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Article

Growth Performance, Meat Quality, and Lipid Oxidation in Pigs Fed Diets Containing Grape Pomace

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Abstract: Grape pomace is a winery byproduct that is rich in polyphenols with antioxidant capacity. This study investigated the effect of 0, 5, and 10% inclusion of dehydrated grape pomace (DGP) in finishing pig diets on the growth performance, carcass traits, fatty acid profile, fresh meat quality, and fat stability of a local pig genotype. A total of 36 pigs, 18 barrows and 18 gilts (83.23 ± 6.03 kg and 132.1 ± 5.6 days old), were allotted in a randomized block design considering the initial weight (block) within sex, with six replicates of each sex per treatment. Including DGP in the diets did not affect daily weight gain or the feed-to-gain ratio, however, daily feed intake increased linearly ($P < 0.05$) and backfat thickness at the last rib, backfat thickness at the first sacral vertebrae, P2 backfat thickness, fat area, and the percentage of lean meat decreased linearly ($P < 0.05$) in pigs. The inclusion of DGP in pig diets did not affect the antioxidant potential evaluated by thiobarbituric acid-reactive substances in mini hamburgers or the quality characteristics of fresh meat, except for intramuscular fat (EE). The dietary inclusion of DGP linearly increased ($P < 0.05$) EE, saturated fatty acids, monounsaturated fatty acids, and $\Sigma\omega-3$ and reduced the $\omega-6:\omega-3$ ratio in a linear way ($P < 0.05$) in the loin of pigs. We concluded that it is feasible to include up to 10% of DGP in pig diets without affecting growth performance, but carcass quality may be impaired due to increased adiposity. Furthermore, meat quality can be improved by increasing intramuscular fat and $\omega-3$ fatty acid content, but fat stability is not affected when DGP is included at up to 10% of the diet for 49 days prior to slaughter.

Keywords: fatty acids; grape pomace; meat quality; oxidative stability; phenolic compounds; pigs

1. Introduction

The lipid oxidation of pork and meat products is a problem that can affect different aspects of meat quality, with a negative impact on sensory and technological aspects. The adipose tissue of pigs fed corn-based diets contains approximately 45% monounsaturated fatty acids (MUFAs) and 15% polyunsaturated fatty acids (PUFAs). Of these, approximately 95% is linoleic acid [1]. As fatty acids increase in their degree of unsaturation, their susceptibility to lipid oxidation increases due to a reduction in bond strength [2]. The low oxidative stability of PUFAs may accelerate the oxidation of meat products, negatively influencing their flavor and aroma and causing the appearance of off-

flavors, especially in processed products [3–5]. Linoleic acid is the precursor of hexanal, the main volatile compound resulting from the auto-oxidation of fats associated with rancidity and warmed-over flavor [6]. The susceptibility of a given tissue to oxidation also depends on the balance between pro-oxidants and antioxidants [7], and it is expected that adding natural antioxidants to the diet provided to animals can help achieve this balance. The antioxidant potential of dietary incorporation of plants, including whole plants, fruits, leaves, extracts, and essential oils, has been tested by different authors searching to improve the balance of pro-oxidants and antioxidants *in vivo*. A previous study showed that the total antioxidant capacity in the longissimus dorsi was increased, while the malondialdehyde content was decreased and meat quality was improved in pigs fed grape seed proanthocyanidin extract [8], which creates the hypothesis that it is possible to improve the endogenous antioxidant status, meat quality, and shelf life of pig meat by including grape byproducts containing bioactive compounds in the pigs' diets.

Grape pomace (GP) is a by-product available in wine-producing regions. There is interest in using GP in swine feeding due to the large volume available in that region and its content of antioxidant compounds, which can potentially act as antioxidants *in vivo*. Grape pomace from wine production, consisting mainly of skins and seeds, contains high levels of phenols, with most phenolic compounds retained in the skin matrix [9]. Despite the transfer of phenolic compounds from the grape skin to the wine during the winemaking process and the possible loss of some of these compounds during the drying process, GP is still a good source of antioxidant compounds [10]. The most prevalent phenolic compounds present in GP are dimeric, trimeric, and oligomeric procyanidins (catechins and epicatechins, epigallocatechin, and gallicocatechin) and phenolic acids, especially gallic acid [9–12]. Phenolic compounds are proton donors acting as free radical scavengers, metal chelators, and recyclers of α -tocopherol, which makes them extremely efficient in improving the endogenous antioxidant status [13–15]. Therefore, we expected that the inclusion of GP in the diet of pigs could improve the balance between the pro-oxidants and antioxidants in the endogenous antioxidant system, which would improve fresh meat quality and the shelf life of processed pig meat, without influencing the growth performance and carcass traits.

Previous reports indicated that incorporating GP into pig or poultry diets reduced oxidation in meat, processed meat products, and eggs [15–17]. Furthermore, the inclusion of 3.0% fermented GP in the diet of finishing pigs improved growth performance and meat quality attributes and altered fatty acid patterns [16]. However, other authors [18–20] did not observe the same effect by adding up to 10% ensiled GP or dehydrated grape pomace (DGP) in pig diets, showing no impact on growth performance, lipid oxidation, backfat fatty acid profile, or meat attributes, except for an increase in the meat color saturation index. In the wine-producing regions of Brazil, GP is available yearly in large amounts, arousing the interest of pig producers for its use as a functional ingredient in the diet of these animals. Furthermore, interest is growing in Brazil in constructing arrangements for pig production, combining local breeds and regionally produced feed resources with properties to imprint differentiated characteristics in meat products. Thus, this study aimed to evaluate the effect of including DGP in the diet on the growth performance, carcass traits, fatty acid profile, fresh meat quality, and fat stability of a local pig genotype.

2. Materials and Methods

2.1. Animal and Design

Thirty six pigs, 18 barrows and 18 gilts (83.23 ± 6.03 kg and 132.1 ± 5.6 days old), from the progeny of MS115-Duroc males (59.4% Duroc, 31.2% Pietrain, and 9.4% Large White) with MO25C sows (50% Landrace, 25% Large White, and 25% Moura—a local Brazilian breed) were used. The animals were individually housed (1.90 m x 1.20 m) in pens with partially slatted floors and slatted sidewalls between pens. Six pens per sex were assigned to one of the following treatments in randomized blocks design, considering the initial weight (block) within sex: 1) Control: corn–soybean meal diet; 2) 5% DGP: diet with 5% DGP; and 3) 10% DGP: diet containing 10% DGP (Table 1). The feeding test was carried out during the finishing phase for a period of 49 days, with feed and water provided *ad libitum* via semi-automatic feeders and nipple-type drinkers.

Table 1. The composition of calculated nutrient and energy content, as well as the analyzed fatty acid composition of the experimental diets.

Ingredients, g/kg	Phase 1 (83-103 kg)			Phase 2 (103-130 kg)		
	Control	5% DGP	10% DGP	Control	5% DGP	10% DGP
Corn	669.47	680.96	692.49	739.96	751.47	759.70
Soybean meal	167.28	173.66	179.92	99.45	105.82	115.52
Wheat bran	134.76	67.37	0.00	134.74	67.34	0.00
DGP	0.00	50.00	100.00	0.00	50.00	100.00
Limestone	10.99	8.93	6.88	10.13	8.07	6.01
Dicalcium phosphate	4.59	6.25	7.93	3.74	5.39	6.98
Salt	2.97	2.98	2.99	1.81	1.82	1.83
Vitamin premix ^a	1.50	1.50	1.50	1.50	1.50	1.50
Mineral premix ^b	1.00	1.00	1.00	1.00	1.00	1.00
L-Lysine	2.03	1.92	1.84	2.45	2.35	2.14
L-Threonine	0.21	0.23	0.25	0.52	0.54	0.52
DL-Methionine	0.00	0.00	0.00	0.00	0.00	0.10
Choline chloride	0.20	0.20	0.20	0.20	0.20	0.20
Mycotoxin adsorbent	4.50	4.50	4.50	4.50	4.50	4.50
Colistin sulfate	0.50	0.50	0.50	0.00	0.00	0.00
Calculated Composition (per kg)						
EM (MJ)	13.16	13.16	13.16	13.24	13.24	13.24
Crude Protein (g)	157.0	157.0	157.0	131.4	131.4	131.4
Ether Extract (g)	31.5	34.8	38.0	32.9	36.2	39.4
Crude fiber (g)	30.2	42.7	55.1	28.9	41.4	53.0
Calcium (g)	5.60	5.60	5.60	4.90	4.90	4.90
Phosphorus available (g)	2.60	2.60	2.60	2.30	2.30	2.30
Digestible lysine (g)	7.70	7.70	7.70	6.40	6.40	6.40
Analyzed Composition (g/kg)						
SFAs	5.90	6.11	6.41	5.88	6.66	7.27
MUFAs	8.94	9.39	9.98	10.26	10.49	11.46
PUFAs	18.93	20.84	22.47	17.89	20.04	23.63
ω -6	18.12	20.04	21.67	16.91	18.94	22.65
ω -3	0.81	0.80	0.80	0.98	0.99	0.98

DGP= dehydrated grape pomace; SFAs= saturated fatty acids; MUFAs= monounsaturated fatty acids; PUFAs= polyunsaturated fatty acids. ^aVitamin Premix supplied per kg of diet: 4,800 UI of vitamin A; 975 UI of vitamin D₃; 12.75 UI of vitamin E; 1.5 mg of vitamin K₃; 0.75 mg of vitamin B₁; 4.2 mg of vitamin B₂; 0.9 mg of vitamin B₆; 15.75 mcg of vitamin B₁₂; 0.15 mg of Biotin; 0.375 mg of Folic Acid; 24 mg of Nicotinic Acid; 14 mg of Pantothenic Acid. ^bMineral premix supplied per kg of diet: 118 mg of Fe as iron sulfate; 20 mg of Cu as copper sulfate; 40.6 mg of Mn as manganese sulfate; 105 mg of Zn as zinc oxide; 1 mg of Co as cobalt sulfate; 0.29 mg of I as calcium iodate, and 0.25 mg of Se as sodium selenite.

The diets followed the requirements and the ideal profile of digestible amino acids according to the NRC [21] for pigs weighing between 80 to 103 kg and 103 to 130 kg. The pigs were weighed every week during the experimental period. Weight gain (DWG), daily feed intake (DFI), and feed-to-gain ratio (F:G) were evaluated. At the end of the experiment, the pigs were transported to the slaughterhouse.

2.2. Measurements and Analytical Methods

2.2.1. Grape Pomace Processing and Characterization

The grape pomace was obtained from a commercial winery as a byproduct of the processing of red grapes, including skin, seeds, and stems. To obtain the DGP, grape pomace was submitted to dehydration in a fixed bed model dryer for 48 h at 45 to 60 °C. For inclusion in the diets, DGP was ground with a hammer mill using a sieve with a screen opening size of 3 mm. The proximal composition was 90.88% dry matter, 12.53% crude protein, 9.86% ether extract, 3.91% ash, and 34.62% crude fiber (procedures following AOAC [22]). The total content of phenolic compounds in DGP was determined. First, the grape pomace extract was obtained according to the method C of Kähkönen et al. [23]. The concentration of phenolic compounds was measured using the method described by Singleton and Rossi [24], with modifications proposed by Kim et al. [25]. Briefly, the extract was mixed with Folin-Ciocalteu's reagent and Na₂CO₃ solution, followed by incubation and measurement of absorbance at 750 nm using a gallic acid standard curve. The total content of phenolic compounds in DGP was 674.57 mg of gallic acid equivalent (GAE)/100 g of sample. Fatty acids were analyzed according to the following procedures: the lipids were extracted with a mixture of methanol:chloroform 2:1 ([26]) and subjected to saponification/esterification to prepare the respective fatty acid methyl esters (FAMES) [27]. After extraction with hexane, the FAMES were analyzed on a Varian CP-3800 gas chromatograph (Walnut Creek, CA, USA) equipped with an autosampler (CP-8410), a split/splitless injector (CP-1177), and a flame ionization detector (FID). A Supelco SP-2380 capillary column (100 m length x 0.25 mm internal diameter, 0.2 µm film thickness) was used for FAME separation under the chromatographic conditions previously described [20]. The fatty acids were quantified via area normalization and expressed in g/kg of sample (Table 2).

Table 2. The fatty acid profile of dehydrated grape pomace (DGP).

Fatty acid	g/kg sample	Fatty acid	g/kg sample
C10:0	Nd	C18:3n6 gama	Nd
C11:0	Nd	C20:0	0.430
C12:0	Nd	C20:1n9c	Nd
C13:0	Nd	C20:2n6c	Nd
C14:0	0.250	C20:4n6c	Nd
C14:1	Nd	C20:5n3c EPA	Nd
C15:0	Nd	C21:0	Nd
C15:1	Nd	C22:0	0.100
C16:0	7.970	C22:1n9c	Nd
C16:1	0.240	C22:2n6c	Nd
C17:0	Nd	C22:6n3 DHA	Nd
C17:1	0.110	C23:0	Nd
C18:0	3.840	C24:0	Nd
C18:1n9c	13.060	C24:1n9c	Nd
C18:1n9t	Nd	ΣSFAs	12.590
C18:1n7c	0.180	ΣMUFAs	13.590
C18:2n6c	49.110	ΣPUFAs	50.990
C18:2n6t	Nd	Total ω-6	49.110
C18:3n3 alpha	1.890	Total ω-3	1.890

Nd= not detected; SFAs= saturated fatty acids; MUFAs= monounsaturated fatty acids; PUFAs= polyunsaturated fatty acids.

2.2.2. Animal Management at the Slaughterhouse and Carcass Measurements

The pigs were subjected to 12 h of feed withdrawal prior to transport, and the slaughtering took place after three hours of lairage. The slaughter process consisted of bleeding preceded by electronarcosis stunning. Slaughter followed the standard procedure adopted by the slaughterhouse in accordance with the Federal Inspection Service. Hot carcass evaluation was performed with an electronic grading device equipped with an HGP4 optical probe (Hennessy Grading System Ltd., Auckland, New Zealand), and the measurements were taken at point P₂ (65 mm away from the body midline at the level of the last rib). The estimated parameters were the backfat thickness (BFHGP), loin depth (LDHGP), and lean meat percentage (PLM).

The backfat thickness was measured with a digital caliper at the left midline of the carcasses on the first rib (BFFR), last rib (BFLR), first sacral vertebra (BFFSV), and P₂ point (BFP2) [28] after the carcasses were stored in a chilling room (at 2 to 4 °C) for 24 hours. The loin eye area (LEA) and fat area (FAT) were drawn on greaseproof paper at the left half of the carcass, between the tenth and eleventh ribs at a right angle to the vertebral column. The LEA and FAT were calculated using Rhinoceros® 4.0 [29] software using loin eye and fat area images scanned with a scale. The fat-to-meat ratio (FMR) was obtained by dividing the FAT by the LEA.

2.2.3. Meat Quality and Fatty Acids

The pH was measured at forty-five minutes (pH 45min) and 24 hours (pH 24h) after slaughter in the Longissimus thoracis muscle via insertion of an electrode (Hanna Instruments, FC 232D) coupled to a portable pH meter (Hanna Instruments, HI 99163).

The color evaluation was performed using the CIELab method (L*, a*, and b* coordinates) via a Minolta chromameter (CR-400, Konica Minolta Inc., Osaka, Japan) calibrated against a standard white tile. The device was equipped with an 8 mm measuring port, D 65 illuminant, and 10° observer. CIE Lightness (L*), redness (a*), and yellowness (b*) values were recorded. Visual scores for color (Color) were evaluated according to NPPC Standards [30]. Drip loss (DL) was evaluated in 8 to 12 g samples. The samples were weighed, placed in meat juice containers, refrigerated at 2–4 °C for 48 h, and re-weighed [31]. Drip loss was given as a percentage by the difference between the initial and the final sample weight [32]. Samples of loin and backfat were obtained from the left half of the carcass and were stored at -20 °C until required for analysis.

Cooking loss (CL) evaluation followed the methodology described by [32]. The samples were thawed under refrigeration at 5 °C for 24 hours, then followed by a water bath at 75 °C until temperature equilibrium. The weight of the loin before and after cooking was recorded, and CL was reported as the percent weight loss relative to the weight of the uncooked sample at room temperature. After CL evaluation, the loin samples were allowed to stabilize at room temperature (~23 °C) and cut into rectangular pieces (1x1x2 cm) for shear force (SF) analysis following the AMSA methodology [33]. The SF values were obtained using an apparatus TA-XTPlus (Stable Micro Systems, Surrey, United Kingdom) with a Warner–Bratzler-type coupled shear blade. The device calibrated with a 10 kg standard weight using an aluminum probe HDP (Heavy Duty Platform) and pre-test, post-test, and test speeds of 2.0 mm/s. The SF assessments were performed with the samples positioned so that the muscle fibers were perpendicular to the direction of the cut. Fatty acids were analyzed in the samples of backfat and loin as described for DGP. Intramuscular fat (EE) was analyzed in the samples of loin as described for DGP in Section 2.2.1.

2.2.4. Mini Hamburger Preparation and TBARS Analyses

The processing of the mini hamburgers (78.38% loin, 19.66% backfat, and 1.96% salt) was performed one day after sample collection, as described by Bernardi et al. [20]. In short, the loin and backfat were diced and homogenized with salt in a domestic food processor (Philips Walita, model Ri1364) for 30 seconds. Each mini hamburger was produced to have a weight of 12.5 g, diameter of 3 cm, and thickness of 1 cm. Mini hamburgers were conserved at -20 °C for two months in bags with oxygen. The thawing procedure was performed under refrigerated storage (2 °C to 6 °C), and the

thiobarbituric acid-reactive substances (TBARS) analysis was performed on days 1 and 3 after thawing. The TBARS analyses were performed in triplicate according to the methodology described by Vyncke [34], and the results are expressed in mg of malonaldehyde (MDA) per kg of sample.

2.3. Statistical Analysis

Statistical analysis was performed using the SAS GLM (2012) procedure (SAS Inst. Inc., Cary, NC, USA) for the model effects. The normal distribution assumption was tested using Shapiro–Wilk, Kolmogorov–Smirnov, Anderson–Darling, and Cramér–von Mises tests. The assumptions for analysis of variance were tested using residual graph analysis. The model used was $Y_{ijk} = \mu + B_i(k) + T_j + S_k + TS_{jk} + e_{ijk}$. Y_{ijk} is an observation of the dependent variable ijk , μ is the overall population mean, $B_i(k)$ is the fixed effect of the block within sex, T_j is the fixed effect of treatments, S_k is the fixed effect of sex, TS_{jk} is the fixed effect of treatment vs. sex interaction, and e_{ijk} is the random error associated with the observation ijk . In those variables in which the F-test detected a significant effect ($P \leq 0.05$), the means were compared using Duncan's multiple range test. Additionally, orthogonal polynomial contrasts were used to detect linear and quadratic responses to dietary levels of DGP.

3. Results

There was no interaction between treatment and sex in any of the growth performance, carcass quality, meat quality, and fatty acid variables (Tables 3–6).

There was a sex effect ($P < 0.05$) on the initial live weight (ILW), with gilts being heavier than barrows. Barrows showed greater ($P < 0.05$) DFI and backfat thickness, FAT, FMR, EE content in the loin, and pH after 24 hours and lower ($P < 0.05$) LEA, LDHG, PLM, and DL than gilts. Also, barrows had higher ($P < 0.05$) content of C17:0, C17:1, C20:0, C20:1n9c, and total saturated fatty acids (Σ SFAs) and lower ($P < 0.05$) content of C18:2n6c, C20:4n6c, total polyunsaturated fatty acids (Σ PUFAs), and ω -6 in backfat than gilts; higher ($P < 0.05$) content of C10:0, C20:0, C16:1, C18:1n7c, C18:1n9c, C20:1n9c, and total monounsaturated fatty acids (Σ MUFAs) in the loin than gilts.

There was no effect of treatments on the final live weight (FLW) and F:G. However, DFI showed a linear increase ($P < 0.05$) and the DWG tended to increase linearly ($P < 0.08$) with increasing levels of DGP in the diet. The inclusion of DGP in the diet also led to a linear increase ($P < 0.05$) of BFP2, BFFSV, BFLR, FAT, and BFHG and a linear decrease ($P < 0.05$) of PLM. The LEA showed a quadratic response, increasing ($P < 0.05$) up to 4.24% of DGP inclusion in the diet and decreasing from that point onwards. The EE in the loin increased linearly ($P < 0.05$) with DGP inclusion in the diet, but none of the other fresh meat quality traits were affected.

There was a linear increase ($P < 0.05$) in the content of C10:0, C12:0, C14:0, C16:0, C18:0, C20:0, Σ SFAs, C16:1, C18:1n7c, C18:1n9c, Σ MUFAs, C18:3n3c, and $\Sigma\omega$ -3 and a linear decrease ($P < 0.05$) in the ω -6: ω -3 ratio in the loin of pigs as the level of DGP increased in the diet. There was no effect of DGP on the fatty acid profile of backfat, except for a linear increase ($P < 0.05$) in the content of C22:1n9c and a quadratic effect ($P < 0.05$) on the content $\Sigma\omega$ -3 with a minimum point at 4.65% DGP in the diet, increasing from that point onwards. Including DGP in the pigs' diet did not affect TBARS in mini hamburgers neither on the first day nor on the third day of cold storage following two months of frozen storage.

Table 3. The means and standard errors of the mean of performance and carcass quality parameters per treatment and sex.

Variables	Treatments			Sex		Prob F				
	Control	5% DGP	10% DGP	Female	Barrow	Treat	Sex	Treat x Sex	Linear	Quadratic
ILW	83.21±1.69	83.20±1.88	83.28±1.78	83.77±1.30	82.68±1.55	0.990	0.034	0.938	0.912	0.936
FLW	129.4±2.46	134.0±2.54	133.2±2.41	131.9±1.77	132.5±2.29	0.127	0.757	0.792	0.112	0.196
DWG	0.944±0.03	1.036±0.03	1.019±0.03	0.982±0.02	1.017±0.03	0.080	0.324	0.670	0.081	0.142
DFI	3.352±0.108 ^b	3.600±0.086 ^{ab}	3.654±0.098 ^a	3.428±0.074	3.643±0.088	0.045	0.040	0.442	0.020	0.367
F:G	3.562±0.077	3.486±0.075	3.590±0.048	3.501±0.057	3.591±0.053	0.548	0.266	0.909	0.776	0.294
HCW	95.16±1.89	99.09±1.97	97.89±1.95	97.06±1.33	97.70±1.84	0.097	0.665	0.555	0.137	0.109
HCY	73.50±0.26	73.97±0.27	73.47±0.33	73.58±0.21	73.71±0.27	0.451	0.712	0.361	0.939	0.212
BFP2	22.56±1.40	24.13±2.35	26.79±1.27	20.98±0.98	28.01±1.37	0.083	<.0001	0.472	0.029	0.736
BFFR	38.91±2.25	40.48±1.93	40.07±1.16	37.91±1.51	41.73±1.32	0.833	0.094	0.850	0.668	0.675
BFFSV	20.33±0.90	20.59±1.18	22.92±0.84	19.74±0.67	22.81±0.83	0.088	0.005	0.568	0.046	0.343
BFLR	25.97±1.28 ^b	28.37±1.00 ^{ab}	31.27±1.30 ^a	27.07±1.10	30.01±0.98	0.007	0.027	0.279	0.002	0.852
LEA	38.30±1.35 ^{ab}	40.75±1.27 ^a	36.14±1.50 ^b	40.52±0.90	36.27±1.24	0.032	0.004	0.626	0.200	0.020
FAT	22.65±0.98 ^b	23.45±1.27 ^{ab}	25.56±0.74 ^a	22.52±0.80	25.26±0.81	0.055	0.009	0.902	0.021	0.528
FMR	0.60±0.03 ^b	0.59±0.04 ^b	0.72±0.03 ^a	0.56±0.02	0.71±0.03	0.004	<.0001	0.798	0.005	0.047
LDHGP	57.77±1.17	59.30±1.38	58.20±1.67	60.24±0.97	56.60±1.16	0.725	0.031	0.885	0.827	0.445
BFHGP	22.63±1.28 ^b	23.73±1.64 ^{ab}	26.50±1.19 ^a	21.44±0.86	27.13±1.04	0.031	<.0001	0.937	0.011	0.501
PLM	53.18±0.73 ^a	52.87±1.01 ^a	51.10±0.82 ^b	54.34±0.47	50.43±0.62	0.039	<.0001	0.971	0.019	0.320

Means followed by different letters on the same line differ statistically according to Duncan's test ($P < 0.05$). DGP= dehydrated grape pomace; Treat= treatment; ILW—initial live weight, kg; FLW—final live weight, kg; DWG—daily weight gain, kg; DFI—daily feed intake, kg; F:G—Feed to Gain ratio; HCW—hot carcass weight, kg; HCY—hot carcass yield, %; BFP2—backfat at the P2 point, mm; BFFR—first rib back fat thickness, mm; BFFSV—first sacral backfat thickness, mm; BFLR—last rib backfat thickness, mm; LEA—loin eye area, cm²; FAT—fat area, cm²; FMR—fat to meat ratio; LDHGP and BFHGP—loin depth and backfat thickness obtained with the electronic grading device at the P2 point, mm; PLM—the percentage of lean meat, %. Values of BFP2, BFFR, BFFSV, and BFLR were determined using the caliper rule, and values for LDHGP and BFHGP were determined using an electronic device for carcass grading.

Table 4. The means and standard error of the mean of meat quality parameters from Longissimus thoracis muscle and TBARS in mini hamburgers per treatment and sex.

Variables	Treatments			Sex		Prob F				
	Control	5% DGP	10% DGP	Female	Barrow	Treat	Sex	Treat x Sex	Linear	Quadratic
DL, %	3.88±0.49	4.41±0.50	3.68±0.40	4.66±0.39	3.32±0.29	0.444	0.009	0.134	0.724	0.225
CL, %	32.56±0.54	33.35±0.31	31.68±0.34	32.65±0.39	32.40±0.37	0.053	0.987	0.777	0.105	0.071
SF, kg	2.94±0.33	2.71±0.39	2.70±0.43	2.71±0.27	2.86±0.33	0.890	0.928	0.416	0.673	0.850
pH 45min	6.26±0.04	6.30±0.05	6.24±0.04	6.27±0.04	6.27±0.03	0.641	0.966	0.816	0.712	0.389
pH 24h	5.51±0.01	5.48±0.02	5.51±0.03	5.48±0.01	5.52±0.02	0.487	0.039	0.072	0.773	0.249
Color ^a	4.17±0.11	3.83±0.11	4.00±0.11	4.11±0.11	3.89±0.08	0.167	0.122	0.535	0.336	0.102
L*	45.96±0.56	47.03±0.62	46.53±0.51	46.72±0.41	46.29±0.52	0.418	0.515	0.602	0.479	0.267
a*	2.72±0.19	3.05±0.24	2.51±0.26	2.90±0.18	2.62±0.20	0.298	0.331	0.412	0.543	0.154
b*	3.59±0.30	4.24±0.20	3.84±0.29	4.02±0.20	3.76±0.20	0.129	0.302	0.498	0.424	0.063
TBARS1	0.272±0.086	0.289±0.064	0.202±0.059	0.332±0.054	0.177±0.051	0.802	0.465	0.465	0.769	0.570
TBARS3	0.739±0.078	0.655±0.133	0.617±0.098	0.760±0.065	0.580±0.094	0.624	0.480	0.553	0.354	0.784

Means followed by different letters on the same line differ statistically according to Duncan's test ($P < 0.05$). DGP= dehydrated grape pomace; Treat= treatment; DL—drip loss; CL—cooking loss; SF—shear force; L* (lightness), a* (redness), b* (yellowness)—determined using the CIELab method. ^aNPPC score. Color: 1 = pale pinkish gray to white, ..., 6 = dark purplish red (NPPC, 1999). TBARS1 = day 1, TBARS3 = day 3 in mg MDA/kg.

Table 5. The means and standard error of the mean of ether extract (EE) and fatty acid, ω -6, ω -3 (mg/100 g of sample), and ω -6: ω -3 ratio in the loin per treatment and sex.

Fatty Acid	Treatments			Sex		Prob F				
	Control	5% DGP	10% DGP	Female	Barrow	Treat	Sex	Treat x Sex	Linear	Quadratic
EE	2400±201.7 ^b	2431±196.9 ^b	3114±306.7 ^a	2280±155.9	2946±209.4	0.029	0.044	0.528	0.017	0.171
<i>Saturated fatty acids (SFAs)</i>										
C10:0	2.658±0.252	2.635±0.255	3.401±0.399	2.399±0.204	3.309±0.250	0.064	0.019	0.426	0.043	0.192
C12:0	1.943±0.200	2.026±0.201	2.535±0.289	1.836±0.148	2.440±0.201	0.092	0.087	0.681	0.045	0.347
C14:0	29.12±3.04	31.29±3.20	39.69±4.42	28.59±2.33	37.22±3.21	0.056	0.122	0.646	0.024	0.376
C15:0	17.60±0.77	17.71±0.51	17.80±0.63	17.36±0.43	18.00±0.57	0.938	0.949	0.928	0.726	0.953
C16:0	558.8±50.2 ^b	573.3±51.9 ^b	738.3±76.3 ^a	532.9±38.9	696.6±53.2	0.032	0.058	0.578	0.018	0.203
C17:0	5.940±0.633	5.679±0.640	6.727±0.544	5.366±0.456	6.741±0.481	0.246	0.219	0.475	0.234	0.221
C18:0	273.3±24.4 ^b	282.6±26.4 ^b	356.5±39.0 ^a	260.7±20.0	339.4±26.4	0.050	0.077	0.496	0.025	0.268
C20:0	3.843±0.315 ^b	4.220±0.385 ^b	5.426±0.632 ^a	3.776±0.316	5.077±0.397	0.012	0.031	0.366	0.005	0.329
C22:0	1.240±0.115	1.240±0.098	1.294±0.097	1.153±0.076	1.349±0.083	0.846	0.274	0.076	0.718	0.649
ΣSFA	893.2±78.8 ^b	919.5±82.5 ^b	1170±121.4 ^a	853.0±62.0	1109±83.9	0.037	0.064	0.552	0.020	0.226
<i>Monounsaturated fatty acids (MUFAs)</i>										
C16:1	66.26±6.05 ^b	66.27±6.84 ^b	88.98±8.84 ^a	62.59±4.35	82.87±6.78	0.027	0.038	0.636	0.019	0.140
C17:1	4.540±0.679	4.357±0.758	5.164±0.656	3.773±0.373	5.465±0.619	0.523	0.145	0.524	0.415	0.418
C18:1n7c	88.95±7.90 ^b	87.81±7.17 ^b	115.3±11.53 ^a	81.61±5.11	110.2±8.02	0.024	0.013	0.456	0.018	0.114
C18:1n9c	860.4±76.4 ^b	862.2±70.5 ^b	1136±123.4 ^a	800.7±58.2	1077±80.5	0.023	0.022	0.441	0.016	0.138
C20:1n9c	14.05±1.34 ^b	14.16±1.31 ^b	18.84±2.36 ^a	12.41±0.91	18.39±1.46	0.015	0.004	0.248	0.010	0.120
C22:1n9c	1.424±0.214	1.563±0.113	1.923±0.157	1.550±0.119	1.696±0.159	0.175	0.584	0.571	0.069	0.677
ΣMUFA	1036±91.7 ^b	1036±85.2 ^b	1366±146.4 ^a	962.7±68.5	1295±96.6	0.022	0.020	0.447	0.015	0.132
<i>Polyunsaturated fatty acids (PUFAs)</i>										
C18:2n6c	227.7±13.7	227.4±12.5	262.9±12.8	231.1±11.3	245.3±11.0	0.120	0.684	0.882	0.076	0.258
C18:3n3c	12.85±1.07 ^b	14.47±0.94 ^b	18.16±1.33 ^a	13.80±0.98	16.18±1.03	0.006	0.165	0.486	0.002	0.406
C20:2n6c	7.705±0.631	7.756±0.567	9.466±0.705	7.736±0.582	8.747±0.490	0.097	0.358	0.901	0.056	0.271

C20:4n6c	4.397±0.214	4.520±0.229	4.511±0.215	4.292±0.171	4.637±0.171	0.879	0.432	0.340	0.622	0.933
C20:5n3c	0.769±0.080	0.882±0.055	0.887±0.087	0.842±0.055	0.852±0.067	0.421	0.410	0.365	0.257	0.512
ΣPUFA	253.6±15.6	255.1±14.1	295.9±14.5	257.7±12.8	275.8±12.5	0.100	0.610	0.877	0.059	0.267
Σω-6	239.8±14.5	239.7±13.2	276.8±13.6	243.1±12.0	258.6±11.6	0.121	0.662	0.881	0.076	0.263
Σω-3	13.79±1.18 ^b	15.35±0.97 ^b	19.04±1.35 ^a	14.64±0.99	17.14±1.08	0.011	0.186	0.632	0.004	0.434
ω-6:ω-3	17.85±0.70 ^a	15.72±0.40 ^b	14.96±0.88 ^b	17.02±0.68	15.50±0.52	0.020	0.098	0.639	0.008	0.383

Means followed by different letters on the same line differ statistically according to Duncan's test ($P < 0.05$). DGP= dehydrated grape pomace; Treat= treatment; SFAs= saturated fatty acids; MUFAs= monounsaturated fatty acids; PUFAs= polyunsaturated fatty acids.

Table 6. The means and standard error of the mean of fatty acid, ω-6, ω-3 (mg/100 g of sample), and ω-6:ω-3 ratio in the backfat per treatment and sex.

Fatty Acid	Treatments			Sex		Prob F				
	Control	5% DGP	10% DGP	Female	Barrow	Treat	Sex	Treat x Sex	Linear	Quadratic
<i>Saturated fatty acids (SFAs)</i>										
C10:0	70.07±2.58	69.65±1.40	69.52±1.46	70.78±1.69	68.67±1.31	0.987	0.459	0.835	0.983	0.874
C12:0	74.70±3.09	75.97±1.70	73.92±1.53	75.64±1.60	74.09±2.03	0.878	0.646	0.899	0.919	0.619
C14:0	1241±28.3	1286±37.9	1249±23.4	1272±16.1	1245±32.3	0.554	0.427	0.138	0.932	0.285
C15:0	50.20±2.63	50.21±2.92	51.18±2.03	48.54±1.95	52.60±2.10	0.961	0.209	0.176	0.806	0.886
C16:0	23490±153.6	23921±242.1	23678±112.6	23576±107.4	23825±184.9	0.263	0.269	0.270	0.481	0.148
C17:0	331.4±13.8	314.7±19.5	312.9±17.6	298.5±11.1	342.6±14.5	0.703	0.035	0.373	0.469	0.700
C18:0	12434±170.8	12193±255.9	11909±185.0	12021±178.0	12362±161.9	0.290	0.096	0.481	0.121	0.913
C20:0	224.8±6.1	231.1±7.69	238.8±8.93	223.5±5.96	239.7±5.91	0.252	0.036	0.233	0.103	0.793
ΣSFA	37917±198.7	38141±334.0	37583±223.9	37586±201.8	38209±204.9	0.372	0.020	0.549	0.466	0.222
<i>Monounsaturated fatty acids (MUFAs)</i>										
C16:1	1653±49.9	1791±77.7	1849±54.2	1784±55.3	1739±51.8	0.138	0.490	0.265	0.063	0.532
C17:1	231.9±11.2	228.0±16.0	225.7±12.2	211.3±7.7	246.9±11.8	0.946	0.026	0.270	0.748	0.949
C18:1n7c	1882±47.2	2039±90.4	2017±63.9	1975±60.0	1982±57.3	0.280	0.935	0.267	0.278	0.254
C18:1n9c	37298±395.5	37411±261.6	37341±143.5	37081±253.9	37636±187.9	0.941	0.119	0.137	0.994	0.731

C20:1n9c	781.1±29.0	778.4±18.8	761.1±22.3	732.3±10.2	818.0±20.9	0.832	0.003	0.791	0.574	0.817
C22:1n9c	117.4±4.6 ^{ab}	108.9±4.2 ^b	129.0±5.3 ^a	121.6±4.5	114.4±3.8	0.008	0.275	0.219	0.050	0.009
ΣMUFA	41963±436.4	42357±258.8	42323±170.3	41905±293.8	42536±175.8	0.569	0.084	0.059	0.481	0.445
<i>Polyunsaturated fatty acids (PUFAs)</i>										
C18:2n6c	13995±464.7	13504±238.9	13983±189.2	14412±236.7	13200±208.7	0.387	0.001	0.215	0.933	0.175
C18:3n3c	976.8±48.2	886.1±26.5	1007±34.8	955.7±33.1	954.4±32.6	0.101	0.902	0.780	0.544	0.039
C20:2n6c	666.8±20.1	640.8±16.0	629.5±9.4	657.7±11.9	634.0±14.5	0.324	0.259	0.580	0.156	0.679
C20:4n6c	79.58±4.14	70.89±4.23	73.52±3.95	81.28±2.75	67.72±3.26	0.238	0.005	0.879	0.251	0.224
ΣPUFA	15718±480.3	15102±248.5	15693±184.3	16106±251.6	14856±211.5	0.249	0.001	0.186	0.926	0.100
Σω-6	14742±474.9	14216±245.5	14686±189.4	15151±237.2	13901±216.9	0.368	0.001	0.204	0.854	0.167
Σω-3	976.8±48.2	886.1±26.5	1007±34.8	955.7±33.1	954.4±32.6	0.101	0.902	0.780	0.544	0.039
ω-6:ω-3	15.44±0.79	16.21±0.56	14.79±0.60	16.12±0.51	14.84±0.54	0.296	0.092	0.977	0.426	0.172

Means followed by different letters on the same line differ statistically according to Duncan's test ($P < 0.05$); DGP= dehydrated grape pomace; Treat= treatment; SFAs= saturated fatty acids; MUFAs= monounsaturated fatty acids; PUFAs= polyunsaturated fatty acids.

4. Discussion

The fact that barrows have a more significant amount of fat is already widely known, as stated by Overholt et al. [35], who found a significantly higher proportion of intramuscular fat and subcutaneous fat in barrows compared to gilts and immunologically castrated males. The explanations for these effects refer to the faster deposition of fat compared to gilts since the gilts have sex hormones that have an anabolic effect on protein, which are mainly absent in barrows due to castration.

The best meat quality observed in barrows follows a study by Woodworth et al. [36], which concluded that barrows had a higher marbling content, higher pH 24h, and lower DL after a literature review. The results of the present study also agree with those of Zhang et al. [37] regarding the higher content of SFAs and MUFAs and the lower content of PUFAs in barrows. The higher intramuscular fat content in the loin of barrows also impacts the content of fatty acids when expressed as the weight/weight of the sample, as shown in Table 6.

The tendency to increase DWG with dietary DGP inclusion may have been caused by the increase in DFI since F:G was not affected. The rise in DFI with dietary DGP inclusion could have been caused by better palatability of these diets and agrees with some previous studies [38,39], where an increased DFI was reported in pigs and broiler chickens fed diets containing GP. On the other hand, this result differs from other studies conducted with pigs and broilers, which did not find an effect of GP on DFI [15,16,20]. According to Costa et al. [40], GP can improve average daily gain when included in pigs diets up to 9%. This response is assigned to improved intestinal health due to the modulation of the intestinal morphology and microbiota and the stimulation of the antioxidant capacity. However, this conclusion was based mainly on studies conducted with nursery piglets.

The inclusion of DGP in the diet caused an increase in the backfat and a reduction in the percentage of meat. It is possible that this increase in adiposity resulted from an overestimation of digestible amino acids in DGP, as it is a variable by-product conditioned to the type of grape from which it originates and the conditions of production and processing. Higher adiposity may also be due to the greater feed consumption of the animals fed the DGP diets. The effect of GP on pig carcass quality has been reported in a few studies, and the present study differs from all of them. Bernardi et al. [20] reported a reduction in backfat thickness by including 10% DGP in the pig diet, but there was no effect on other carcass quality parameters. On the other hand, the dietary inclusion of 3.5% or 7.0% GP for finishing pigs did not affect carcass quality [19], and including 3.0% of fermented GP in the diet of pigs did not affect the *longissimus* muscle area [16].

The increased intramuscular fat content observed with inclusion of DGP in the diet is not corroborated by previous studies [18,20,39]. Furthermore, other authors reported an increase in the redness of meat by supplementing GP ([16,18] or grape seed extracts in pig diets, as well as an increase in the final pH and a reduction in lightness, drip loss, and shear force in pigs supplemented with grape seed extracts [8,41]. This variety of results may be a consequence of differences in the content and availability of phenolic compounds in grape by-products evaluated in different studies, their metabolization by the intestinal microbiota, as well as the use of different base raw materials and fat sources in the experimental diets. Moreover, the antioxidants present in the grape seed extracts may be more readily available and thus more effective in dietary use as antioxidants than GP.

The current results suggest that, under the conditions of this research, the inclusion of DGP in the diet of pigs does not improve the shelf life of meat products, since the TBARS in mini hamburgers were not affected. This result contrasts with previous studies [16,17,42,43], which reported reduced oxidation of lipids in meat, processed products, and eggs when different types of GPs or its fractions were included in the diets of pigs and poultry. On the other hand, other authors [18–20,44] found no effect of dietary supplementation with DGP or grape seed extract on TBARS in fresh meat and in pork mini hamburgers. It is possible that with a longer supply of GP in the diet the desired effects on fresh meat quality and oxidative stability of meat lipids could be achieved in the present study.

At least three other factors may have influenced the results of this research regarding the fresh meat quality and oxidative stability of meat lipids: a low concentration and/or low availability of phenolic compounds in the DGP used in this study, no adverse presence of added fat sources in the experimental diets that could increase the demand for antioxidant compounds, and adequate levels of vitamin E and selenium in the experimental diets. The content of phenolic compounds present in the grape pomace used in this study is low compared to that reported in other studies [15–17,35,42]. Furthermore, according to Chamorro et al. [15], most of the phenolic compounds of GP are in the skin matrix, therefore, degradation of the cell-wall polysaccharides is fundamental for phenol release from grape skins. As the main constituents of fiber on GP are cell wall polysaccharides and lignin, and considering that proteins and phenols are cross-linked to the lignin and carbohydrates [45], we can expect some restriction in the digestibility of phenolic compounds inserted into the cell wall. The levels of supplemented selenium and vitamin E in the experimental diets were 67% and 16%, respectively, above those recommended by NRC (2012) [21]. Therefore, adequate levels of antioxidants from minerals and vitamins supplied by the diet may have balanced the endogenous antioxidant system in the tissues so that it would be sufficient to face the challenges of post mortem and processing transformations.

The lack of the effect of DGP on the fatty acid profile of backfat agrees with the results obtained by Bertol et al. [18]. However, Yan and Kim [16] found a reduction in the proportion of SFA and an increase in C18:2n6 and total PUFA in the subcutaneous fat of pigs due to the inclusion of 3.0% fermented GP in the diet.

Because ω -6 fatty acids make up approximately 50% of the ether extract of GP, we would expect an increase in the content of these fatty acids in pig fat. However, this study showed that dietary supplementation with DGP resulted only in a tendency to increase the content of ω -6 but it increased the content of $\Sigma\omega$ -3 fatty acids and reduced the ω -6: ω -3 ratio in the intramuscular fat of pigs. Previous studies also reported increased ω -3 fatty acids in meat from pigs fed diets containing GP [10] and in meat from broilers fed diets supplemented with grape seed proanthocyanidin extract [8]. Furthermore, Kafantaris et al. [46] reported increased ω -3 fatty acids and a decreased ω -6: ω -3 ratio in the intramuscular fat of piglets fed ensiled GP.

The effect of treatments on the content of EE and on fatty acid profile of intramuscular fat could be the result of polyphenol stimulation on fatty acid synthesis and elongation. Vitali et al. [47] concluded that adding ω -3 PUFAs and polyphenols derived from linseed, grape skin, and oregano to the diets of pigs stimulates gene expression for lipogenesis and oxidative processes. For instance, their results indicated a more significant effect of a diet with both plant extracts and ω -3 PUFAs on gene expression, resulting in an increased expression of genes coding for fatty acid synthesis, desaturation, and elongation in pig *longissimus thoracis* muscle, than the effect of a diet enriched only with ω -3 PUFAs. Rocchetti et al. [48] also stated that dietary supplementation with extracts of grape skin and oregano promotes the expression of genes responsible for lipid biosynthesis and elongation, leading to an increased accumulation of fatty acids, especially phospholipids, which are richer in PUFAs than the triacylglycerols. This may explain the greater content of intramuscular fat and ω -3 PUFAs in the loin of pigs fed the diet containing DGP in the present study. A higher EE content in the loin also impacts the content of individual fatty acids when expressed as the weight/weight of the sample, as observed in several individual fatty acids, Σ SFAs, and Σ MUFAs.

5. Conclusions

Taking into account the set of results obtained in this study, we concluded that it is feasible to include up to 10% of DGP in pig diets without affecting growth performance, but carcass quality may be impaired due to increased adiposity. Furthermore, meat quality can be improved by increasing intramuscular fat and ω -3 fatty acid content, but fat stability is not affected when DGP is included at up to 10% of the diet for 49 days prior to slaughter. Additional studies with a longer dietary supply time of grape pomace are indicated to evaluate its effect on the oxidative stability of lipids associated with meat in pigs.

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