

Ideal particle size in the main ingredients in pig feed

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ABSTRACT

Objective: To determine the optimal particle size of the primary ingredients used in pig feed.

Design/methodology: A literature review was conducted to identify the optimal particle size of corn, sorghum, and soybean meal in pig diets.

Results: The optimal ingredient particle size by production stage is as follows: transition, 339-534 μm ; Initiation I, 339-534 μm in pellets or 305 μm in meal form; Initiation II, 920-943 μm ; and growth-finishing, 500-700 μm .

Study implications: The optimal particle size of all grains included in the diet should be evaluated across particle-size strata, as most studies assess only the mean particle size of a single ingredient.

Conclusions: Fine grinding enhances feed digestibility in pigs, which is reflected in improved productive performance. However, excessively small particle size for a given production stage may adversely affect intestinal health.

Keywords: swine production, milling, pellets, meal.

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INTRODUCTION

Ingredient milling is a processing operation in which the particle size of a feed ingredient is reduced. Its primary purpose is to decrease particle size to facilitate intake and enhance the nutritional availability of dietary fractions. This, in turn, increases the feed's contact surface area, making it more accessible to digestive enzymes and consequently improving feed efficiency. Ingredient milling also confers additional advantages, including improved mixing capacity and uniformity, reduced segregation during bulk transport, increased starch gelatinization, and enhanced pellet quality. However, producing excessively fine



ingredients can increase production costs, intensify contamination from generated dust, and induce functional alterations in the pigs' gastrointestinal tract (Almeida *et al.*, 2021). Therefore, the objective of this work was to synthesize available evidence on the ideal particle size achieved during the milling process for the main ingredients used in pig feeding, based on an analysis of publicly available results.

The milling process

Milling quality is assessed through factors such as feed particle homogeneity, uniformity, and size (Kiarie and Mills, 2019). One of the principal challenges in manufacturing feed for non-ruminants is achieving mixture uniformity and homogeneity, namely, controlling particle-size distribution (Goodarzi Borojeni *et al.*, 2016; Vukmirovic *et al.*, 2017).

An appropriate ingredient particle size is beneficial for feed-manufacturing processes such as mixing and hydrothermal treatments, including pelleting, extrusion, and expansion (Kiarie and Mills, 2019). Recommendations regarding optimal particle size and particle-size distribution in pigs are inconsistent and vary by production stage, as they are influenced by factors such as the physical form of the feed (ingredient particle size is reduced during pelleting and nutrient digestibility improves), diet complexity, grain type, endosperm hardness, the milling method (hammer mill, roller mill, multicracker, or multistage grinding), and pellet quality (Al-Rabadi *et al.*, 2017; Vukmirovic *et al.*, 2017).

From an economic standpoint, a particle-size distribution tailored to the animal's physiological requirements enables optimal nutrient utilization and improvements in productive outcomes. Nevertheless, more intensive grinding entails higher production costs, particularly due to the energy required to achieve smaller particle sizes (Almeida *et al.*, 2021).

In addition to increased energy consumption, grinding capacity and flowability decline, dust-related problems intensify, and excessively fine particles are associated with detrimental effects on the health and function of the gastrointestinal tract. The effectiveness of particle-size reduction also depends on factors such as the physical form of the feed (meal or pellet), whether it is offered to healthy animals, the animal's age, the raw materials used, the type of facilities, and even genetics. For example, because feed compaction increases when particle size falls below 500 μm , flowability may be impaired. This can be exacerbated in diets supplemented with oils and in silos or conveying lines with certain characteristics, ultimately leading to reduced feed intake (Scianca, 2021).

Effect of particle size on nutrient digestibility

Reducing the particle size of feed raw materials increases the exposed surface area for digestive enzymes, thereby enhancing nutrient digestibility and absorption; in turn, this may improve pigs' productive performance (Kiarie and Mills, 2019; Huting *et al.*, 2021).

Decreasing the particle size of corn, sorghum, and soybean meal has been associated with improvements in pigs' productive performance due to greater nutrient digestibility and enhanced feed efficiency (FE) (Kim *et al.*, 2016; Dzierva *et al.*, 2023). Physiological differences attributable to the particle size of the offered feed may be related to age-dependent endogenous enzyme production (Scianca, 2021). Reducing particle size

in ingredients improves starch digestibility by increasing grain surface area, which subsequently intensifies interaction with digestive enzymes (Huang *et al.*, 2015; Rojas and Stein, 2015; Rojas *et al.*, 2016a). Accordingly, the apparent ileal digestibility of starch and the gross energy of corn increase in growing pig diets as particle size is reduced from 865 to 339 μm (Rojas and Stein, 2015).

Although starch and energy digestibility may improve, the effects of particle-size reduction on nitrogen and amino acid digestibility in ingredients are inconsistent. Reducing corn particle size (400, 600, 800, and 1000 μm) in diets for growing pigs increased protein digestibility as particle size decreased (Ma *et al.*, 2021). However, reducing corn particle size did not improve the digestibility of most amino acids in weaned or growing pigs (Huang *et al.*, 2015; Rojas and Stein, 2015). Fastinger and Mahan (2003) reported that reducing soybean meal particle size (900, 600, 300, and 150 μm) increased amino acid digestibility by only 1% at a particle size of 600 μm . Table 1 summarizes studies evaluating different production stages of finishing pigs fed diets containing the main ingredients used in the Mexican feed industry, milled to diverse particle sizes.

During Initiation I [7-8 kg initial live weight (ILW)], a smaller particle size for corn and soybean meal (305-534 μm) increases the digestibility of energy and ether extract (Almeida *et al.*, 2021; Dzierva *et al.*, 2023; Almeida *et al.*, 2022; Huang *et al.*, 2015); however, an excessively reduced particle size may cause problems related to intestinal permeability (Huang *et al.*, 2015). For Initiation II (10-12 kg ILW), the optimal corn particle size depends on feed presentation (pellet or meal). Almeida *et al.* (2021) found that, at this stage, 943 μm is optimal for improving dry matter and ether extract digestibility. In contrast, Dzierva *et al.* (2023) reported that the best particle size for pelleted corn would be 696 μm to increase ether extract digestibility.

Although the particle size in that study is smaller than that reported by Almeida *et al.* (2021), both studies converge in indicating that the optimal particle size to improve productive performance lies between 920 and 943 μm . Conversely, when corn is offered as meal to pigs in Initiation II, a smaller particle size (400 μm) appears more appropriate to improve the digestibility of energy, dry matter, protein, and fiber (Ma *et al.*, 2021).

For the growth stage (20-34 kg), the evidence compiled in this review indicates that the particle size of the main macronutrient ingredients incorporated into the diet (corn and soybean meal) falls within 511-600 μm in both meal and pelleted forms, as this range provides a balance between nutrient digestibility and feed efficiency (Gao *et al.*, 2021; Jo *et al.*, 2021). A particle size below 511 μm does not improve nutrient digestibility (Gao *et al.*, 2021), whereas a particle size above 600 μm also fails to improve nutrient digestibility (Jo *et al.*, 2021). Gao *et al.* (2020) observed that reducing the mean particle size of corn and soybean meal from 511 to 390 μm in diets for growing pigs neither modified nutrient utilization nor affected the activity of amylase, trypsin, and chymotrypsin. Considering the mean particle size of the diet's macro-ingredients, Gao *et al.* (2020) recommend a mean particle size of 511 μm in corn-soybean diets to enhance productive performance and dietary nutrient-use efficiency in growing pigs, as particle sizes below 390 μm do not improve nutrient utilization; likewise, they indicate that it is not necessary to reduce the mean particle size of corn below 682 μm . Their results further show that the mean

particle size of duodenal digesta, ileal digesta, and feces decreased with particle-size reduction (511 vs. 390 μm), but mean particle size did not affect digestibility (total tract, energy, protein, ether extract, and fiber).

Additionally, reducing corn particle size (400, 600, 800, and 1000 μm) in diets for growing pigs increased the digestibility of energy, protein, dry matter, and fiber as corn particle size decreased (Ma *et al.*, 2021). Particle-size reduction improved energy digestibility in growing-finishing pigs fed sorghum (1062, 802, or 471 μm ; Owsley *et al.*, 1981). Moreover, in finishing pigs, corn particle size should be <618 μm to increase both energy and fiber digestibility (Lyu *et al.*, 2020).

Effect of particle size on productive performance

Reducing particle size increases the availability of certain nutrients, which may subsequently enhance pigs' productive performance (Lancheros *et al.*, 2020). The ideal particle size depends on the grain type used in the diet, the physical form of the feed (meal or pellets), and the pigs' growth phase.

In weaned piglets during the transition phase, reducing the particle size of corn and sorghum (300, 500, 700, and 900 μm) in pelleted feed linearly improved feed efficiency and average daily gain (ADG) during the first two weeks post-weaning for both ingredients; however, after these two weeks, the beneficial effect diminished, with the best feed efficiency observed at 500 μm . This suggests that, during the transition phase, responsiveness to particle-size reduction is greater in the first two weeks post-weaning, and that the optimal particle size for corn and sorghum increases with pig age after this period (Healy *et al.*, 1991).

Table 1 summarizes evidence on the effect of particle size on the productive parameters of finishing pigs. In Initiation I (initial live weight [ILW] of 7-8 kg), Dzierva *et al.* (2023) and Almeida *et al.* (2021) recommend corn particle sizes of 339 and 534 μm , respectively, for pelleted feed to increase feed efficiency. In contrast, Huang *et al.* (2015) reported that a corn particle size of 305 μm in meal improves ADG and dry matter intake (DMI). However, at this same stage, when soybean meal particle size was evaluated (1017 μm), a substantially larger particle size than that of corn was associated with increased ADG and feed intake. When pigs enter Initiation II (>10 kg), the mean particle size of pelleted feed increases relative to Initiation I, because a corn particle size between 920 and 943 μm increases DMI (Almeida *et al.*, 2021; Dzierva *et al.*, 2023) and ADG (Dzierva *et al.*, 2023). For pigs in the growth and finishing stages, the optimal corn particle size increases further. Jo *et al.* (2021), evaluating ground corn particle sizes of 600, 750, and 900 μm in diets for growing pigs, found that feed efficiency improved when a particle size of 600 μm was used. In growing-finishing gilts fed meal-based corn diets, feed efficiency decreased linearly as particle size was reduced (865, 677, 485, and 339 μm), with no effects on ADG or feed intake (Rojas *et al.*, 2016a). Nemechek *et al.* (2016) reported that reducing corn particle size in the complete diet from 650 to 350 μm in growing-finishing pigs resulted in decreased ADG, DMI, and feed efficiency when diets were provided as meal; however, pigs fed pelleted diets did not show negative effects on DMI or feed efficiency attributable to particle size. Regardless of whether pigs are fed

Table 1. Optimal particle size for ingredients supplied to fattening pigs.

Feed	Particle size (μm)	Observations	Stage	Author
Corn / Pellets	394, 534, 647, 695	↑ Feed efficiency (FE) at 534 μm .	Initiation (7 kg)	Almeida <i>et al.</i> (2021)
Corn / Pellets	339, 588	↑ FE and ↑ ether extract (EE) digestibility at 339 μm .	Initiation (7 kg)	Dzierva <i>et al.</i> (2023)
Soybean meal / Meal	411, 585, 1017	↑ Dry matter intake (DMI) and ↑ average daily gain (ADG) at 1017 μm ; ↑ digestible energy (DE) at 411 μm .	Initiation (7 kg)	Almeida <i>et al.</i> (2022)
Corn / Meal	305, 428	↑ ADG, ↑ DMI, and ↑ energy and EE digestibility at 305 μm ; however, ↓ intestinal permeability.	Initiation (8 kg)	Huang <i>et al.</i> (2015)
Corn / Pellets	587, 625, 798, 943	↑ DMI and ↑ dry matter (DM) and EE digestibility at 943 μm .	Initiation (12 kg)	Almeida <i>et al.</i> (2021)
Corn / Pellets	696-920	↑ DMI and ↑ ADG at 920 μm ; ↑ EE digestibility at 696 μm .	Initiation (11 kg)	Dzierva <i>et al.</i> (2023)
Corn / Meal	400, 600, 800	↑ energy, DM, crude protein (CP), and fiber digestibility as particle size decreased.	Initiation (10 kg) and Growth (36 kg)	Ma <i>et al.</i> (2021)
Sorghum / Meal or pellets	456, 890	↑ DMI with pellets; ↑ ADG and ↑ FE at 456 μm .	Growth (20 kg)	Al-Rabadi <i>et al.</i> (2017)
Corn-soybean meal / Pellets	390, 511, 682	Particle size did not modify nutrient utilization.	Growth (22 kg)	Gao <i>et al.</i> (2021)
Corn-soybean meal	600, 750, 900	↑ FE and ↑ incidence of keratinization at 600 μm .	Growth (22 kg)	Jo <i>et al.</i> (2021)
Corn / Meal or pellets	350, 650	↓ DMI and ↓ FE in meal form at 350 μm ; ↑ ADG at 650 μm .	Growth (34 kg)	Nemechek <i>et al.</i> (2016)
Corn / Meal	441, 543, 618, 659, 768	↑ energy digestibility as particle size decreased; ↑ fiber digestibility at 618 μm .	Finishing (53 kg)	Lyu <i>et al.</i> (2020)
Sorghum / Pellets	724, 573, 319	↑ FE and ↑ carcass yield at the smallest particle size.	Finishing (46 kg)	Paulk <i>et al.</i> (2015)

Abbreviations: FE, feed efficiency; EE, ether extract; CP, crude protein; DM, dry matter; DMI, dry matter intake; ADG, average daily gain; DE, digestible energy.

meal or pellets, they prefer diets manufactured with more coarsely ground corn (700 μm) (Gebhardt *et al.*, 2018). Conversely, for sorghum, a smaller particle size (319, 573, and 724 μm) in pelleted feed reduced feed intake and improved feed efficiency in finishing pigs (Paulk *et al.*, 2015).

The influence of ingredient particle size on pigs' productive performance is not consistent, and the underlying reasons are not fully understood. A major contributor to the observed variability and inconsistency in nutrient availability and productive responses is that most studies address mean particle size of ingredients or the diet. Lyu *et al.* (2021) found that the nutritional composition and physical characteristics of different particle-size strata of ground corn and soybean meal differ markedly, which helps explain differences in pigs' productive responses. Recognizing this issue, Al-Rabadi *et al.* (2017) ground sorghum using a 4-mm screen (890 μm), then separated and reground the coarser fraction of the ground sorghum (80%) using a 3.2-mm screen, achieving a more

homogeneous particle size (456 μm); this resulted in improved ADG and feed efficiency in growing pigs.

Effect of particle size on carcass quality

Reducing feed particle size improves carcass yield in pigs (Lancheros *et al.*, 2020) fed corn-based (Wondra *et al.*, 1995a; Rojas *et al.*, 2016a) and sorghum-based diets (Paulk *et al.*, 2015). A plausible explanation for the higher carcass yield observed in pigs fed finer particle sizes is reduced microbial fermentation, which in turn decreases intestinal tract weight (Rojas *et al.*, 2016b). With respect to backfat thickness and lean meat percentage, particle-size reduction does not appear to modify these variables (Paulk *et al.*, 2015; Rojas *et al.*, 2016a).

Effect of particle size on short-chain fatty acids

Most starch is digested in the small intestine; however, starch that escapes small-intestinal digestion is fermented in the large intestine, resulting in the synthesis of short-chain fatty acids (SCFAs) (Bach Knudsen, 2011). Therefore, reducing particle size may decrease SCFA production (Lancheros *et al.*, 2020). Rojas *et al.* (2016a) reported that feeding pigs finely ground corn (339-865 μm) reduced SCFA synthesis.

Effect of particle size on intestinal health

When high-grain diets are fed, there is a practical limit to how finely particles should be ground because excessive fineness increases acidity and pepsin activity due to an inadequate protective mucus layer in the esophageal region of the stomach. This negatively affects gastrointestinal health by increasing the incidence of gastric ulcers and gastric keratinization, which are common problems in the swine industry (Kiarie and Mills, 2019; Lancheros *et al.*, 2020). Fine grinding is associated with a higher incidence of ulcers and non-specific diarrhea in sows and in growing-finishing pigs (Wondra *et al.*, 1995a,b; Melnichouk, 2002). Brunsgaard (1998) indicated that particle size influences mucus production and composition (which protects against gastric infections) as well as gastrointestinal morphology, highlighting digestive disturbances and ulceration when grains are excessively ground. Notably, the issue appears to be driven less by mean particle size than by a higher proportion of extremely fine particles. Feeding high-grain diets based on finely ground ingredients increases acidity and pepsin activity due to the lack of a protective mucus layer in the esophageal region of the stomach (Varum *et al.*, 2010). Pigs fed diets containing corn ground to 400 μm exhibited a higher incidence of ulcers and parakeratosis than pigs fed diets containing corn ground to 1200 μm (Wondra *et al.*, 1995a). This aligns with findings in growing pigs, in which the incidence of parakeratosis increased as particle size decreased (600, 750, and 900 μm) in meal or pelleted feed (Jo *et al.*, 2021). However, ulcer development may not immediately impair productive performance in growing-finishing pigs, as reducing ground corn particle size to 339 μm increased the incidence of ulcers and tissue keratinization without affecting feed efficiency (Rojas *et al.*, 2016a). Therefore, paraqueratosis which precedes ulcer formation does not appear to be detrimental to pig growth.

Effect of particle size on pH and bacterial populations

The presence of coarse particles in the diet is important to ensure proper stomach function and a gradual transition of digesta from the stomach to the intestine (Huting *et al.*, 2021). In young piglets, larger feed particle size may influence the gastric emptying rate, because a slower nutrient transit from the stomach to the intestine reduces the risk of gastrointestinal infections; this results in a lower gastric pH due to the stomach's physical resistance to accommodating larger amounts of feed (Bornhorst *et al.*, 2013). Coarse particle size increases acidification in the stomach and the distal intestine, which may be beneficial for controlling the proliferation of enteric pathogens (Vukmirovic *et al.*, 2017), such as *Salmonella* or *Escherichia coli* (Kiarie and Mills, 2019).

Moreover, fine particles may promote undesirable intestinal outcomes, including colonization by *Streptococcus suis* in the stomach (Warneboldt *et al.*, 2016) and *Salmonella typhimurium* in the ileum (Hedemann *et al.*, 2005). Feeding pigs finely ground corn (339-865 μm) increased pH in the large intestine (Rojas *et al.*, 2016a). In pigs fed either a coarsely ground diet (671 μm) or a finely ground diet (217 μm), gastric pH was lower with the coarsely ground diet (pH 2.5) than with the finely ground diet (pH 5.0) (Warneboldt *et al.*, 2016).

CONCLUSIONS

Fine grinding can improve feed digestibility, feed efficiency, weight gain, and carcass yield in pigs; however, the optimal particle size depends on the production stage and the physical form of the feed. During the transition stage, the recommended particle size is 300 μm (pellets), and it increases gradually throughout the initiation period. The optimal particle size for Initiation I diets (7-8 kg initial live weight [ILW]) is 339-534 μm in pellets and 305 μm in meal form. In contrast, for pigs in Initiation II (10-12 kg ILW), the particle size of pelleted feed should be 920-943 μm .

For pigs in the growth-finishing stage, mean particle sizes between 500 and 700 μm are advisable. Furthermore, an excessively small particle size relative to each production stage may negatively affect pigs' intestinal health.

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