SEMINA Ciências Agrárias

DOI: 10.5433/1679-0359.2025v46n5p1509

Effect of soybean meal protein solubility in diets of grower-finisher pigs: growth performance, blood profile, apparent digestibility, and carcass and meat traits

Efeito da proteína solúvel do farelo de soja em dietas para suínos em crescimento-terminação: desempenho, perfil sanguíneo, digestibilidade aparente, e características de carcaça e carne

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Highlights

Soybean meal PS is determinant for dietary nutritional quality in pigs.
Variations in soybean meal PS influence the blood hematological profile.
Soybean meal PS affects protein and energy digestibility.
Soybean meal PS values between 75% and 85% maintain performance and meat quality.

Abstract

Potassium hydroxide (KOH) protein solubility (PS) is one of the most commonly used parameters to evaluate the degree of heat processing and the quality of protein and amino acids in soybean meal (SBM). Therefore, the objective of this study was to assess SBM KOH-PS levels in diets for grower-finisher pigs and their effects on growth performance, blood biochemical and hematological profile, apparent digestibility of nutrients and energy, and carcass and meat traits. A total of 80 entire male

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Received: Dec. 02, 2024 Approved: Oct. 06, 2025

pigs (Landrace × Large White; 35.24 ± 2.09 kg BW) were alloted for 88 days to a randomized block design (10 replicates and two pigs per pen as the experimental unit) with four dietary treatments: 1) SBM75 (diet containing SBM with 75% PS), SBM77 (diet containing SBM with 77% PS), SBM80 (diet containing SBM with 80% PS), and SBM85 (diet containing SBM with 85% PS). Experimental phases were defined as: grower I (77–97 d), grower II (97–111 d), grower III (111–139 d), finisher I (139–153 d), and finisher II (153–165 d). Finisher II pigs fed SBM75 or SBM80 diets showed greater (P=0.032) mean corpuscular hemoglobin concentration (MCH) compared with those fed the SBM85 diet. Grower II pigs fed the SBM80 diet showed greater (P=0.005) digestible protein compared with those fed SBM75 or SBM85 diets. Additionally, grower II pigs fed the SBM85 diet exhibited greater (P=0.007) digestible energy (DE) compared with those fed the SBM75 diet. In contrast, finisher II pigs fed the SBM85 diet had greater (P=0.039) DE than those fed the SBM77 diet. Animals fed the SBM77 diet showed a greater (P=0.042) carcass pH 24 hours postmortem compared with those fed the other dietary treatments. Diets containing soybean meal with 75% to 85% KOH-PS did not alter growth performance or meat quality of grower-finisher pigs; however, they promoted changes in blood profile, apparent digestibility of nutrients and energy, and carcass pH.
Key words: Antinutritional factors. Assessing method. Blood. Heat processing. KOH protein solubility. Soybean meal quality.

Resumo

A solubilidade proteica (PS) em hidróxido de potássio (KOH) é um dos parâmetros mais utilizados para avaliar o grau de processamento térmico e a qualidade da proteína e aminoácidos do farelo de soja (FS). Portanto, o objetivo foi avaliar teores de PS em KOH do FS em dietas para suínos em crescimento e terminação e seus efeitos no desempenho, perfil bioquímico e hematológico sanguíneo, digestibilidade aparente dos nutrientes e energia, e características de carcaça e carne. Um total de 80 suínos (35,24 kg ± 2,09 kg BW) machos inteiros (Landrace × Large White), foram designados por 88 dias em um delineamento de blocos casualizados, constituído por 4 tratamentos dietéticos: FS75 (dieta com 75% de PS do FS), FS77 (dieta com 77% PS do FS), FS80 (dieta com 80% de PS do FS), FS85 (dieta com 85% de PS do FS), 10 repetições e 2 suínos por baia como unidade experimental. As fases experimentais foram definidas como crescimento I (77 a 97 dias), crescimento II (97 a 111 dias), crescimento III (111 a 139 dias), terminação I (139 a 153 dias), e terminação II (153 a 165 dias). Suínos em terminação II alimentados com as dietas FS75 ou FS80 exibiram maior (P=0,032) concentração de hemoglobina corpuscular média do que suínos alimentados com a dieta FS85. Os suínos em crescimento II que consumiram a dieta FS80 apresentaram maior (P=0,005) proteína digestível em relação aos animais alimentados com as dietas FS75 ou FS85. Além disso, os suínos em crescimento II que consumiram a dieta FS85 exibiram maior (P=0,007) energia digestível (ED) do que quando consumiram a dieta FS75. Os suínos em terminação II que consumiram a dieta FS85 tiveram maior (P=0,039) ED do que àqueles que consumiram a dieta FS77. Os animais alimentados com a dieta FS77 mostraram maior (P=0,042) pH da carcaça 24 h após abate do que os demais. Dietas com farelo de soja entre 75% a 85% de proteína solúvel em KOH não alterou o desempenho e a qualidade da carne dos suínos em crescimento-terminação, mas promoveram alterações no perfil sanguíneo, digestibilidade aparente dos nutrientes e energia e no pH da carcaça.
Palavras-chave: Fatores antinutricionais. Método de avaliação. Processamento térmico. Qualidade do farelo de soja. Sangue. Solubilidade proteica em KOH.

Introduction

Soybean meal (SBM) is the main source of plant protein (44% to 48% CP) and amino acids in pig feeding (Upadhaya et al., 2016; Marchal et al., 2024). However, studies have shown that variations in soybean thermal processing, especially temperature and toasting time, directly affect SBM quality, impacting its nutritional value and nutrient digestibility (Araba & Dale, 1990; Căpriţă et al., 2010; Veum et al., 2017).

One strategy to improve the nutritional efficiency of pig diets is to use SBM with high potassium hydroxide protein solubility (KOH-PS) (Araba & Dale, 1990). The determination of KOH-PS has been indicated as an effective method for assessing SBM quality, as it allows identifying the degree of processing, including both underheating and overheating (Lee et al., 2007). An effectively processed SBM should present KOH-PS between 78% and 84% (Dozier et al., 2011).

A KOH-PS value below 78% indicates overheating, and SBM presents a darker, caramelized color due to the Maillard reaction, which not only inactivates antinutritional factors but also reduces available lysine and protein digestibility (Căpriţă et al., 2010; Dozier et al., 2011; Veum et al., 2017). On the other hand, a KOH-PS value above 84% indicates underheating, where antinutritional factors (e.g., trypsin inhibitors, hemagglutinins, antigenic factors, and oligosaccharides) may still be active, impairing dietary nutrient digestion and pig growth performance (Dozier et al., 2011; Lima et al., 2014; Veum et al., 2017).

The KOH-PS may influence nitrogen utilization, digestibility, and growth rates in production animals (Milani et al., 2022). In pigs, KOH-PS affects amino acid availability, digestive efficiency, weight gain, feed conversion, and carcass traits (Žilić et al., 2006; Maurya & Said, 2014). Moreover, evaluations of blood biochemical and hematological profiles can provide important information on the metabolic state and overall health of animals in response to dietary protein quality (Isaac et al., 2013; Etim et al., 2014).

Considering the limited information available on this topic and the knowledge gaps regarding the optimal KOH-PS in SBM for grower-finisher pigs, this study was conducted based on the hypothesis that a high KOH-PS in SBM would improve the performance of grower-finisher pigs by effectively inhibiting antinutritional factors and increasing the apparent digestibility of nutrients in the digestive tract (ATTD). Therefore, the present study was conducted to assess growth performance, blood biochemical and hematological profiles, ATTD of nutrients and energy, as well as carcass and meat traits of grower-finisher pigs fed diets containing SBM with different levels of KOH-PS.

Material and Methods

Ethical approval, animals, experimental design, housing, and dietary treatments

The study was conducted in the swine sector of the experimental farm Professor Antônio Carlos dos Santos Pessoa, belonging to the Universidade Estadual do Oeste do Paraná (Unioeste), Marechal Cândido Rondon, PR, Brazil. The Ethics Committee on the Use of Production Animals (Protocol number 25-2024) of Unioeste (Marechal Cândido Rondon, Paraná, Brazil) approved all the experimental procedures.

A total of 80 entire hybrid male pigs (Landrace × Large White), weighing 35.24 ± 1.86 kg BW, were used. Pigs were allotted to 1 of 4 dietary treatments in a randomized block design with 10 replicates, and two pigs per pen as the experimental unit. Blocks were based on initial body weight: light (2 blocks), medium (6 blocks), and heavy (2 blocks). On day 0 of the experiment, animals were identified with numbered ear tags, weighed, and housed in pens (1.79 m × 1.60 m, 2.86 m²) equipped with a manual feeder and a nipple drinker.

Room temperature and relative humidity were recorded four times daily (08:00h, 11:00h, 14:00h, and 17:00h) using a digital datalogger (Hygro-Thermometer, model RT811, Taipei, TP, Taiwan) located in the middle of the experimental facility. Throughout the experiment, room temperature and relative humidity averaged 26.74 ± 4.74 °C and 65.03 ± 17.12%, respectively.

The experimental period lasted 88 days and was divided into five phases: grower I (77 to 97 days), grower II (97 to 111 days), grower III (111 to 139 days), finisher I (139 to 153 days), and finisher II (153 to 165 days). All diets were corn- and SBM-based with industrial amino acids. Mash diets (Table 1) were formulated to meet the nutritional requirements (Rostagno & Albino, 2024) of pigs in each phase and were offered in controlled amounts (grower I: 1.90 kg/animal; grower II: 2.60 kg/animal; grower III: 2.80 kg/animal; finisher I: 2.90 kg/animal; finisher II: 3.40 kg/animal) twice daily, without quantitative restriction. Water was provided *ad libitum* throughout the experimental period.

The dietary treatments were: (1) SBM75 (diet containing SBM with 75% protein solubility), (2) SBM77 (diet containing SBM with 77% protein solubility), (3) SBM80 (diet containing SBM with 80% protein solubility), and (4) SBM85 (diet containing SBM with 85% protein solubility). The SBM for each treatment was obtained from a local soybean crushing plant and toasted for 20 min at different temperatures: (1) SBM75: 170 ºC; (2) SBM77: 160 ºC; (3) SBM80: 150 ºC; and (4) SBM85 130 ºC.

Table 1
Composition of diets with different percentages of protein solubility from soybean meal provided to grower and finisher pigs (as feed base)

	Experimental phases[2]				
Item (kg)[1]	Grower I	Grower II	Grower III	Finisher I	Finisher II
Ground corn, 7.86 % CP	68.31	72.67	73.56	72.23	68.94
Soybean meal, 45.4 % CP	24.00	20.00	19.00	20.00	23.00
Meat flour, 52.0 % CP	3.80	3.80	3.80	3.80	3.90

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Soybean oil	1.35	1.00	1.00	1.25	1.50
Calcitic limestone	0.40	0.50	0.60	0.50	0.50
Mineral-vitamin premix	0.20	0.20	0.20	0.20	0.20
L-lys, 80.0 %	0.57	0.56	0.51	0.57	0.57
DL-met, 99.0 %	0.22	0.17	0.13	0.17	0.19
L-thr, 98.0 %	0.17	0.15	0.13	0.16	0.17
L-trp, 60.0 %	0.05	0.04	0.04	0.06	0.06
L-val, 95.5 %	-	-	-	0.04	0.03
Copper sulfate	0.06	0.06	0.06	0.06	0.05
Betaine	0.03	0.03	0.10	0.10	0.10
Organic mineral additives	-	-	0.12	0.12	0.12
Mycotoxin adsorbent	0.10	0.08	0.05	0.05	-
Enzymes	0.10	0.10	0.10	0.10	0.10
Phytotherapeutic	0.10	0.08	0.10	0.05	0.05
Salt	0.55	0.50	0.50	0.50	0.50
Tilmicosin	-	0.05	-	-	-
Florfenicol	-	-	-	0.02	-
Tilvalosin	-	-	-	0.01	-
Ractopamine	-	-	-	0.02	0.02
Calculated chemical composition					
ME, kcal/kg	3,400	3,380	3,380	3,385	3,410
CP, %	19.51	17.96	17.57	17.98	19.20
Digestible lysine, %	1.20	1.10	1.05	1.10	1.18
Digestible methionine + cysteine, %	0.59	0.58	0.58	0.59	0.59
Digestible threonine, %	0.65	0.65	0.65	0.65	0.65
Digestible tryptophan, %	0.19	0.19	0.19	0.19	0.19
Total calcium, %	0.71	0.74	0.77	0.74	0.75
Available phosphorus, %	0.42	0.41	0.41	0.41	0.42
Total sodium, %	0.27	0.25	0.25	0.25	0.26

[1]Mineral-vitamin premix: contains vitamin A, 7,000 UI/kg; vitamin D3, 1,500 UI/kg; vitamin E, 50.00 mg kg^{-1}; vitamin K, 3.50 mg kg^{-1}; vitamin B1, 1.00 mg kg^{-1}; vitamin B2, 6.00 mg kg^{-1}; vitamin B6, 1.50 mg kg^{-1}; vitamin B12, 25.00 mcg/kg; niacin, 40.00 mg kg^{-1}; pantothenic acid, 20.00 mg kg^{-1}; folic acid, 0.35 mg kg^{-1}; biotin, 120.00 mg kg^{-1}; total selenium, 0.30 mg kg^{-1}; organic mineral additives: chrome, 8.00 mg kg^{-1}; zinc-methionine, 4.00 mg kg^{-1}; enzymes: protease, 5,000 un/g; beta-mannanase, 40,000 un/g; endo-xylanase, 2,000 un/g; fitase, 1,000 FTU; phytotherapeutic: thyme extract, carob flour, selenium; tilmicosin: hi-bac®; florfenicol: farmaflor® 50; tilvalosin: aivlosin® FG50; ME: metabolizable energy; CP: crude protein.
[2]Composition of the diets for each experimental phase with SBM75: soybean meal with 75% protein solubility; SBM77: soybean meal with 77% protein solubility; SBM80: soybean meal with 80% protein solubility; SBM85: soybean meal with 85% protein solubility.

Growth performance

The feed provided and refusals in each experimental phase were recorded using a scale (Digi-tron, model UL-50, Curitiba, PR, Brazil). Individual body weights were recorded at the beginning and end of each phase using a digital two-bar scale (Digi-tron, model ULB-3000, Curitiba, PR, Brazil). From these data, initial body weight (IBW, kg), final body weight (FBW, kg), average daily feed intake (ADFI, kg/day), average daily gain (ADG, kg/day), and feed to gain ratio (F:G, kg:kg) were calculated.

Blood profile sampling and analysis

Blood samples were taken from all animals at the end of the grower II (day 105) and finisher II (day 161) phases after an 8-hour fast. Animals were restrained, and 20 mL of blood was collected from the anterior cranial vena cava using 1.2 × 40 mm needles and disposable syringes. Blood samples were transferred into four tubes (Sol-Millennum, São Paulo, SP, Brazil) containing potassium fluoride, sodium heparin, ethylenediaminetetraacetic acid (EDTA), or no anticoagulant, according to the manufacturer's instructions.

Immediately after blood collection, complete blood counts were performed with EDTA-containing samples from each animal using an automated hematology analyzer (Mindray, model BC-2800Vet, Nanshan, SZ, China) at the blood analysis laboratory of Unioeste. This analysis determined platelet count, mean corpuscular volume, hematocrit, mean corpuscular hemoglobin concentration, total leukocytes, mean corpuscular hemoglobin, red cell distribution width, platelet distribution width, hemoglobin, mean platelet volume, total erythrocytes, and procalcitonin. The other blood samples were centrifuged (Daiki, model 80-2B, Curitiba, PR, Brazil) at 3000 rpm for 10 min. Plasma or serum was then transferred into polyethylene microtubes and stored at -20 ºC for further analyses.

Serum samples were used to determine concentrations of albumin (enzymatic-colorimetric method), urea (enzymatic-colorimetric method), and total protein (enzymatic-biuret method). Plasma samples were used to determine glucose concentrations (enzymatic-colorimetric method), and activities of aspartate aminotransferase (AST, kinetic-UV method) and alanine aminotransferase (ALT, kinetic-UV method). All analyses were performed in a spectrophotometer (Tecnal, model SF-325, Piracicaba, SP, Brazil) at the blood analysis laboratory of Unioeste, using commercial kits (Gold Analisa Diagnóstica, Belo Horizonte, MG, Brazil).

Apparent digestibility of nutrients and energy

Digestibility was assessed via an indirect method (Sakomura & Rostagno, 2016) using acid-insoluble ash (AIA, Celite®) added at 1% to the diets of grower II (104 days) and finisher II (160 days). Partial fecal collection was performed on days 107 and 163 in the grower II and finisher II phases, respectively. Pens were thoroughly cleaned before collection, and then partial fecal collections were carried out continuously for 12 hours immediately after defecation.

The feces collected over the 12-h period were placed in plastic bags and kept on ice within coolers (4°C). After collection, feces were homogenized, and two subsamples (120 g each) per pen were weighed on a scale (Líder, model LD1050, Araçatuba, SP, Brazil) and dried in a forced-air oven (Tecnal, model TE 394/3, Piracicaba, SP, Brazil) at 55 °C for 72 h, according to Association of Official Analytical Chemists [AOAC] (2012). After drying, feces were ground in a micro-powder grinding mill (Tecnal, model TE-350, Piracicaba, SP, Brazil).

AIA was analyzed as described by Kavanagh et al. (2001). Briefly, ash from feces and diet samples was digested in heated 20 mL of hydrochloric acid (HCl) until complete acid evaporation, and subsequently filtered with distilled water at 38 ºC until the solution was acid-free. The chemical composition of the diets and feces was determined as described in AOAC (2012). The gross energy of diets and feces was determined using a bomb calorimeter (IKA®, model C200, Wilmington, NC, USA).

Based on laboratory analyses, the apparent digestibility coefficients of dry matter (ADCDM, %), organic matter (ADCOM, %), crude protein (ADCCP, %), and gross energy (ADCGE, kcal/kg) were calculated. Digestible dry matter (DDM, %), digestible organic matter (DOM, %), digestible protein (DP, %), and digestible energy (DE, kcal/kg) were calculated using the equations reported by Sakomura and Rostagno (2016).

Slaughter procedures, carcass traits, and meat quality

At the end of grower II (day 109) and finisher II (day 164) pahses, the in vivo loin depth and backfat thickness (Biscegli & Fávero, 1996) were assessed in the lumbar area P2 (between the last and second to last ribs, 5 cm below the midline of the dorsal spine) using ultrasonography (Aloka, model Echo Camera - SSD-500 vet, Tokyo, HS, Japan) and a 15 cm linear transducer operating at 3.5 MHz.

On day 165, all animals were subjected to a 12-h fast before transportation. Transport and lairage at the commercial slaughterhouse lasted 6 hours (total fasting of 18 h). Pigs were slaughtered with CO_2 stunning followed by exsanguination. Carcass and meat quality traits were assessed as suggested by Bridi and Silva (2009). Lean meat yield (kg/carcass), loin depth, and backfat thickness (mm) were measured at the slaughterhouse using a pig carcass typification pistol (Carometec, model Ultrafom 300, Herlev, RC, Denmark). Carcass weight was measured on a scale (Alpha Instruments, São Paulo, SP, Brazil) installed on the slaughter line, and lean meat percentage (%) and carcass yield (%) were calculated. Lean meat percentage was calculated by dividing the lean meat weight by the carcass weight.

After a 24-h period in a cold chamber (stage 1: -18 ºC to -15 ºC; stage 2: -15 ºC to -12 ºC; stage 3: -10 ºC to -8 ºC, for 180 min), the pH24h of the *l. thoracis* was measured at the last thoracic vertebra (caudal to cranial direction) of the carcass (Testo SA, model Testo 205, Barcelona, CL, Spain). Subsequently, a sample of the *l. thoracis* (20 cm) between the last thoracic and the first lumbar vertebra (in a caudal to cranial direction) was collected. Samples were stored in coolers (4 °C) and transported to the Animal Products Technology Laboratory at Unioeste. To determine the loin eye area (LEA, cm^2) of the *l. thoracis*, samples were scanned (HP, model Officejet 4500 Desktop - G510a, São Paulo, SP, Brazil). A black box was used to block the lighting and improve the image quality. Then, readings were made using a commercial software (ImageJ 1.53e - Java).

Meat color was determined using six surface luminosity measurements with a Minolta colorimeter (Konica Minolta Holdings, model CR400, Tokyo, Japan). Measurements were taken using the CIELAB color system with an 8 mm aperture, area illumination, illuminant C D65, and 0° viewing angle. Parameters included luminosity (L*; 0 = black, 100 = white), red-green component (a*), and yellow-blue component (b*), which represent the saturation (chroma or purity) and the tint (color or hue).

Marbling and subjective color were analyzed based on photographic standards (National Pork Board [NPB], 2011). For marbling, a 7-point scale (1 = traces of marbling and 7 = excessive marbling) was used. The subjective color analysis was performed using a 6-point scale (1 = light color and 6 = trend to red). Backfat thickness and loin depth were measured using a digital pachymeter (MTX, model 316119, São Paulo, SP, Brazil).

Samples were then deboned, and a 2.5 cm thick subsample of the *l. thoracis* was stored at -20 ºC until thaw loss (TL), cooking loss (CL), and shear force analyses. For TL analysis, frozen samples were weighed (Líder, model LD1050, Araçatuba, SP, Brazil), placed in plastic trays, stored at 4 ºC for 24 h, and then weighed again. TL was expressed as the percentage of weight loss relative to the initial weight.

Subsequently, the samples were cooked at 170 ºC on a preheated grill (Britânia, model Multi Grill 2, Curitiba, PR, Brazil). Samples were flipped when the internal core temperature reached 40 ºC and removed from the grill when it reached 71 ºC. Internal temperature was measured using a digital probe thermometer (EOS, model TP101, Rio de Janeiro, RJ, Brazil). Afterward, samples were stored at 4 ºC for 24 h and weighed to determine CL. Then, shear force analysis was performed using five cores (1.5 cm) removed from samples using a stainless-steel cylinder sampler. The cores were submitted to a TA.HD.plusC texture meter (Stable Micro Systems, model Texture Analyser, Surrey, LH, UK) equipped with a standard shear blade calibrated for force (15 g), deformation (20 mm), and speed (2.0 mm/s), which was calibrated for pork meat.

Statistical analysis

A Studentized residuals analysis (RStudent) was performed before analysis of variance (ANOVA). Values greater than or equal to three standard deviations in absolute value were considered outliers. Pen with two pigs was considered the experimental unit for growth performance and ATTD data. Normality of residuals and homogeneity of variance among treatments were assessed using the Shapiro-Wilk and Levene tests, respectively. Dietary treatments were considered as fixed effects, while block and residual error were considered as random factors in the statistical model.

The effects of dietary treatment classes on the dependent variables were evaluated via ANOVA. Multiple comparisons among treatment means were performed using Tukey's post hoc test at a 5% significance level. All statistical analyses were conducted using the general linear models procedure of SAS University Edition (SAS Inst. Inc., Cary, NC, USA).

Results and Discussion

Increasing SBM KOH-PS levels (75%, 77%, 80%, and 85%) did not affect the growth performance of grower-finisher pigs (Table 2). This result suggests that under conditions in which dietary protein and energy are adequately supplied, protein solubility variation may not influence growth, possibly due to the high protein digestibility and high quality of the amino acid profile of SBM (Milani et al., 2022).

Greater SBM processing inactivates a higher amount of antinutritional factors, which would be beneficial for pig growth performance (Căpriţă et al., 2010; Veum et al., 2017). However, excessive processing favors the Maillard reaction and reduces KOH-PS. Thus, amino acids become less available for intestinal absorption, impairing protein synthesis and being excreted in urine without nutritional value for animals (Fernandez & Parsons, 1996; Žilić et al., 2006). Low KOH-PS (<70%) negatively affects growth performance and is associated with low protein bioavailability (Araba & Dale, 1990). This effect may explain the absence of growth performance difference among treatments in the present study, where SBM with KOH-PS between 75% and 85% was assessed.

Table 2
Effect of protein solubility from soybean meal on the growth performance of grower and finisher pigs

Item[1]	Dietary[2]				SEM[3]	*P-value*[4]
	SBM75	SBM77	SBM80	SBM85		
	Grower I (77 - 97 days)					
IBW (kg)	36.03	34.55	35.78	35.13		
FBW (kg)	57.25	55.40	56.23	55.60	0.422	0.418
ADFI (kg/day)	1.93	1.87	1.91	1.87	0.021	0.717
ADG (kg/day)	1.06	1.04	1.05	1.02	0.012	0.746
F:G (kg:kg)	1.82	1.82	1.83	1.81	0.014	0.945
	Grower II (97 - 111 days)					
FBW (kg)	72.17	71.09	73.00	71.33	0.435	0.433
ADFI (kg/day)	2.58	2.60	2.63	2.59	0.021	0.853
ADG (kg/day)	1.12	1.21	1.18	1.12	0.017	0.170
F:G (kg:kg)	2.28	2.16	2.25	2.31	0.027	0.206

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Grower III (111 - 139 days)						
FBW (kg)	105.86	105.55	106.11	105.63	0.496	0.981
ADFI (kg/day)	2.77	2.81	2.79	2.81	0.019	0.901
ADG (kg/day)	1.21	1.18	1.16	1.21	0.011	0.438
F:G (kg:kg)	2.33	2.35	2.36	2.33	0.018	0.936
Grower I, II e III (77 - 139 days)						
ADFI (kg/day)	2.46	2.45	2.49	2.46	0.017	0.912
ADG (kg/day)	1.14	1.15	1.13	1.14	0.007	0.966
F:G (kg:kg)	2.16	2.12	2.18	2.14	0.011	0.253
Finisher I (139 - 153 days)						
FBW (kg)	127.36	127.73	126.36	127.60	0.607	0.869
ADFI (kg/day)	2.88	2.94	2.82	2.93	0.027	0.406
ADG (kg/day)	1.54	1.58	1.47	1.57	0.028	0.487
F:G (kg:kg)	1.88	1.87	1.93	1.84	0.027	0.684
Finisher II (153 - 165 days)						
FBW (kg)	145.20	142.97	144.28	144.40	0.565	0.603
ADFI (kg/day)	3.42	3.41	3.39	3.40	0.015	0.886
ADG (kg/day)	1.37	1.40	1.42	1.40	0.025	0.936
F:G (kg:kg)	2.45	2.45	2.40	2.47	0.041	0.957
Finisher I e II (139 - 165 days)						
ADFI (kg/day)	3.13	3.15	3.13	3.14	0.017	0.942
ADG (kg/day)	1.48	1.50	1.43	1.53	0.016	0.247
F:G (kg:kg)	2.11	2.11	2.16	2.06	0.018	0.400
Overall period (77 - 165 days)						
IBW (kg)	36.03	34.55	35.78	35.13	0.317	0.353
FBW (kg)	145.20	142.97	144.28	144.40	0.565	0.561
ADFI (kg/day)	2.65	2.65	2.69	2.66	0.014	0.791
ADG (kg/day)	1.24	1.25	1.24	1.24	0.006	0.939
F:G (kg:kg)	2.14	2.10	2.17	2.16	0.010	0.119

[1]IBW (kg): initial body weight; FBW (kg): final body weight; ADFI (kg/day): average daily feed intake; ADG (kg/day): average daily gain; F:G (kg:kg): feed-to-gain ratio.
[2]SBM75: soybean meal with 75% protein solubility; SBM77: soybean meal with 77% protein solubility; SBM80: soybean meal with 80% protein solubility; SBM85: soybean meal with 85% protein solubility.
[3]Standard error of the mean.
[4]Significance level.

Finisher II pigs fed SBM75 or SBM80 diets showed higher (P=0.032) mean corpuscular hemoglobin concentration (MCH) compared with those fed the SBM85 diet (Table 3). The lower MCH concentration in pigs fed the SBM85 diet may be related to the presence of antinutritional factors not completely inactivated by SBM processing (Rumsey et al., 1994), affecting hemoglobin synthesis or erythrocyte volume related to protein availability or digestion, and the quality of heat processing applied to SBM (Rochell et al., 2015; Milani, 2021).

Table 3
Effect of protein solubility from soybean meal on the blood profile in grower and finisher pigs

Item[1]	Dietary[2]				SEM[3]	*P-value*[4]
	SBM75	SBM77	SBM80	SBM85		
Grower II (105 days)						
Glucose (mg/dL)	105.81	99.29	105.83	105.57	1.978	0.575
Urea (mg/dL)	32.91	32.44	36.46	33.84	0.971	0.481
AST (U/L)	23.52	23.41	25.95	24.70	0.776	0.619
ALT (U/L)	21.30	22.01	21.76	19.19	0.452	0.135
Total protein (g/dL)	6.40	6.33	6.62	6.33	0.071	0.466
Albumin (g/dL)	3.22	3.07	3.21	3.10	0.045	0.569
PLT (×10³/uL)	161.35	166.47	148.29	157.00	6.952	0.818
MCV (fL)	53.73	52.87	53.23	53.64	0.253	0.606
HCT (%)	35.67	36.42	35.96	35.48	0.333	0.760
MCHC (g/dL)	32.76	32.88	32.73	32.71	0.069	0.843
WBC (×10³/uL)	20.80	19.85	22.03	20.44	0.579	0.632
MCH (pg)	17.52	17.38	17.36	17.72	0.084	0.412
RDW (%)	17.09	17.11	16.77	16.93	0.120	0.719
PDW (%)	14.97	14.99	14.98	14.96	0.044	0.993
HGB (g/dL)	11.73	11.89	11.77	11.90	0.103	0.921
MPV (fL)	7.51	7.40	7.44	7.35	0.062	0.835
RBC (×10⁶/uL)	6.57	6.84	6.56	6.62	0.054	0.198
PCT (%)	0.12	0.12	0.11	0.12	0.005	0.882
Finisher II (161 days)						
Glucose (mg/dL)	69.71	72.44	64.60	72.33	1.732	0.327
Urea (mg/dL)	30.78	30.66	29.11	29.99	0.611	0.768
AST (U/L)	25.75	24.28	28.69	27.42	0.768	0.182
ALT (U/L)	22.61	23.64	23.55	21.94	0.659	0.768
Total protein (g/dL)	6.26	6.06	6.22	6.12	0.079	0.819
Albumin (g/dL)	3.43	3.55	3.47	3.44	0.039	0.711

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continuation...

PLT (×10³/uL)	177.67	188.73	182.18	182.00	3.390	0.740
MCV (fL)	54.81	54.69	54.52	55.66	0.212	0.224
HCT (%)	39.95	39.08	38.61	40.31	0.369	0.331
MCHC (g/dL)	33.09[a]	32.84[ab]	33.05[a]	32.75[b]	0.049	0.032
WBC (×10³/uL)	22.12	21.26	23.03	21.35	0.369	0.280
MCH (pg)	18.13	17.98	18.05	18.35	0.080	0.379
RDW (%)	15.81	16.06	15.82	15.83	0.076	0.634
PDW (%)	15.40	15.39	15.45	15.50	0.033	0.646
HGB (g/dL)	13.27	13.02	12.87	13.22	0.118	0.617
MPV (fL)	7.86	7.76	7.83	7.79	0.054	0.934
RBC (×10⁶/uL)	7.31	7.20	7.06	7.20	0.072	0.686
PCT (%)	0.14	0.15	0.14	0.14	0.003	0.664

[ab]Means followed by different lowercase letters on the same row differ by the post hoc of Tukey test ($P<0.05$).
[1]AST (U/L): aspartate aminotransferase; ALT (U/L): alanine aminotransferase; PLT (×10³/uL): platelets; MCV (fL): mean corpuscular volume; HCT (%): hematocrit; MCHC (g/dL): mean corpuscular hemoglobin concentration; WBC (×10³/uL): total leukocytes; MCH (pg): mean corpuscular hemoglobin; RDW (%): red cell distribution width; PDW (%): platelet distribution width; HGB (g/dL): hemoglobin; MPV (fL): mean platelet volume; RBC (×10⁶/uL): total erythrocytes; PCT (%): procalcitonin.
[2]SBM75: soybean meal with 75% protein solubility; SBM77: soybean meal with 77% protein solubility; SBM80: soybean meal with 80% protein solubility; SBM85: soybean meal with 85% protein solubility.
[3]Standard error of the mean.
[4]Significance level.

Reduced hemoglobin values imply lower efficiency in cellular oxygen transport (Nwanbe & Elechi, 2009) and may be associated with dietary nutritional factors (Togun et al., 2007; Oliveira et al., 2010). However, no other hematological changes were observed in the present study, and this isolated reduction in MCH concentration is insufficient to conclude that the SBM85 diet caused major negative metabolic effects in pigs.

Grower II pigs fed the SBM80 diet showed greater (P=0.005) digestible protein compared with those fed SBM75 or SBM85 diets (Table 4). This result may be associated with reduced lysine availability and lower protein digestibility resulting from overheating of SBM in the SBM75 diet (Căpriţă et al., 2010). Highly soluble protein forms (SBM85) tend to be more accessible to endogenous enzymes (Milani et al., 2022), enabling better amino acid absorption and utilization (Goebel & Stein, 2011). However, this effect was not confirmed in the present study, possibly because the SBM85 diet contained greater concentrations of antinutritional factors (Milani et al., 2022), which may have impaired nutrient absorption due to underprocessing of SBM (Dozier et al., 2011; Lima et al., 2014).

Table 4
Effect of protein solubility from soybean meal on the apparent digestibility of nutrients in grower and finisher pigs

Item[1]	Dietary[2]				SEM[3]	*P-value*[4]
	SBM75	SBM77	SBM80	SBM85		
Grower II (107 days)						
ADCDM (%)	86.35	87.34	85.97	86.38	0.235	0.185
ADCOM (%)	88.08	89.12	87.66	88.11	0.232	0.129
ADCCP (%)	84.56	85.23	85.81	85.09	0.316	0.610
ADCGE (%)	85.64	86.57	85.74	86.38	0.248	0.472
DDM (%)	85.92	87.09	85.48	85.98	0.246	0.106
DOM (%)	83.33	84.53	83.11	83.89	0.222	0.095
DP (%)	18.66[b]	18.87[ab]	19.28[a]	18.41[b]	0.093	0.005
DE (kcal/kg)	3,687[b]	3,724[ab]	3,756[ab]	3,815[a]	13.661	0.007
Finisher II (163 days)						
ADCDM (%)	85.79	84.95	85.94	85.42	0.330	0.755
ADCOM (%)	88.06	87.29	88.09	87.73	0.306	0.812
ADCCP (%)	83.75	83.29	83.67	84.08	0.374	0.911
ADCGE (%)	85.94	84.96	85.71	85.90	0.374	0.811
DDM (%)	85.32	84.47	85.41	85.02	0.344	0.800
DOM (%)	83.25	82.90	83.67	82.85	0.285	0.719
DP (%)	19.64	19.90	19.88	20.06	0.104	0.592
DE (kcal/kg)	3,795[ab]	3,693[b]	3,746[ab]	3,834[a]	18.336	0.039

[ab]Means followed by different lowercase letters on the same row differ by the post hoc of Tukey test (P<0.05).
[1]ADCDM (%): apparent digestibility coefficient of dry matter; ADCOM (%): apparent digestibility coefficient of organic matter; ADCCP (%): apparent digestibility coefficient of crude protein; ADCGE (%): apparent digestibility coefficient of gross energy; DDM (%): digestible dry matter; DOM (%): digestible organic matter; DP (%): digestible protein; DE (kcal/kg): digestible energy.
[2]SBM75: soybean meal with 75% protein solubility; SBM77: soybean meal with 77% protein solubility; SBM80: soybean meal with 80% protein solubility; SBM85: soybean meal with 85% protein solubility.
[3]Standard error of the mean.
[4]Significance level.

Greater DE (P=0.007) was observed in grower II pigs fed the SBM85 diet compared with those fed the SBM75 diet. Finisher II pigs fed the SBM85 diet had greater DE (P=0.039) than those fed the SBM77 diet. Less-processed SBM has been reported to have greater GE (Milani, 2021), which may explain the greater DE in pigs fed the SBM85 diet, as the energy content of SBM can be influenced by residual oil in underprocessed SBM (Bellaver & Snizek, 1999).

Table 5
Effect of protein solubility from soybean meal on the characteristics of the carcass and meat quality in grower and finisher pigs (165 days)

Item[1]	Dietary[2]				SEM[3]	*P-value*[4]
	SBM75	SBM77	SBM80	SBM85		
pH_{24h}	5.48[b]	5.57[a]	5.48[b]	5.48[b]	0.015	0.042
Carcass weight (kg)	107.40	104.83	104.83	106.08	0.723	0.563
BFTpist (mm)	12.83	12.44	13.00	12.96	0.284	0.890
Muscle of the carcass (%)	64.08	63.33	64.50	62.53	0.394	0.296
Lean meat (%)	60.72	60.88	60.73	60.63	0.146	0.933
Lean meat (kg)	65.36	63.52	63.42	64.79	0.451	0.356
LEA (cm^2)	76.39	74.08	73.88	73.11	0.995	0.677
LD pac. (mm)	76.67	74.74	74.22	74.63	0.695	0.618
BFT pac. (mm)	11.09	10.25	11.46	10.96	0.276	0.464
TL (%)	3.11	3.33	3.89	2.92	0.235	0.516
CL (%)	24.36	24.12	24.20	24.57	0.488	0.990
Shear force (kgf/s)	4.42	4.08	4.49	4.24	0.089	0.362
Color score	2.88	3.19	3.27	3.27	0.084	0.303
Marbling score	1.06	1.29	1.27	1.20	0.051	0.343
Minolta L*	47.75	48.04	47.60	47.62	0.286	0.949
Minolta a*	1.69	1.67	1.81	1.96	0.071	0.461
Minolta b*	3.35	3.56	3.70	3.78	0.101	0.457
Chroma	3.75	4.02	4.15	4.35	0.110	0.256
Tint	65.23	64.07	61.96	62.18	0.919	0.558
Ult. ld. grower (mm, 109 days)	46.99	46.97	45.46	46.64	0.500	0.676
Ult. bt. grower (mm, 109 days)	7.98	8.14	8.66	8.46	0.100	0.069
Ult. ld. finisher (mm, 164 days)	68.73	68.50	68.41	67.13	0.530	0.711
Ult. bt. finisher (mm, 164 days)	12.07	12.09	11.83	12.04	0.160	0.943

[ab]Means followed by different lowercase letters on the same row differ by the post hoc of Tukey test ($P<0.05$).
[1]pH_{24h}: hydrogen ion potential 24 hours after slaughter; BFTpist (mm): backfat thickness mensured with typification pistol; LEA: loin eye area; LD pac. (mm): loin depth measured using pachymeter; BFT pac. (mm): backfat thickness measured using pachymeter; TL (%): thaw loss; CL (%): cooking loss; Minolta L*: indicates the degree of brightness of the meat (L* = 0 dark meat, L* = 100 white meat); Minolta a*: indicates the color of the meat, ranging from red to green (a* = greater indicates red color, a* = smaller indicates green color); Minolta b*: indicates the color of the meat, ranging from yellow to blue (b* = larger indicates a more yellow color, b* = smaller indicates a bluer color); Chroma: indicates the saturation of the meat (calculated from the values of a* and b*); Tint: indicates the tone of the meat (calculated from the values of a* and b*); Ult. ld. grower (mm, 109 days): loin depth measured in vivo using an ultrasound in grower II; Ult. bt. grower (mm, 109 days): backfat thickness measured in vivo using an ultrasound in grower II; Ult. ld. finisher (mm, 164 days): loin depth measured in vivo using an ultrasound in finisher II; Ult. bt. finisher (mm, 164 days): backfat thickness measured in vivo using an ultrasound in finisher II.
[2]SBM75: soybean meal with 75% protein solubility; SBM77: soybean meal with 77% protein solubility; SBM80: soybean meal with 80% protein solubility; SBM85: soybean meal with 85% protein solubility.
[3]Standard error of the mean.
[4]Significance level.

Additionally, excessive heat processing (SBM75 and SBM77 diets) may reduce SBM energy availability through nutrient degradation or the formation of less digestible compounds (Milani et al., 2022). Thus, greater digestibility is crucial for optimizing feed efficiency in pigs, although this did not reflect in growth performance changes. This result may be related to a meeting of minimum nutritional requirements for growth, so improvements in digestibility did not provide additional performance advantages, possibly due to compensatory effects in pigs.

Pigs fed the SBM77 diet exhibited higher (P=0.042) pH_{24h} in the *l. thoracis* muscle compared with those fed the other diets (Table 5). The pH_{24h} values ranged from 5.48 to 5.57, classified as pale, soft, and exudative (PSE), as the final pH was ≤ 5.6 and L* ≥ 50 (Bridi & Silva, 2009). However, L* values ranged from 47 to 48, considered suitable for pork, suggesting that pH_{24h} results alone do not allow specific conclusions regarding meat parameters.

The effect we observed on pH_{24h} in pig carcasses may have implications for meat quality (Tarczyński et al., 2021), as carcass pH is directly associated with postmortem biochemical changes in muscle tissue. SBM protein solubility may have influenced muscle glycogen depletion or lactic acid production, affecting postmortem pH decline in pigs fed SBM75, SBM80, and SBM85 diets (Guo et al., 2021; Yin et al., 2022). Meat quality traits such as tenderness, color, and water-holding capacity are often influenced by postmortem pH (Boler et al., 2010; Tarczyński et al., 2021). However, no changes in these parameters were detected, possibly due to the small pH variation between treatments, which was insufficient to impact meat quality.

Conclusion

Using soybean meal with 75% to 85% KOH-protein solubility in diets for grower-finisher pigs did not impair growth performance or meat quality. However, it altered the blood hematological profile, apparent digestibility, and carcass pH.

Aknowlegments

The authors thank Copagril for providing the animals and feed ingredients, the Universidade Estadual do Oeste do Paraná for providing the facilities, and CAPES for granting scholarships.

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