 128, 157, and 185 days of age to calculate average body weight (ABW, kg) and average daily gain (ADG, g/d). Daily feed provisions were recorded to calculate daily feed intake (DFI, g/d). Feed conversion ratio (FC) was calculated as the ratio between DFI and ADG.

2.6 EXPERIMENTAL DESIGN AND STATISTICAL ANALYSES

Pigs were allocated to the treatments according to a randomized complete block design with five treatments and eight replicate pens per treatment, and five pigs per pen. Initial BW was used as the blocking criterion. For statistical analysis purposes, the pen was considered the experimental unit. Data were submitted to the Shapiro-Wilk normality test and Bartlett's homoscedasticity test ($P<0.05$). Once these conditions were satisfied, analysis of variance ($P<0.05$) was performed. When significance was detected ($P<0.05$), the following orthogonal contrasts ($P<0.05$) were evaluated: 1- mash *vs*. all processed diets; 2 - pelleted + expanded-pelleted *vs*. expanded-mash + expanded corn and soybean meal, in order to compare feed physical form; 3 - pelleted *vs*. expanded-pelleted, to compare diets submitted to double processing; and 4 – expanded-mash *vs*. expanded corn and soybean meal, to compare the expansion of the whole diet with the expansion of the main ingredients only. All statistical procedures were performed using the software R (R CORE TEAM, 2009).

3 RESULTS

The growth performance results obtained during the starter phase (63 to 98 days of age) are shown in Table 3. Although no DFI differences were detected among treatments, ADG and FC were influenced by the treatments (P<0.01). Compared with the mash diet (orthogonal contrast 1), all diets submitted to processing promoted, on average, a 2.94% improvement in ADG and FC (P=0.001), resulting in 1.92% higher ABW (P=0.002) at the end of the starter phase. The comparison of diet physical form (contrast 2) showed that pigs fed the expanded-mash diets or diets with expanded corn and soybean meal performed better (P<0.05) than those fed pelleted or expanded-pelleted diets. On average, improvements of 1.86% in ADG, 1.93% in FC, and 1.32% in ABW were obtained with expanded-mash diets compared to pelleted diets.

During the cumulative period of 63 to 128 days of age (Table 3), no differences were detected for DFI. Compared with the mash diet, pigs fed the processed diets had 2.62% greater ADG (23.02 g), and 2.86% improvement in FC (P<0.01), and were 2.27% (1.757 kg) heavier (P<0.001) at 128 days of age. Growth performance variables for the cumulative periods of 63 to 157 days of age (finisher 1) and 63 to 185 days of age (finisher 2) were not influenced by treatment.

TABLE 3. GROWTH PERFORMANCE OF PIGS FED THERMAL PROCESSED OR UNPROCESSED DIET.

	M[1]	Pe	ExM	ExPe	IngExM	SEM	*P*-value	*P* – Orthogonal contrasts[3]			
								1	2	3	4
					63 to 98 d						
DFI[2], g	1406	1407	1404	1405	1406	1.01	0.918	0.847	0.863	0.374	0.910
ADG, g	739	758	773	750	765	3.08	0.003	0.001	0.020	0.342	0.351
FC	1.902	1.855	1.817	1.873	1.839	0.007	0.002	0.001	0.016	0.389	0.281
ABW, kg	46.93	47.71	48.40	47.35	47.94	24.59	0.001	0.002	0.012	0.395	0.132
					63 to 128 d						
DFI, g	1701	1695	1697	1700	1697	1.87	0.835	0.487	0.485	0.707	0.483
ADG, g	853	872	887	871	875	3.25	0.018	0.003	0.153	0.919	0.195
FC	1.993	1.944	1.912	1.952	1.939	0.006	0.002	<0.001	0.095	0.670	0.154
ABW, kg	75.67	77.47	78.23	76.83	77.18	29.34	0.002	<0.001	0.207	0.342	0.067
					63 to 157 d						
DFI, g	1913	1912	1915	1919	1916	2.13	0.872	0.387	0.831	0.698	0.607
ADG, g	917	929	945	936	930	3.28	0.088	0.447	0.059	0.107	0.202
FC	2.085	2.058	2.025	2.049	2.061	0.006	0.057	0.576	0.026	0.098	0.219
ABW, kg	108.02	109.12	110.35	109.12	108.63	37.16	0.136	0.830	0.033	0.158	0.586
					63 to 185 d						
DFI, g	2082	2083	2086	2090	2088	2.28	0.820	0.378	0.879	0.680	0.464
ADG, g	925	935	948	942	935	3.17	0.229	0.433	0.124	0.197	0.307
FC	2.252	2.229	2.201	2.219	2.233	0.007	0.242	0.571	0.086	0.207	0.414
ABW, kg	134.69	135.81	137.13	136.0	135.30	42.75	0.327	0.720	0.088	0.253	0.677

[1]M – unprocessed mash; Pe – Pelleted; ExM – expanded-mash; ExPe – expanded-pelleted; IngExM – mash diet previously expanded corn and soybean meal.
[2]DFI – daily feed intake; ADG – average daily gain; FC – feed conversion ratio; ABW – average body weight.
[3]1 – M *vs.* all processed diets; 2 – Pe and ExPe *vs.* ExFa and IngExM; 3 – Pe *vs.* ExPe; 4 – ExM *vs.* IngExM.
SEM = Standard error of the mean.

4 DISCUSSIONS

The diets submitted to thermal processing (expansion and/or pelleting and/or expansion of corn and soybean meal only) promoted better growth performance during the starter and growing phases compared with mash diet, but not during the finisher phase. Wondra et al. (1995) obtained 5% and 7% better ADG and FC, respectively, when growing pigs (55.4 kg average BW) were fed pelleted diets compared with those fed mash diets *ad libitum*. Likewise, Nemechek et al. (2015) observed a 12% improvement in pigs' gain to feed ratio (56.8 kg average initial BW) fed good-quality pellets than that fed mash or poor-quality pellets *ad libitum*.

Surek et al. (2012) compared mash diets with pelleted diets in the nursery phase. Although no differences in DFI were detected, improvements were obtained for ADG and FC with the pelleted diet, which the authors attributed to the reduction in feed waste of 9.15% for the mash diet, and 1.68% for the pelleted diet. In the current study, however, there were no DFI nor feed waste differences among treatments, which may be attributed to the quantitative control of feed offered in each phase. Therefore, the better ABW, ADG, and FC results obtained up to 128 days of age with the expanded and pelleted diets compared with the mash diet may be attributed to changes in the structure of feed fractions caused by heat processing. Heat processing promotes starch gelatinization and protein denaturation (SKOCH et al., 1983; O’DOHERTY et al., 2001; ROJAS et al., 2016; ROJAS and STEIN, 2017), which increases the digestibility of these fractions (MEDEL et al., 2004; LUNDBLAD et al., 2011).

Starch is a homopolysaccharide composed of amylose chains, consisting of a linear chain of glucose units joined by α-1,4 glycosidic bonds and amylopectin, in which glucose units are joined in α-1,4 and α-1,6 positions, forming a branched structure. The combination of heat, moisture, and pressure applied during pelleting and expansion breaks the intermolecular bonds of amylose and amylopectin (MASAKUNI et al., 2013), increasing the accessibility of dietary starch to digestive enzymes (LUND and LORENZ, 1984; MORITZ et al., 2005). However, improvements in starch utilization are strongly influenced by processing parameters. Lundblad et al. (2012) obtained starch gelatinization of 9, 14, 15, 24, and 77% in mash pig diets, and those pelleted at low (47°C) and high (90°C) temperatures, expanded, and extruded, respectively.

Although, when corn is cooled after heat processing, the linear amylose segments of gelatinized starch realign, forming double helices (resistant starch), making α-1,4 glycosidic bonds inaccessible to amylase (HTOON et al., 2009). Wang et al. (2019) evaluated pig diets submitted to increasing conditioning temperatures (65 to 85°C). They observed a quadratic response for gelatinized starch and a linear increase in resistant starch, which indicates that the starch digestibility improvement obtained with gelatinization can be impaired if a large amount of resistant starch is formed.

The physical changes (disruption) of proteins' secondary, tertiary, and quaternary structures, which determine protein stability and conformation, is called protein denaturation (ARAÚJO et al., 2009). Heat processing increases dietary protein digestibility because it causes the partial loss of the tertiary structure of proteins, increasing the accessibility of proteases (DOZIER, 2001). However, exceedingly high temperatures during processing may affect the non-covalent interactions among proteins, which changes their structure, exposing hydrophobic amino acid residues and reducing their solubility and digestibility (WANG et al. 2019). Muramatsu et al. (2013) verified a reduction of protein solubility in expanded-pelleted broiler diets (645 g/kg of protein) compared with diets only pelleted (686 g/kg of protein).

From 63 to 98 days of age, expanded diets resulted in better growth performance than pelleted diets, possibly because the expansion process was enough to generate extensive physical structural changes, and therefore, improve the digestibility of dietary fractions. On the other hand, the expanded-pelleted treatment consisted of a more aggressive processing in terms of the greater temperature applied during the production of the diet, as the mash diet was both expanded and pelleted. This double processing may have increased the dietary content of resistant starch and decreased protein solubility, compromising the digestibility of both starch and protein fractions, consequently resulting in worse growth performance. However, only pelleting the diet was perhaps not sufficient to cause any prominent structural change compared to diets that had been expanded.

In the current study, pelleted diets had, on average, 28% more fines when compared to expanded-pelleted diets, which is according to Muramatsu et al. (2016), who reported that pre-pelleting expansion might be an option to improve pellet quality. Pellet quality has been shown to be an essential aspect in order to achieve the benefits of pelleting. Stark et al. (1993) and Nemechek et al. (2015) observed that the effect of pelleted diets in improving the feed efficiency of nursery and finishing pigs fed *ad libitum* was influenced by the amount of fines percentage, i.e., the magnitude of improvement was higher when the percentage of fines in the diet was minimized. For Ball et al. (2015), the improvement in FC with pelleted diets is mainly due to a reduction of feed wastage. However, the growth performance results obtained in this study were not affected by a high percentage of fines (pelleted diets *vs.* expanded-pelleted diets – contrast 3), possibly due to the quantitative feed control applied throughout the experiment. Because of this feed strategy, the pigs fed the heat-processed diets may have experienced feed restriction, which would help justify the lack of influence of the treatments on the performance results in finishing phases 1 (63 to157 days of age) and 2 (63 to 185 days of age).

5 CONCLUSIONS

Feed processing (expansion and/or pelleting and/or expansion of corn and soybean meal only) improved the average daily gain and feed conversion ratio of growing pigs (63 to 128 days of age) submitted to controlled feeding compared with those fed mash diets. Double feed processing or expanding the complete diet did not improve growth performance compared with pelleted diet and expansion of corn and soybean meal only, respectively.

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FINAL CONSIDERATIONS

The study of feed processing is continuous, after all, there is a constant evolution of the technologies involved in these processes. Our goal when studying feed processing is to understand how it will impact product quality, animal health, growth performance, and consequently production cost. Therefore, this thesis evaluated processes that are regular in a feed mill, such as grinding, but also processes that are becoming more and more common - pelleting and expansion.

Soybean meal (SBM) is an ingredient that is widely used in piglets' diets but unfortunately still understudied. During the first experiment, the effect of unground (1017 µm) or ground SBM (585 or 411 µm) with different particle sizes was evaluated on nutrient digestibility and growth performance of nursery piglets. It showed us that it is not necessary to ground the SBM for pigs in this phase. The animals consuming the coarser SBM particle size presented better growth performance results. The greater amount of coarser feed consumed was fundamental for the piglets to achieve these results. Possibly the diets that had coarser SBM were more palatable/attractive to the animals and consequently also influenced the intestinal health and functionality, digestive and absorptive capacity of the animals. The results of this study also showed us the negative impact on growth performance when working with fine SBM particle size (411 µm) in a mash diet for piglets.

When pelleting a reduction in particle size may occur because during this feed process shear and compression forces are acting (roll-friction-die and between the particles themselves) and breaking down the particles. The degree of grinding that occurs during pelleting is influenced by several factors, including: the initial particle size, the compression ratio, the distance between matrix and rolls, the temperature, and the conditioning retention time. Although piglets' diets are usually manufactured with a finer particle size than poultry diets (less grinding effect during pelleting), the literature has shown that there is a different response when evaluating the same particle size of pelleted or non-pelleted diets. So different particle sizes of a pelleted diet were evaluated. The particle size of 534 µm was ideal for animals aged 28 to 42 d, and a particle size of 943 µm was ideal for animals aged 43 to 63 d. Hence, the older the piglets, the better the performance response to an increased particle size of the pelleted feed. It is important to mention that the particle size was evaluated before pelleting, so the real particle size (after secondary processing) is unknown. This is due to the difficulty that still exists in the methodology to determine this effect.

Good pellet quality is critical to achieving the benefits of pelleting. The hardness of the pellet will influence the intake of the animals, and the percentage of whole pellets in the feeder will influence feed wasted. Unfortunately, in our study, we did not evaluate pellet hardness, and this may have influenced the response of the animals because piglets prefer softer pellets to harder pellets; probably the diets had different hardness due to the change in particle size. However, all the diets produced showed a low percentage of fines. Then, this study showed us that is possible to work with coarse particle size and pelleted diets for piglets.

In the other experiments, quantitative feed control or feed restriction programs were applied to growing and finishing pigs. As the animals were fed with different levels of restriction, the possible effect of physical form on increasing feed intake and/or reducing feed waste was not significant. The heat processing diets (expanded and/or pelleted) showed to provide beneficial effects on the growth performance of pigs, and this effect can be attributed to an optimized nutrient utilization. The magnitude of this response, which can be either negative or positive, depends on several factors, mainly related to the processing of feed/ingredients (equipment, temperature, retention time, and raw material, among others) but also on the animal age/weight. The impact on growth performance generated by pelleting was less evident in the younger animals, probably because heavier animals may present a longer retention time of the digesta along the gastrointestinal tract, as well as higher enzyme activity and secretion rate, higher absorptive efficiency, and higher microbial activity.

The feed strategy used in feed processing trials needs to be plain cautiously. The pigs fed the heat-processed diets (chapter V) may have experienced feed restriction, which would help justify the lack of influence of the treatments on the performance results in finishing phases 1 (63 to157 days of age) and 2 (63 to 185 days of age). In addition, the conditioning process used must also be planned carefully, because if the temperature applied on the feed is too high, it could be expected the formation of negative structures (i.e resistant starch) in the feed; and when temperature and retention time are too low, it may not cause enough changes in the feed to be evident in the pigs' growth performance.

The results of this thesis can contribute to the understanding of how feed processes can be used as tools to enhance animal performance. These processes (grinding, pelleting, and expansion) are very complex, and they can interact with each other. Therefore, further research is needed to help the animal feed industry understand the importance of feed processing and develop it in the best possible way to take full advantage of its benefits.

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ANNEX 1 – ANIMAL USE ETHICS COMMITTEE APPROVAL (N^O 047/2020)

UNIVERSIDADE FEDERAL DO PARANÁ
SETOR DE CIÊNCIAS AGRÁRIAS
COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o protocolo número 047/2020, referente ao projeto de pesquisa **"Efeito de diferentes tamanhos de partícula média do farelo de soja, sobre o desempenho e digestibilidade de suínos na fase de creche",** sob a responsabilidade de **Alex Maiorka** – que envolve a produção, manutenção e/ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica ou ensino – encontra-se de acordo com os preceitos da Lei nº 11.794, de 8 de Outubro de 2008, do Decreto nº 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA) DO SETOR DE CIÊNCIAS AGRÁRIAS DA UNIVERSIDADE FEDERAL DO PARANÁ - BRASIL, com grau 2 de invasividade, em 06/11/2020.

Finalidade	Pesquisa
Vigência da autorização	Dezembro/2020 até Janeiro/2021
Espécie/Linhagem	*Sus scrofa domesticus* (suíno)/PIC
Número de animais	72
Peso/Idade	4,5 – 25 kg/21 - 64 dias
Sexo	Macho e fêmea
Origem	Fazenda Experimental Canguiri da Universidade Federal do Paraná, Pinhais/PR, Brasil.

*A autorização para início da pesquisa se torna válida a partir da data de emissão deste certificado.

CERTIFICATE

We certify that the protocol number 047/2020, regarding the research project **"Effect of different particle sizes of soybean meal, on the performance and digestibility of pigs in the nursery phase"** under **Alex Maiorka** – which includes the production, maintenance and/or utilization of animals from Chordata phylum, Vertebrata subphylum (except Humans), for scientific or teaching purposes – is in accordance with the precepts of Law nº 11.794, of 8 October 2008, of Decree nº 6.899, of 15 July 2009, and with the edited rules from Conselho Nacional de Controle da Experimentação Animal (CONCEA), and it was approved by the ANIMAL USE ETHICS COMMITTEE OF THE AGRICULTURAL SCIENCES CAMPUS OF THE UNIVERSIDADE FEDERAL DO PARANÁ (Federal University of Paraná, Brazil), with degree 2 of invasiveness, in session of 11/06/2020.

Purpose	Research
Validity	December/2020 until January/2021
Specie/Line	*Sus scrofa domesticus* (swine)/PIC
Number of animals	72
Weight/Age	4.5 - 25 kg/21 - 64 days
Sex	Male and female
Origin	Canguiri Experimental Farm of the Federal University of Paraná, Pinhais/PR, Brazil.

*The authorization to start the research becomes valid from the date of issue of this certificate.

Curitiba, 20 de novembro de 2020

Simone Tostes de Oliveira Stedile
Coordenadora CEUA-SCA

ANNEX 2 – ANIMAL USE ETHICS COMMITTEE APPROVAL (N^{O} 062/2019)

UNIVERSIDADE FEDERAL DO PARANÁ
SETOR DE CIÊNCIAS AGRÁRIAS
COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o protocolo número 062/2019, referente à pesquisa **"Diferentes tamanhos de partícula do milho, com ou sem amilase na dieta peletizada de suínos na fase de creche"**, sob a responsabilidade de **Alex Maiorka** – que envolve a produção, manutenção e/ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica ou ensino – encontra-se de acordo com os preceitos da Lei nº 11.794, de 8 de Outubro, de 2008, do Decreto nº 6.899, de 15 de julho de 2009,e com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA) DO SETOR DE CIÊNCIAS AGRÁRIAS DA UNIVERSIDADE FEDERAL DO PARANÁ - BRASIL, com grau 1 de invasividade, em 02/10/2019.

Finalidade	Pesquisa científica
Vigência da autorização	Novembro/2019 até Dezembro/2019
Espécie/Linhagem	*Sus domesticus* (suíno)/PIC
Número de animais	704
Peso/Idade	4,5 – 25 Kg/21 – 64 dias
Sexo	Macho
Origem	Granja comercial de suínos, Santa Tereza/RS, Brasil.

CERTIFICATE

We certify that the protocol number 062/2019, regarding the discipline **"Different corn particle size, with or without amylase in pelleted diets for nursery pigs"** under **Alex Maiorka** supervision – which includes the production, maintenance and/or utilization of animals from Chordata phylum, Vertebrata subphylum (except Humans), for scientific or teaching purposes – is in accordance with the precepts of Law nº 11.794, of 8 October, 2008, of Decree nº 6.899, of 15 July, 2009, and with the edited rules from Conselho Nacional de Controle da Experimentação Animal (CONCEA), and it was approved by the ANIMAL USE ETHICS COMMITTEE OF THE AGRICULTURAL SCIENCES CAMPUS OF THE UNIVERSIDADE FEDERAL DO PARANÁ (Federal University of the State of Paraná, Brazil), with degree 1 of invasiveness, in session of 02/10/2019.

Purpose	Cientific research
Validity	November/2019 until December/2019
Specie/Line	*Sus domesticus* (swine)/PIC
Number of animals	704
Wheight/Age	4.5 – 25 Kg/21 – 64 days
Sex	Male
Origin	Commercial farm, Santa Tereza/RS, Brazil.

Curitiba, 02 de outubro de 2019

Chayane da Rocha

Chayane da Rocha

Coordenadora CEUA-SCA

Comissão de Ética no Uso de Animais do Setor de Ciências Agrárias - UFPR

ANNEX 3 – ANIMAL USE ETHICS COMMITTEE APPROVAL (N^{O} 045/2019)

UNIVERSIDADE FEDERAL DO PARANÁ
SETOR DE CIÊNCIAS AGRÁRIAS
COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o protocolo número 045/2019, referente à pesquisa **"Efeito de diferentes formas físicas e processamento térmico das rações no desempenho de suínos em crescimento e terminação"**, sob a responsabilidade de **Alex Maiorka** – que envolve a produção, manutenção e/ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica ou ensino – encontra-se de acordo com os preceitos da Lei nº 11.794, de 8 de Outubro de 2008, do Decreto nº 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA) DO SETOR DE CIÊNCIAS AGRÁRIAS DA UNIVERSIDADE FEDERAL DO PARANÁ - BRASIL, com grau 1 de invasividade, em 28/02/2020.

Finalidade	Pesquisa científica
Vigência da autorização	Abril/2020 até Maio/2020
Espécie/Linhagem	*Sus domesticus* (suíno)
Número de animais	90
Peso/Idade	70 – 150 kg/ 90 – 130 dias
Sexo	Fêmea
Origem	Fazenda Canguiri da Universidade Federal do Paraná, Pinhais/PR, Brasil.

CERTIFICATE

We certify that the protocol number 045/2019, regarding the research **"Effect of different physical forms and thermal processing of diets on the performance of growing and finishing swines"** under **Alex Maiorka** supervision – which includes the production, maintenance and/or utilization of animals from Chordata phylum, Vertebrata subphylum (except Humans), for scientific or teaching purposes – is in accordance with the precepts of Law nº 11.794, of 8 October 2008, of Decree nº 6.899, of 15 July 2009, and with the edited rules from Conselho Nacional de Controle da Experimentação Animal (CONCEA), and it was approved by the ANIMAL USE ETHICS COMMITTEE OF THE AGRICULTURAL SCIENCES CAMPUS OF THE UNIVERSIDADE FEDERAL DO PARANÁ (Federal University of Paraná, Brazil), with degree 1 of invasiveness, in session of 28/02/2020.

Puporse	Cientific research
Validity	April/2020 until May/2020
Specie/Line	*Sus domesticus* (swine)
Number of animals	90
Wheight/Age	70 – 150 kg/90 – 130 days
Sex	Female
Origin	Canguiri farm of the Federal University of Paraná, Pinhais/PR, Brazil.

Curitiba, 02 de março de 2020

Simone Tostes de Oliveira Stedile

Coordenadora CEUA-SCA

Comissão de Ética no Uso de Animais do Setor de Ciências Agrárias - UFPR

ANNEX 4 – ANIMAL USE ETHICS COMMITTEE APPROVAL (N^O 051/2021)

UNIVERSIDADE FEDERAL DO PARANÁ
SETOR DE CIÊNCIAS AGRÁRIAS
COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o protocolo número 051/2021, referente ao projeto de pesquisa **"Efeito da peletização e diferentes programas alimentares do desempenho de suínos",** sob a responsabilidade de **Simone Gisele de Oliveira** – que envolve a produção, manutenção e/ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica ou ensino – encontra-se de acordo com os preceitos da Lei nº 11.794, de 8 de Outubro de 2008, do Decreto nº 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA) DO SETOR DE CIÊNCIAS AGRÁRIAS DA UNIVERSIDADE FEDERAL DO PARANÁ - BRASIL, com grau 1 de invasividade, em 03/09/2021.

Finalidade	Pesquisa
Vigência da autorização	Outubro/2021 até Dezembro/2021
Espécie/Linhagem	*Sus Scrofa domesticus* (suíno)
Número de animais	240
Peso/Idade	22kg a 75kg/63 a 113 dias
Sexo	Machos
Origem	Granja de produção de suínos em Chapecó, Santa Vatarina, Brasil

*A autorização para início da pesquisa se torna válida a partir da data de emissão deste certificado.

CERTIFICATE

We certify that the protocol number 051/2021, regarding the research project **"Effect of pelleting and feeding program on pigs' performance"** under **Simone Gisele de Oliveira** – which includes the production, maintenance and/or utilization of animals from Chordata phylum, Vertebrata subphylum (except Humans), for scientific or teaching purposes – is in accordance with the precepts of Law nº 11.794, of 8 October 2008, of Decree nº 6.899, of 15 July 2009, and with the edited rules from Conselho Nacional de Controle da Experimentação Animal (CONCEA), and it was approved by the ANIMAL USE ETHICS COMMITTEE OF THE AGRICULTURAL SCIENCES CAMPUS OF THE UNIVERSIDADE FEDERAL DO PARANÁ (Federal University of Paraná, Brazil), with degree 1 of invasiveness, on 2021, September 3rd.

Purpose	Research
Validity	October/2021 to December/2021
Specie/Line	*Pigs (Sus Scrofa domesticus)*
Number of animals	240
Weight/Age	From 22kg to 75kg/ From 63 to 113 days old
Sex	Male
Origin	Private farms in Chapecó, Santa Catarina, Brazil

*The authorization to start the research becomes valid from the date of issue of this certificate.

Curitiba, 03 de setembro de 2021

Maity Zopollatto

Vice-coordenadora
Comissão de Ética no Uso de Animais
AG - UFPR

ANNEX 5 – ANIMAL USE ETHICS COMMITTEE APPROVAL (N^O 075/2018)

UNIVERSIDADE FEDERAL DO PARANÁ
SETOR DE CIÊNCIAS AGRÁRIAS
COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o protocolo número 075/2018, referente ao projeto **"Efeito de diferentes formas físicas e processamento térmico das rações no desempenho de suínos em fase de creche, crescimento e terminação",** sob a responsabilidade **Alex Maiorka** – que envolve a produção, manutenção e/ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica ou ensino – encontra-se de acordo com os preceitos da Lei nº 11.794, de 8 de Outubro, de 2008, do Decreto nº 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA) DO SETOR DE CIÊNCIAS AGRÁRIAS DA UNIVERSIDADE FEDERAL DO PARANÁ - BRASIL, com grau 1 de invasividade, em reunião de 07/11/2018.

Vigência do projeto	Janeiro/2019 até Abril/2019
Espécie/Linhagem	*Sus scrofa domesticus* (suíno)
Número de animais	632
Peso/Idade	6 e 22 kg/21 e 64 dias, respectivamente
Sexo	Macho
Origem	Centro Tecnológico Agropecuário, Videira, Santa Catarina, Brasil

CERTIFICATE

We certify that the protocol number 075/2018, regarding the project **"Effect of different dietary physical form and thermal processing on the performance of pigs in nursery piglets, growing and finishing phase"** under **Alex Maiorka** supervision – which includes the production, maintenance and/or utilization of animals from Chordata phylum, Vertebrata subphylum (except Humans), for scientific or teaching purposes – is in accordance with the precepts of Law nº 11.794, of 8 October, 2008, of Decree nº 6.899, of 15 July, 2009, and with the edited rules from Conselho Nacional de Controle da Experimentação Animal (CONCEA), and it was approved by the ANIMAL USE ETHICS COMMITTEE OF THE AGRICULTURAL SCIENCES CAMPUS OF THE UNIVERSIDADE FEDERAL DO PARANÁ (Federal University of the State of Paraná, Brazil), with degree 1 of invasiveness, in session of 07/11/2018.

Duration of the project	January/2019 until April/2019
Specie/Line	*Sus scrofa domesticus* (swine)
Number of animals	632
Wheight/Age	6 and 22 kg/21 and 64 days, respectively
Sex	Male
Origin	Agricultural Technological Center, Videira, Santa Catarina, Brazil

Curitiba, 07 de novembro de 2018

Chayane da Rocha

Chayane da Rocha

Coordenadora CEUA-SCA