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Corn physical characteristics on piglet performance

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ABSTRACT. This study aimed to correlate the physical characteristics of ground corn, at different crushing intensities, with the zootechnical performance of piglets in the nursery phase. Forty piglets (20 castrated males and 20 females) with an initial average weight of 15.7±1.98 kg and final weight of 32.5±3.27 kg were used. They were subjected to the same type of experimental diet (4% of commercial premix for the phase, 29% of soybean meal, and 67% of ground corn), with the only difference being the corn grinding process. The corn used was fractionated into five portions, and each one of them was crushed in a hammermill equipped with a different screen hole diameter (2; 2.5; 3; 3.5 and 4 mm). Which resulted in ground corn with the following particle sizes (PS): 518, 580, 628, 706 and 740 µm, and the following corn geometric standard deviations (GSD): 1.72, 1.71, 1.75, 1.80 and 1.90, respectively. The piglets were distributed in a completely randomized design with five treatments and four replications, with the experimental units being formed by pens with two piglets each. There was no effect ($p > 0.10$) from grinding intensities on daily feed intake (DFI) and daily weight gain (DWG). Conversely, there was an effect ($p < 0.10$) from different grinding intensities on feed conversion (FC). The PS and GSD of both the corn and diet, as well as the corn fractions retained on the 4-, 2- and 1.2-mm test sieves showed positive correlations with FC ($p < 0.05$). On the other hand, the corn fractions retained on the 0.6-, 0.3- and 0.15-mm teste sieves showed negative correlations with FC ($p < 0.05$). The linear model was the one that fitted the estimated data into the data observed for FC. A corn PS reduction from 740 to 580 µm promoted a linear improvement in FC. The use of corn fractions, retained on the 1-, 2- and 0.3-mm test sieves, and the use of corn GSD and diet GSD as independent variables showed a higher R^2 than that obtained with the use of corn PS as an independent variable in linear equations for estimating FC.

Keywords: granulometry; ground corn; nutrition; particle size.

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Introduction

Corn is one of the most important ingredients in swine nutrition, and its energy value allows it to be added in large amounts to diet formulations (Naderinejad et al., 2016). Thus, since the ingredient is used at large proportions, its impact on zootechnical performance is substantially high.

Before being used in diet, corn needs to be processed, with grinding being the most common type of processing. Grinding aims to reduce particle size (Lyu, Wang, Wu, & Huang, 2020) to a size suitable for the species. Particle size is one of the physical factors with the greatest impact on swine nutrition, since most of the digestion is carried out through endogenous enzymes (Vukmirovic et al., 2017). Reducing particle size improves feed efficiency and increases animal performance due to better nutritional digestibility (Al-Rabadi et al., 2017; Bao et al., 2016; Rojas & Stein, 2015), in addition to interfering with the quality of feed mixtures (Paiano et al., 2014).

Grinding and the consequent reduction in particle size provide a greater surface area/corn mass, which promotes a better interaction between ingredients and digestive enzymes (Lv et al., 2015). However, excessively fine crushing increases electrical energy consumption and decreases the mill productivity (Kiarie & Mills, 2019).

Determining the best particle size (PS) of corn for swine diets is the subject of several studies, such as those by Nemecheck et al. (2016) and Lyu et al. (2020). However, in most cases, the zootechnical performance is only correlated with PS, while other physical characteristics of corn, such as geometric standard deviation (a measure of grinding dispersion), and the relationship between the physical characteristics of feed and zootechnical performance, are not fully explored.

Thus, the objective of the present study was to provide a new approach for zootechnical performance estimation by correlating physical characteristics, such as geometric standard deviation as well as corn and diet fractions retained on different test sieves, with the performance of piglets in the nursery phase.

Material and methods

Forty piglets from a commercial lineage (selected for high gain) were utilized in the experiment with average initial weight of 15.7 ± 1.98 kg. The piglets were housed in pens with two piglets each (one male and one female), resulting in 20 experimental units. The piglets were housed in suspended experimental pens, each one equipped with a linear feeder at the front and a nipple drinker at the back.

The experimental diet was based on corn, soybean meal and commercial premix for the phase (Table 1). The experimental design used was a completely randomized one with five grinding levels and four replications per treatment.

Table 1. Composition of the experimental diets.

Ingredients	g kg^{-1} as-feed basis
Corn	670
Soybean Meal	290
Premix*	40
Calculated composition	
Digestible Energy, Mcal kg^{-1}	3,35
Crude protein, g kg^{-1}	178,1
Total Lysine, g kg^{-1}	8,9
Total Threonine, g kg^{-1}	6,91
Total Tryptophan, g kg^{-1}	2,10
Total Methionine + Cystine, g kg^{-1}	5,9
Total Calcium, g kg^{-1}	6,80
Total Phosphorus, g kg^{-1}	6,00

*Guarantee levels per kg of product, maximum: Ca 220 g; Minimums: P 70 g; Cu 3.75 g, Fe 2.5g; I 37.5 mg; Mn 1 g; Se 7.5 mg; Zn 2.5g; Folic acid 20 mg; Choline 18.7g; Riboflavin 125 mg; Pyridoxine 75 mg; Vit. At 250,000 IU; Vit. D3 37,500 IU; Vit. E 750 IU; Vit B12 780 µg; Vit K3 50 mg; Calcium Pantothenate 300 mg; Niacin 764 mg; Biotin 2.5g; Thiamine 50 mg.

The treatments were distinguished by the degree of corn grinding, characterized in accordance with the particle size, expressed in µm. A hammermill with 28 hammers, 20 hp and 3.550 rpm was used to grind the corn. Screens with a hole diameter of 2; 2.5; 3; 3.5 or 4 mm were used for treatments A, B, C, D and E, respectively. Corn from the same batch was used for all treatments, it was divided into five fractions, each fraction was ground with one of the previously described sieves.

The stacked sieving methodology was used to determine the PS of the corn and diets, with prior drying at 105°C for 24 hours, as proposed by Henderson and Perry (1955), in duplicates with 200 g of sample (Figure 1). The Particle size and geometric standard deviations were calculated from the percentages retained on the test sieves (Aperture sizes for test sieves 4, 2, 1.2, 0.6, 0.3, 0.15 mm and pan) in accordance with the equations described in ANSI/ASAE S319.3 (American Society of Agricultural and Biological Engineers [ASABE], 2008).

At the end of the experimental period, the piglets were weighed, and their feed intake was computed in order for daily feed intake (DFI), daily weight gain (DWG) and feed conversion (FC) to be calculated.

Performance data were analyzed as to normality of errors using the Kolmogorov-Smirnov test ($p > 0.05$) and showed normality of residuals. Afterwards, the data were subjected to analysis of variance, considering ($p < 0.10$) as difference in this step. Post-hoc Tukey tests were then performed to determine specific differences between the treatments. Then, the data obtained were subjected to Pearson's correlation analysis (r) to estimate the coefficients and respective significance values.

In the regression analysis, variables with correlation coefficient below -0.5 or above +0.5 were used as independent variables in order for those with the best R^2 in estimating performance to be determined. Linear, quadratic and square root models were applied to the data. The least squares method was used to estimate the coefficients of the regression models, and the verification of the significance of each coefficient was evaluated using the t-test ($p < 0.05$).

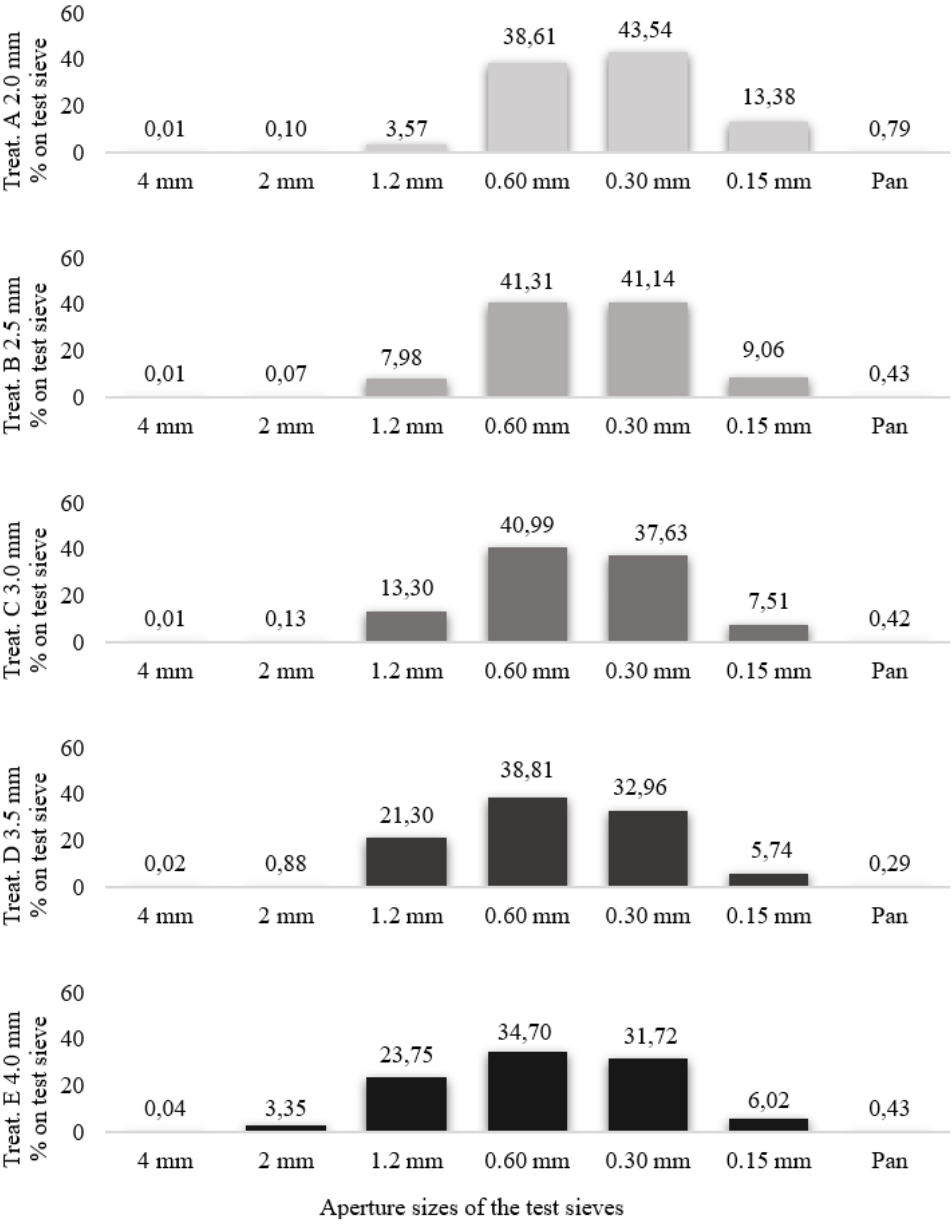

Figure 1. Ground corn fractions retained on the test sieves, at different grinding intensities (screen hole diameter), in accordance with methodology by Handerson and Perry (1955).

Results and discussion

Feed and diets characteristics

The results for corn and diet PS and corn and diet GSD increased with lower grinding intensity (grinding in screens with larger hole diameters, Table 2), with the greatest increases being observed for corn PS (42%) and diet PS (25%).

Table 2. Retained fractions and physical characteristics of the corn and experimental diets.

	Features of the hammermill screen				
Screen hole diameter, mm	2.0	2.5	3.0	3.5	4.0
	Physical characteristics of the corn				
Particle size, µm	518.7	579.9	627.7	706.3	739.8
Geometric standard deviation	1.72	1.71	1.75	1.80	1.90
	Physical characteristics of the diet				
Particle size, µm	555.3	607.3	626.5	670	698.2
Geometric standard deviation	1.88	1.84	1.89	1.92	1.99

*PS: particle size; GSD: geometric standard deviation.

The increase in grinding intensity obtained by reducing the screen hole diameter (screen used to surround the grinding chamber in hammer mill) makes it difficult for the corn to leave the crushing chamber in the grain process, with a consequent greater number of hammer impacts on the corn particles, which leads to reduced PS and GSD (Table 2). This reduction in GSD with the reduction in PS is a relatively common behavior and has already been reported by Paiano et al. (2014); Rojas and Stein (2015); Chiodelli, Folador, Boiago, Carvalho, and Paiano (2018) and Gebhardt et al. (2018); said behavior is associated with grain reprocessing, which is characterized by reduced particle size variability.

Corn grinding close to 400 μm is common in piglet nutrition (Nemechek et al., 2016), and greater reductions tend to be beneficial from the point of view of digestibility. However, excessively fine grinding increases processing time, energy expenditure with grinding, and may compromise the fluidity of the diets due to the increase in their angle of repose (Chiodelli et al., 2018; Gebhardt et al., 2018). In adult animals, excessively fine particle size can increase the incidence of gastric ulcerations (Maxwell et al., 1970; Potkins, Lawrence & Thomlinson, 1989).

Zootechnical performance

The corn grinding degrees used in this experiment did not alter feed intake and daily weight gain of the piglets (p > 0.10) (Table 3).

Table 3. Zootechnical performance of piglets subjected to diets with different physical characteristics.

	Different corn grinding intensities						
Sieves aperture diameter, mm	2.0	2.5	3.0	3.5	4.0	P values[1]	CV[2]
Initial body weight, kg	15.60	15.76	15.71	15.74	15.81	1.00	0.50
Final body weight, kg	33.09	33.19	32.51	31.94	31.78	0.970	2.05
Daily feed intake, kg	1.372	1.326	1.336	1.342	1.33	0.990	1.41
Daily weight gain, kg	0.700	0.698	0.672	0.648	0.639	0.674	4.26
Feed conversion, g g^{-3}	1.962ab	1.903a	1.985ab	2.084b	2.086b	0.094	4.10

[1]P values = significance values in the analysis of variance; [2]CV = Coefficient of variation. [3]Means in the same line followed by different letters differ by Duncan test (p < 0.10)

However, grinding corn using a coarser screen hole diameter (3.5 and 4 mm) compared to a finer screen hole diameter (2.5 mm), with a consequent increase in corn particle size, worsened feed conversion by about 6% (p < 0.10) (Table 3).

The effects of corn grinding intensity on DWG and FC are contradictory in the literature. Some studies such as the one carried out by Ball et al. (2015), which characterized feeds as finely or coarsely ground, did not observe any effect on these variables in the finishing phase. Likewise, Gebhardt et al. (2018), in a study of corn ground in a roller mill, with PS ranging between 267 and 525 μm, did not verify any effect on DFI and DWG for piglets in the nursery phase. However, Huang et al. (2015), in a study with weaned piglets, detected an improvement in DFI and DWG with increasing corn grinding intensity (PS reduction from 405 to 285 μm), and Gebhardt et al. (2018) found negative effects on intake and gain in the finishing phase of swine, with a PS reduction from 561 to 285 μm.

The differences between the swine's responses in the different phases (initial or finishing) may be due to several factors. One of them is the lower relative participation of corn in their diet during the initial phases, with a reduction in the corn processing effects during this phase. Additionally, the development of the digestive tract and its microbiota, which can be positively influenced by finer particle sizes (Bao et al., 2016).

On the other hand, fine particles in feeds raise the risk of gastric ulcers (Ulens, Demeyer, Ampe, Langenhove, & Millet, 2015), which, for a developing digestive system, can be harmful. In general, coarse particles for swine are important to improve intestinal health (Millet et al., 2012).

In the present study, different grinding intensities influenced FC (p < 0.10). Grinding intensification and particle size reduction, with consequent increase in surface area, can improve the swine's digestion and, as a result, influence zootechnical performance (Huang et al., 2015; Ball et al., 2015). The same behavior was observed by Gebhardt et al. (2018), with gains that the authors consider marginal in feed conversion (P=0.091) when comparing less intense grinding for piglets with initial weights close to 12 kg. Likewise, Huang et al. (2015), in a study with weaned piglets, obtained P=0.08 values for the feed conversion when comparing fine grinding with coarse grinding for weaned piglets.

The improvement in FC is associated with better digestion of starch and other corn nutrients, given the greater surface area of ground grains and consequent greater interaction with digestive enzymes (Rojas & Stein, 2015).

Pearson's correlations

The screen hole diameter, corn and diet PS, corn and diet GSD, and corn fraction retained on the 4-, 2- and 1.2-mm test sieves were variables that showed positive correlations ($p < 0.05$) with the FC, with an amplitude close to 0.5 (Table 4). The corn fractions retained on the 0.6, 0.3- and 0.15-mm test sieves showed negative correlations ($p < 0.05$) with the FC, with highlight to the fraction retained on the 0.3 mm test sieve that showed an amplitude of -0.563 with FC (Table 4).

The positive correlations between corn and diet PS and GSD and the corn fractions retained on the test sieves, whose number was above 1.2 mm, with FC ($p < 0.05$) are related to the factors previously discussed, such as the fact that corn ground at a lower intensity. Therefore, with greater corn particle size has a smaller surface area in relation to mass, which reduces the contact between digestive enzymes and corn nutrients. On the contrary, the corn fractions retained on the 0.6, 0.3- and 0.15-mm screens present negative correlations ($p < 0.05$) with FC, reiterating the beneficial impact that fine particles, due to their greater surface area in relation to weight, cause on this zootechnical index for the piglets in the studied phase.

It is noteworthy that the fraction retained on the 0.3 mm test sieve showed the greatest correlation amplitude among the studied variables -0.563 with FC.

Table 4. Pearson's correlation (r) and significance values (ρ=) between the corn and diet physical variables and zootechnical performance.

	Final body weight		DFI		DWG		*FC*	
Items*	r	(ρ=)	r	(ρ=)	r	(ρ=)	r	(ρ=)
DFI	0.906	(<0.001)						
DWG	0.863	(<0.001)	0.827	(<0.001)				
FC	-0.137	(0.283)	0.083	(0.365)	-0.490	(0.014)		
GSA	-0.172	(0.235)	-0.080	(0.369)	-0.359	(0.060)	0.533	(0.008)
PRT 4 mm	-0.149	(0.265)	-0.073	(0.379)	-0.317	(0.087)	0.465	(0.019)
PRT 2 mm	-0.140	(0.278)	-0.045	(0.425)	-0.292	(0.106)	0.463	(0.020)
PRT 1,2 mm	-0.176	(0.230)	-0.072	(0.382)	-0.364	(0.057)	0.560	(0.005)
PRT 0,6 mm	0.122	(0.305)	-0.008	(0.486)	0.244	(0.150)	-0.463	(0.020)
PRT 0,3 mm	0.176	(0.229)	0.070	(0.385)	0.365	(0.057)	-0.563	(0.005)
PRT 0,15 mm	0.149	(0.266)	0.104	(0.332)	0.317	(0.087)	-0.420	(0.033)
PRP	0.109	(0.324)	0.110	(0.322)	0.239	(0.155)	-0.275	(0.121)
Corn PS	-0.172	(0.234)	-0.079	(0.371)	-0.360	(0.059)	0.540	(0.007)
Corn GSD	-0.164	(0.245)	-0.048	(0.420)	-0.339	(0.072)	0.544	(0.007)
Diet PS	-0.166	(0.242)	-0.089	(0.354)	-0.350	(0.065)	0.505	(0.012)
Diet GSD	-0.156	(0.255)	-0.014	(0.476)	-0.315	(0.088)	0.548	(0.006)

*DFI: daily feed intake; DWG: daily weight gain; FC: feed conversion; GSA: grinder sieve aperture (2, 2.5, 3, 3.5 or 4 mm); PRT: Percentage of corn retained on the test sieves; PRP: percentage or corn retained in pan; PS: Particle size; GSD: geometric standard deviation.

Regressions

The regression coefficients of the quadratic and square root models were not significant ($p > 0.05$). The linear model showed the best fit for estimating the FC values ($p < 0.05$) and using the values of the 1.2 mm and 0.3 mm test sieve as independent variables in the linear model provided the best R^2 values (Table 5).

Table 5. Modeling of the feed conversion in accordance with different physical characteristics of corn and diets, with correlation amplitudes greater than -+0.5 with FC.

	Analysis of independent variables to estimate FC					
	1,2 mm	0,3 mm	Corn PS	Corn GSD	Diet PS	Diet GSD
P-Values	0.010	0.0097	0.014	0.013	0.023	0.012
R2	0.275	0.279	0.253	0.257	0.213	0.262
	Linear equations*					
Linear coefficient (b)	1.88802	2.52916	1.52203	0.43977	1.27528	-0.27331
Angular coefficients (a)	0.00829	-0.01404	0.00076	0.87939	0.001154	1.19620

*Feed conversion=a.X+b, where: a= Intercept, b= Angular coefficient, and X= independent variable.

The equations for estimating FC by using the corn percentage retained on the 1.2 and 0.3 mm in test sieves, and corn GSD and feed GSD as independent variables showed slightly higher R2 values than obtained using PS. The R2 values for the equations were 0.275, 0.279, 0.257 and 0.262, respectively, while R2 for the equation using PS was 0.253 (Table 5 and Figure 2).

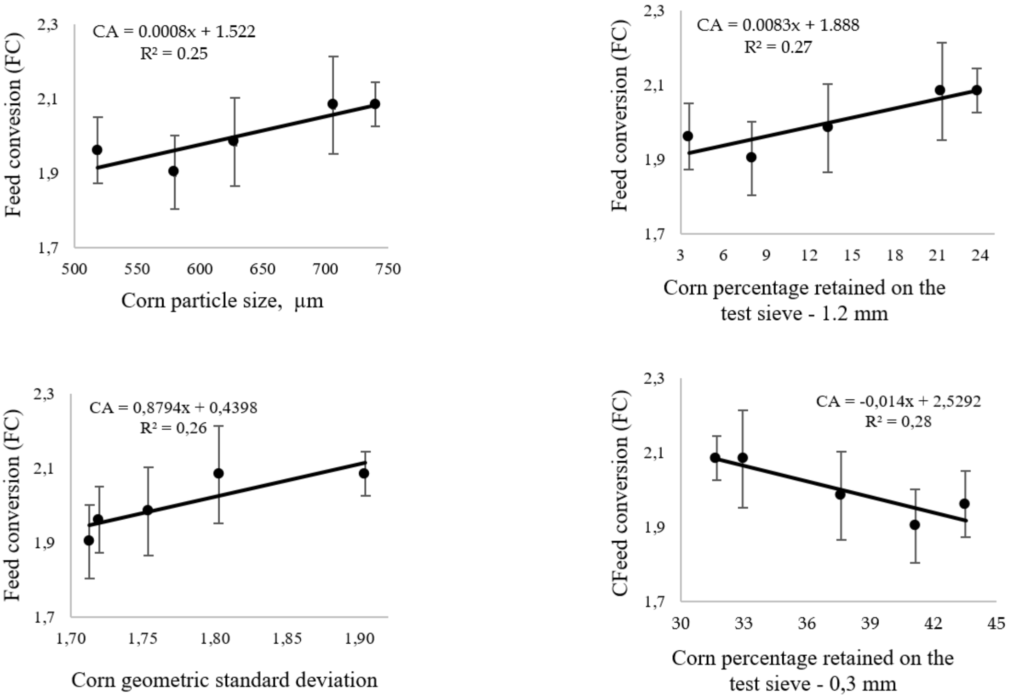

Figure 2. Feed conversion estimate based on use of corn particle size, corn geometric standard deviation, percentage of corn retained on the 1.2- or 0.3-mm test sieves as independent variables for the regression analysis.

The best fit obtained with the linear model for the FC estimates is related to the previously mentioned factors, such as the greater surface area of the greater grinding intensities (fine particles), which promoted better feed digestibility and improved FC. The linear result obtained indicates that PS reduction up to 518 µm did not cause any damage to the piglets, such as intake difficulty or harms to their beneficial intestinal microbiota (Bao et al., 2016), with consequent improvement in digestibility up to said level of crushing.

The method of determining the PS used in this work, proposed by Henderson and Perry (1955), later published by Zanotto and Bellaver (1996) and ASABE (2008), although routinely used as a reference methodology, is subject to problems such as clogging in smaller-diameter screens. Clogging or the blinding effect, as described by Liu (2009), causes failures in the correct estimation of the PS.

The best R^2 obtained when the 0.3- and 1.2-mm Test sieves used as independent variable, compared to the R^2 when used corn PS as an independent variable, is associated with the smaller blinding effect to which these fractions are subject. Fractions above 0.3 mm have a smaller area in relation to weight, being therefore less prone to the blinding effect; consequently, they were better estimated in the sieving process, thus being more efficient in estimating FC when used as independent variable.

The lowest R^2 value obtained when using diet PS as an independent variable to estimate FC can be attributed with the previously mentioned problems (screen blinding). This problem is more severe in the case of diet PS estimation, the diet contains ingredients with high powdery, such as calcitic limestone and dicalcium phosphate, among others (components of the premix). These ingredients, when combined, have a greater negative impact on the accuracy of PS estimation compared to corn when analyzed separately.

Corn and diet GSD, though sparsely used as an independent variable, were as effective as PS in estimating FC, a result that is associated with the GSD calculation methodology (based on the corn fractions retained on the test sieves). It is noteworthy that, in these variables (corn and diets GSD), treatments B (1.84 corn GSD) and treatment A (1.88 corn GSD), unlike the other treatments, were positioned in a different sequence, compared to PS, in the regression analysis (Figure 2).

The results obtained indicate that the fraction retained on the 1.2- and 0.3-mm test sieves, because it presents the broadest correlations among the variables studied with FC and the highest determination coefficients, can be used to determine corn-grinding quality for the feeds of piglets weighing 15 to 30 kg. It is worth noting that other studies, under different processing conditions, with different corn varieties, pigs in other phases, must be conducted with a view to confirming these results.

Conclusion

Reducing the particle size of corn from 740 to 580 μm resulted in a linear improvement in feed conversion for piglets in the nursery phase. In addition using corn particle size as an independent variable, incorporating corn fractions retained on 1.2- and 0.3-mm test sieves, as well as the geometric standard deviation of corn or diet, in the linear equations improved the coefficient of determination (R2) slightly. Therefore, these variables can be considered for estimating the feed conversion of piglets in the nursery phase with linear equations.

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