http://dx.doi.org/10.5380/avs.v27i3.

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Archives of Veterinary Science

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The effect of thermal processing and physical form of pig's diet

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INFO ARTIGO

Palavras-chaves:

Performance
Wastage
Carcass
Pelleting

Received: 26/02/21
Accepted: 01/03/21
Published: 12/09/22

ABSTRACT

Changes in diet form and thermal processing can be beneficial to pig production. Our objective with this study was to better understand and analyze the effects of diet form (mash vs. pellets) on feed wastage, performance, and the carcass of pigs. Forty pigs, castrated males and females between 21 and 127 days old, were distributed in a randomized block design into two treatments: mash diet and pelleted diet. We analyzed the data through generalized linear mixed models, considering the blocks (initial weight and sex) as random effects and the pens as the experimental unit, totalizing two treatments with 10 replicates of two animals each. We applied the F-test to compare means and considered significant if P<0.05 and marginally significant if 0.05≤P<0.1. During the nursery period (21 to 62 days old), pigs fed with the pelleted diet showed a decrease in (P<0.05) daily feed intake (DFI) and an improvement in feed conversion ratio (FCR). However, the diets showed no difference (P>0.1) in daily weight gain (DWG). From 21 to 42 days old, we found that those fed mash diet had higher feed wastage (P<0.05) compared to those fed with the pelleted diet. In the following phase, FCR (P<0.05) and DWG (P<0.05) were higher in pigs up to 80 days old, and a higher DWG (P<0.1) in those up to 101 days old fed with the thermally processed diet. In pigs from 62 to 127 days old, DFI, DWG, and FCR had no statistical difference (P>0.1) between the groups evaluated. Regarding the carcass, we observed an increase in backfat thickness (P<0.1) in pigs fed with the pelleted diet when compared to others, but there was no change in loin depth (P>0.1). These results suggest that pelleting is a viable thermal processing for pig production, because it reduces the amount of feed wastage, improves performance of male and female pigs in the nursery and growing phases and altered the carcass of these animals.

1. Introduction

About 70% of the total cost of pig production is attributed to animal diet. Given its importance, there is a constant search for alternatives that improve the efficiency in transforming diets into animal protein by increasing digestibility, consumption of the diet and reducing feed wastage. Studies have found that to achieve these improvements, animal diet should not be simply mashed into fine grains. Instead, diets now undergo mechanical and thermal processes such as pelleting, expansion or extrusion, and may even be subjected to more than one of these processes at once. Pelleting, the most popular processing technique in poultry farming, is a molding process in which mash diet is subjected to a certain temperature, moisture and pressure that transform the particles into pellets (Muramatsu et al., 2015).

A pelleted diet is more beneficial when compared to mash diet; the ingredients are less segregated, less feed is wasted, the time spent eating is shorter, the digestibility of ingredients improves, and the microbial population in the diet decreases (Behnke, 1994). In addition to the benefits of the thermomechanical process applied to pelleted diet, the performance (Wondra et al., 1995; O'Doherty et al., 2000; De Jong et al., 2016; Paulk and Hancock, 2016; Potter et al., 2017; Groehring et al., 2020; Almeida et al., 2021) and carcass of pigs (Park et al., 2003; De Jong et al., 2012) improves, leading to increased backfat thickness and loin depth when compared to animals consuming a mash diet.

However, to achieve these benefits, pellets must be of high quality, with a high durability index (PDI) and a low amount of fine particles. This owes to the fact that as the percentage of fines in the diet increases, the efficiency of the pig diet decreases (Stark et al., 1993). Furthermore, the intake of pelleted diet with over 33% fines does not improve feed efficiency in weaning pigs (Nemechek et al., 2015).

Thus, the objective of this study was to evaluate how diet form (mash and pellet) and quality affect diet wastage, performance, and changes in the carcass (backfat thickness and loin depth) of pigs.

2. Materials and Methods

The experimental procedures involving the animals were approved by the Ethics Committee on Animal Use in Research of the Federal University of Paraná, Curitiba, Brazil.

In our experiment, we used 40 pigs, castrated males and females, bred commercially (PIC®), with an average initial weight of 6.06 ± 0.78kg and between 21 and 127 days old. During the nursery period, from 21 to 62 days old, animals of the same sex were housed in pairs, in 1.2m^2 pens (0.6m^2/animal) with partially slatted flooring (approximately 66%), equipped with an electrical heating source, a trough feeder, and a bowl drinker. In the growing/finishing phases (62 to 127 days old), the animals were transferred to another facility, fed with the same treatments, and housed in 3.25m^2 stalls (1.625m^2/animal) with partially slatted flooring (approximately 40%), equipped with a trough feeder and a bite ball drinker.

The experimental treatments consisted in comparing two diet forms: mash and pellet, processed to meet the nutritional demands of pigs. During the nursery phase, diets were divided into 3 phases: pre-initial, from 21 to 28 days old; pre-initial 2, from 28 to 42 days old; and initial, from 42 to 62 days old (Table 1). In the growing/finishing phases of the experiment, the diets were divided into: grower 1, from 62 to 80 days old; grower 2, from 80 to 101 days old; and finisher, from 101 to 127 days old (Table 2). During all phases, the diets were available to the animals at will.

The mash diet was subjected to the pelleting process, through which we obtained the pelleted diet. This process took place in a 315kW steam-powered pellet mill (C900 model, Van AArsen, Panheel, Netherlands) equipped with a 75mm thick die with 4mm bore diameter for all growing phases. We set conditioning time at 8 seconds with a pressure of 0.9kgf/cm^2 and a temperature of 62 to 64ºC for the pre-initial diets and 75ºC for the initial, grower 1, grower 2, and finisher diets. After the pelleting process, the diets were dried and cooled to 32ºC.

The particle size distribution was determined with the method developed by Zanotto and Bellaver (1996). Mash samples from each phase (200g; 4 replicates) were sieved for 10 minutes through a set of sieves (4.0; 2.0; 1.19; 0.30; 0.15; and 0.0mm). We accounted for the amount of diet retained on each sieve and calculated the geometric mean diameter (GMD) and geometric standard deviation (GSD) for each sample (Table 3).

The quality of the produced diet was evaluated based on three variables: percentage of diet fines, pellet durability index (PDI) and pellet hardness (Table 3). To determine the percentage of fines, we weighed and sieved 500g of the pelleted diets of each phase for approximately 30s using 3.4mm sieves (Tyler no.6, TelastemPeneiras para Análises LTDA). The percentage of fines corresponded to the percentage of material retained on the sieve in relation to the initial weight.

We evaluated the PDI using a PDI tester (Durabilímetro, RA Electromecânica, Santa Helena, Brazil). Approximately 500g of the pellets retained on the sieves during the determination of fine percentage were used in the PDI tester. All samples were processed at 50rpm for 10min, and after that, the samples were sieved again (3.4mm) for approximately 30s to remove fines and broken pellets. To calculate the PDI, expressed as a percentage according to Ensminger's (1985) methodology, we divided the sample weight after sieving by the weight before sieving. The hardness analysis was performed using a durometer (Nova Ética®, model 298 DGP - Ethiktechnology, São Paulo, Brazil) on individual pellets (20 pellets per pelleted diet).

The animals were weighed at the beginning of the experiment, then at 42, 62, 80, 101 and 127 days old. The provided diets and leftovers were weighed at the same time intervals. From this information, we determined the daily feed intake (DFI), daily weight gain (DWG), feed conversion ratio (FCR), and the average live weight (LW) of the animals.

At 27, 34, and 41 days old, we measured weekly feed wastage (FW) per pen (g) and calculated daily feed intake adjusted for feed wastage (DFI-FW) over the cumulative time period. At 80, 101, and 127 days old, the animals were submitted to an *in vivo* ultrasound for carcass evaluation. We used the KX2000G (Xuzhou Kaixin Electronic Instrument Co., Ltd., Jiangsu, China) ultrasound device with a 15cm acoustic probe at 3.5 MHz. The probe was positioned at point P_2, the insertion region of the last thoracic vertebra with the first lumbar vertebra, six centimeters from the animal's midline. We then measured the backfat thickness and loin depth (*Longissimus dorsi* muscle) of each animal.

The experimental design was in randomized blocks. The animals were randomly distributed into two treatments (mash and pelleted diets) according to sex and initial weight, with 10 repetitions of two animals each. There were five repetitions for males and five repetitions for females.

The data were analyzed using the Linear Mixed-Effects Models package (Bates et al., 2015) in the R program (R Core Team, 2009). We considered the blocks (sex and initial weight) as a random effect and the pens (repetitions) as an experimental unit. Subsequently, the means were compared through the F-test and considered significant if $P<0.05$ and marginally significant if $0.05 \leq P<0.1$.

Ingredients (kg)	Pre-initial 1	Pre-initial 2	Initial
Corn	492.50	552.00	606.50
Soybeanmeal 46%	252.64	270.90	301.88
Soybeanoil	33.0	32.0	45.5
Wheypowder	106.25	50.00	-
Micronizedsoybeans	31.25	25.00	-
Sugar	25.00	18.75	-
Plasma	25.00	12.50	-
Premix[1]	3.00	3.00	3.00
Mycotoxinadsorbent	-	-	6.25
Kaolin	0.133	0.133	0.133
Iodizedgranulatedsalt	3.900	5.050	6.100
Calciticlimestone	4.250	4.825	6.100
Granulatedbicalciumphosphate 19%	6.400	8.650	9.500
Copper sulfate pentahydrate 25%	0.320	0.320	0.520
White zinc oxide 80%	3.019	2.390	-
Choline	0.119	0.099	0.079
L-LysineHCl 78%	4.910	5.510	6.100
DL-methionine 99%	2.855	2.873	2.888
L-Threonine	2.138	2.433	2.715
L-Tryptophan 98%	1.180	1.220	1.248
L-Valine	1.260	1.468	1.338
Phytaseenzyme	0.050	0.050	0.050
Flavoringadditive	0.250	0.250	-
Palatabilityadditive	0.075	0.075	0.075
Antioxidant	0.500	0.500	0.025
Calculated composition			
Metabolizableenergy, kcal/kg	3450	3400	3380
Crudeprotein, %	20.90	20.30	19.60
Etherealextract, %	6.48	6.43	7.33
Lactose, %	7.91	3.725	-
Crudefiber, %	2.20	2.35	2.45
Digestibleaminoacids, %			
Lysine	1.450	1.400	1.350
Methionine	0.552	0.545	0.537
Met + Cis	0.870	0.840	0.810
Threonine	0.943	0.910	0.877
Tryptophan	0.348	0.336	0.324
Arginine	1.184	1.171	1.153
Isoleucine	0.770	0.743	0.717
Leucine	1.580	1.518	1.453
Histidine	0.490	0.473	0.454
Total calcium, %	0.630	0.675	0.722
Total phosphorus, %	0.506	0.520	0.507
Sodium, %	0.290	0.270	0.250

[1] Content per kg: Vit. A, 8,000UI; Vit. D3, 1,500UI.; Vit. E, 9.8UI.; Vit. K3, 1mg.;Vit. B2, 3.5 mg.;Vit. B12, 15mg.; Ac. Pantothenic, 15mg.; Ac. Nicotinic, 20mg.; Se, 0.60mg.; Mg, 45mg.; Cu, 52mg.; Fe, 100mg.; Zn, 1100mg.; I, 1.50mg.

Table 1 *– Ingredients and calculated composition of diets during the nursery phase.*

Ingredients (kg)	Grower 1	Grower 2	Finish
Corn	711.45	742.85	844.00
Soybeanmeal 46%	178.12	151.99	91.73
Poultrymeal	66.85	48.57	32.00
Poultryfat	20.51	26.28	13.00
Premix[1]	2.000	1.000	0.500
Mycotoxinadsorbent	0.500	10.00	0.375
Kaolin	0.133	0.133	0.133
Iodizedgranulatedsalt	5.200	4.885	4.550
Calciticlimestone	4.142	4.514	5.800
Coppersulphatepentahydrate 25%	0.3400	0.3714	0.385
L-LysineHCl 78%	55.486	50.686	4.190
DL-methionine 99%	20.714	16.771	-
Liquidmethionine	-	-	12.575
L-Threonine	20.200	17.457	15.375
L-Tryptophan 98%	0.3829	0.3514	0.3875
L-Valine	0.5314	0.4029	0.0100
Phytase enzyme[2]	0.0500	0.0500	0.0500
Antioxidant	0.0250	0.0250	0.0250
Enramycin 8%	0.0625	0.0625	0.0625
Calculated composition			
Metabolisable energy, kcal/kg	3.350	3.350	3.325
Crudeprotein, %	18.81	16.56	13.39
Etherealextract, %	5.75	6.19	4.98
Crudefiber, %	2.03	1.94	1.84
Digestibleaminoacids, %			
Lysine	1.200	1.050	0.800
Methionine	0.466	0.398	0.302
Met + Cis	0.720	0.630	0.504
Threonine	0.780	0.683	0.560
Tryptophan	0.204	0.179	0.144
Arginine	1.060	0.914	0.691
Valine	0.780	0.683	0.520
Isoleucine	0.637	0.558	0.433
Histidine	0.406	0.365	0.304
Total Calcium, %	0.760	0.665	0.570
Total Phosphorus, %	0.450	0.395	0.337
Sodium, %	0.240	0.220	0.200

[1] Content per kg: Vit. A, 6,500UI.;Vit.D_3, 2,000UI.; Vit. E, 42mg; Vit. K_3, 2.0mg; Vit. B_2, 6.4mg; Vitamin B_6, 3.0mg; Vitamin B_{12}, 24µg; D-biotin, 160µg; D-Calciumpantothenate, 20mg; Folicacid, 1.2mg; Niacin, 24mg; Copper, 125mg; Potassiumiodate, 0.5mg; Iron, 100mg; Manganese, 50mg; Zinc, 100mg; Selenium, 250µg; andCholinechloride, 250mg.

[2] 500 phytase units/kg (AxtraPhy, Danisco Animal Nutrition, Marlborough, UK)

Table 2 – *Ingredients and calculated composition of diets during the growing/finishing phases.*

	GMD, µm	GSD, %	PDI, %	% Fines	Hardness, kg
Pre-initial 1	521	1.63	97.17	12.04	9.1
Pre-initial 2	575	1.57	96.54	23.40	7.0
Initial	629	1.52	91.84	10.50	5.6
Grower 1	715	1.54	89.26	11.75	5.1
Grower 2	760	1.54	92.61	6.35	5.2
Finisher	629	1.58	87.03	39.60	3.6

Table 3 *- Geometric Mean Diameter (GMD) and Geometric Standard Deviation (GSD) of the mash diets; and pellet durability index (PDI), percentage of fines (% Fines) and hardness of the pelleted diets.*

3. Results and Discussion

During the weaning period, pelleting did not influence the DWG of pigs (P>0.1). However, their DFI (P<0.05) was lower compared to the animals that received the mash diet and, due to this, we observed an improvement in FCR (P<0.05) in animals that consumed the thermally processed diet (Table 4). Feed wastage was higher (P<0.05) in animals fed mash diets, on average 57% higher than animals receiving pelleteddiets (Table 5). Thus, we found that the pelleted diet form affected feed wastage levels and consequently contributed to the performance of the animals. However, after correcting feed wastage in the DFI of the pigs (DFI-FW) with 21 to 42 days old, the consumption of animals receiving the pelleteddiet remained lower (P<0.1; Table 4).

	Mash	Pelleted	SEM[1]	P-value
	21 to 42 daysold			
DFI[2], g	363	320	16.3	0.049
DFI-FW[3], g	354	316	16.1	0.085
DWG[4], g	253	271	18.9	0.211
FCR[5]	1.412	1.230	0.052	0.001
Live weight at 42 d, kg	11.54	11.80	0.62	0.536
	21 to 62 daysold			
DFI, g	696	653	25.6	0.037
DWG, g	408	423	18.7	0.473
FCR	1.708	1.554	0.038	0.002
Live weight at 62 d, kg	22.84	24.09	0.94	0.106

SEM[1] – standard error of the mean; DFI[2]– daily feed intake; DFI-FW[3] – daily feed intake adjusted for feed wastage; DWG[4] – daily weight gain; FCR[5] – feed conversion ratio

Table 4 *– Effect of thermal processing and diet form on the performance of castrated male and female weaning pigs.*

	21 to 27 d	28 to 34 d	35 to 41 d
Mash (g)	115.4	127.6	158.8
Pelleted (g)	49.8	45.0	80.8
P-value	0.006	<0.001	<0.001
SEM[1]	17.9	11.8	21.3

SEM[1] - standard error of the mean

Table 5 *– Effect of diet form on weekly feed wastage of pigs from 21 to 41 days old.*

Surek et al. (2017) had similar results in a study in which animals that consumed mash dietshowedhigherfeed wastage rates (9.15 *vs.* 1.68%) compared to those that received processed diet. Medel et al. (2004), however, found that pelleting reduced DFI by 18.2% and improved the FCR of animals by 20%. This improvement can be attributed not only to feed wastage, but also to the improvement of crude energy digestibility, as there was an increase of approximately 3.6% in the energy used by animals that consumed the pelleted diet compared to those that received the mash diet.

Moreover, maintaining the physical form of the pelleted diet is important to achieve better performance results. Low PDI pellets have a large amount of fines when they reach the feeders; these fine particles are equal in size or smaller than the fine particles in mash diets. This may not provide the expected performance gain of the pelleted diet in relation to mash diet. This was demonstrated byNemechek et al. (2015), who compared weaning pigs consuming mash diet, poor quality pellets (33 to 37% of fines) and screened pellets with minimal fines (3 to 5% of fines); only the group fed with the screened pellets showed improvement in FCR (about 4%) compared to the others. Thus, the quality of the weaning pelleted diets in this study may have influenced its results, mainly due to their lower percentage of fines (Table 3).

Other aspects that may interfere with diet preference, and consequently with performance, are pellet hardness and size, as pointed out by Van Der Poel et al. (1997). They compared different thermal processes (pelleting and expansion followed by pelleting) and pellets with different levels of hardness (2.9 and 8.1 kg). However, there was no negative impact on pig diet preference or consumption according to a more recent study (Van Den Brand et al., 2014) in which the pellet hardness ranged from 0.8 to 13.9 kg and the pellet size, from 2 to 12 mm.

In the following period, from 62 to 80 days old, there was no difference (P>0.05) in DFI between the studied treatments though we observed a higher DWG (P<0.05) for animals consuming the pelleted diet compared to animals consuming the mash diet, as well as improved FCR and LW (P<0.05) for the thermally processed diet. At this growing phase, from 62 to 101 days old, we found no difference between the groups evaluated for DFI and FCR (P>0.05), but the pigs fed with the pelleted diet had better DWG (P<0.1) and were on average 3.28 kg heavier (P<0.05) than those fed mash diet (Table 6).

	Mash	Pelleted	SEM[1]	P-value
	62 to 80 daysold			
DFI[2], g	1609	1606	72.9	0.954
DWG[3], g	872	936	44.6	0.033
FCR[4]	1.823	1.722	0.039	0.068
Live weight at 80 d, kg	38.02	40.95	1.30	0.009
	62 to 101 daysold			
DFI, g	1813	1878	148.1	0.291
DWG, g	978	1030	76.0	0.066
FCR	1.861	1.827	0.028	0.384
Live weight at 101 d, kg	60.98	64.26	3.68	0.044
	62 to 127 daysold			
DFI, g	2184	2216	182.1	0.627
DWG, g	1066	1101	78.3	0.229
FCR	2.047	2.013	0.031	0.438
Live weight at 127 d, kg	92.18	95.67	5.79	0.120

SEM[1] - standard error of the mean; DFI[2] - daily feed intake; DWG[3] - daily weight gain; FCR[4] - feed conversion ratio

Table 6 *- Effect of thermal processing and diet form on the performance of castrated male and female growing/finishing pigs.*

Pelleting thediet of growing/finishing pigs usually results in a 2 to 8% increase in FCR (Skoch et al., 1983; Wondra et al., 1995; O'Doherty et al., 2000; De Jong et al., 2016; Paulk and Hancock, 2016; Almeida et al., 2021) and of 2 to 5% in the DWG (Wondra et al., 1995; O'doherty et al., 2000; Jong et al., 2016; Paulk and Hancock, 2016; Potter et al., 2017; Almeida et al., 2021). This study found similar results for animals up to 101 days old (62.6 kg on average). These performance improvements are mainly attributed to reduced wastage due to the diet form and increased digestibility, especially of energy and protein, as a result of the thermomechanical pelleting process (Wondra et al., 1995; Medel et al., 2004; Lundblad et al., 2012).

However, from 62 to 127 days old, none of the analyzed variables in the entire period (P>0.1; Table 6) showed any differences. It is possible that the higher percentage of fines in the finisher diet (39.60%, Table 3) prevented an improvement in the performance of these animals in relation to those that received a mash diet. Stark et al., (1993) demonstrated that the percentage of fines in the diet is closely related to the improvement in FCR, when they found that the FCR (2.65; 2.78; 2.77; and 2.82) of growing/finishing pigs worsened linearly asthe percentage of fines in the diet increased (0%; 20%; 40%; and 60%, respectively).

There was a marginally statistical difference (P<0.1) in backfat thickness at all the measured ages.Animals fed with the pelleted diet showed higher backfat thickness compared to those fed with the mash diet. However, there was no difference in loin depth (P>0.1) between the evaluated groups (Table 7). Park et al. (2003) and De Jong et al. (2012) also observed a higher backfat thickness in animals consuming the pelleted diet compared to animals consuming the mash diet. This increase in backfat thickness may have been caused by the higher energy value of the processed dietsas a result of their higher digestibility (Park et al., 2003). However, other studies found no differences (P>0.1) in backfatthickness and loin depth between animals fed either pelleted or mash diets (Nemechek et al., 2016; O'Meara et al., 2020).

	Backfat thickness, mm			**Loindepth, mm**		
Age, days	80	101	127	80	101	127
Mash	7.94	9.52	12.47	37.64	47.66	55.22
Pelleted	8.53	10.12	13.62	38.61	50.45	55.83
P-value	0.058	0.061	0.075	0.291	0.109	0.621
SEM[1]	0.26	0.31	1.27	0.86	2.70	1.72

SEM[1] - standard error of the mean

***Table** 7- Effect of thermal processing and diet form on backfat thickness and loin depth in castrated males and females during the growing/finishing periods.*

4. Conclusion

The results suggest that pelleting is a viable diet processing option to improve the performance of castrated male and female pigs during the nursery and growing phases. One of the mechanisms that promotes this improvement is the diet form, which had a positive effect on the feed wastage of the animals under study. Thus, the quality of the produced pellets becomes crucial if the pelleting objectives are to be achieved. The pelleted diet also altered the carcass of the animals, presenting higher values of backfat thickness, possibly due to the improvement in digestibility.

Acknowledgements: This study was carried out with the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - funding Code 001. The author(s) would like to thank the Academic Publishing Advisory Center (Centro de Assessoria de PublicaçãoAcadêmica, CAPA – www.capa.ufpr.br) of the Federal University of Paraná (UFPR) for assistance with English language translation and editing.

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