applied biosciences

MDPI

Article

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

Barbara Cristina da Silveira Almeida [1], Maria do Carmo Mohaupt Marques Ludke [1], Teresinha Marisa Bertol [2,*], Jorge Vitor Ludke [2], Daniela Miotto Bernardi [3], Anildo Cunha Jr. [2] and Arlei Coldebella [2]

[1] Animal Science Department, Universidade Federal Rural de Pernambuco UFRPE, Rua Dom Manuel de Medeiros, s/n, Dois Irmãos, Recife 52171-900, Brazil; profa.babisilveira@gmail.com (B.C.d.S.A.); maria.mmarques@ufrpe.br (M.d.C.M.M.L.)

[2] Embrapa Swine and Poultry, BR 153, KM 110, Vila Tamanduá, Concórdia 89715-899, Brazil; jorge.ludke@embrapa.br (J.V.L.); anildo.cunha@embrapa.br (A.C.J.); arlei.coldebella@embrapa.br (A.C.)

[3] Nutrition Department, Universidade Estadual do Oeste do Paraná UNIOESTE, Rodovia PR 182, Km 449, Água Branca, Francisco Beltrão 85601-839, Brazil; dani_miotto@yahoo.com.br

* Correspondence: teresinha.bertol@embrapa.br; Tel.: +55-(49)-3441-0460 or +55-(54)-981668462

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 Σω-3 and reduced the ω-6:ω-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 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.

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

Citation: da Silveira Almeida, B.C.; Ludke, M.d.C.M.M.; Bertol, T.M.; Ludke, J.V.; Bernardi, D.M.; Cunha Jr., A.; Coldebella, A. Growth Performance, Meat Quality, and Lipid Oxidation in Pigs' Fed Diets Containing Grape Pomace. *Appl. Biosci.* **2024**, *3*, 378–391. https://doi.org/10.3390/applbiosci3030025

Academic Editors: Adriana Basile, Viviana Maresca and Piergiorgio Cianciullo

Received: 22 May 2024
Revised: 19 August 2024
Accepted: 22 August 2024
Published: 31 August 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

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 proantocianidin 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 gallocatechin) 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

In total, 36 pigs, 18 barrows, and 18 gilts (83.23 $\pm$ 6.03 kg and 132.1 $\pm$ 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 $\times$ 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.

	Phase 1 (83–103 kg)			**Phase 2 (103–130 kg)**		
Ingredients, g/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. [a] Vitamin Premix supplied per kg of diet: 4800 UI of vitamin A; 975 UI of vitamin D_3; 12.75 UI of vitamin E; 1.5 mg of vitamin K_3; 0.75 mg of vitamin B_1; 4.2 mg of vitamin B_2; 0.9 mg of vitamin B_6; 15.75 mcg of vitamin B_{12}; 0.15 mg of Biotin; 0.375 mg of Folic Acid; 24 mg of Nicotinic Acid; 14 mg of Pantothenic Acid. [b] Mineral premix supplied per kg of diet: 118 mg of Fe as ion 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 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 Na_2CO_3 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 × 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 P_2 (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 P_2 point (BFP2) [28] after the carcasses were stored in a chilling room (at 2 to 4 °C) for 24 h. 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 45 min) and 24 h (pH 24 h) 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 of 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 h, 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 (1 cm × 1 cm × 2 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 was 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 s. 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 Yijk = μ + Bi(k) + Tj + Sk + TSjk + eijk. Yijk is an observation of the dependent variable ijk, μ is the overall population mean, Bi(k) is the fixed effect of the

block within sex, Tj is the fixed effect of treatments, Sk is the fixed effect of sex, TSjk is the fixed effect of treatment vs. sex interaction, and eijk 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, backfat thickness, FAT, FMR, EE content in the loin, and pH after 24 h and lower ($p < 0.05$) LEA, LDHGP, 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 (ΣSFAs); lower ($p < 0.05$) content of C18:2n6c, C20:4n6c, total polyunsaturated fatty acids (ΣPUFAs), and ω-6 in backfat than gilts; and higher ($p < 0.05$) content of C10:0, C20:0, C16:1, C18:1n7c, C18:1n9c, C20:1n9c, and total monounsaturated fatty acids (ΣMUFAs) 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 BFHGP 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 onward. 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, ΣSFAs, C16:1, C18:1n7c, C18:1n9c, ΣMUFAs, C18:3n3c, and Σω-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 Σω-3 with a minimum point at 4.65% DGP in the diet, increasing from that point onward. Including DGP in the pigs' diet did not affect TBARS in mini hamburgers either on the first day or 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 × 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	<0.0001	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	<0.0001	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	<0.0001	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	<0.0001	0.971	0.019	0.320

[ab] 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, cm^2; FAT—fat area, cm^2; 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 BTP2, 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 × 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 45 min	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 24 h	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

[ab] 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. [a] NPPC 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 × 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
Saturated fatty acids (SFAs)										
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
Monounsaturated fatty acids (MUFAs)										
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
Polyunsaturated fatty acids (PUFAs)										
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

[ab] 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 × Sex	Linear	Quadratic
Saturated fatty acids (SFAs)										
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	23,490 ± 153.6	23,921 ± 242.1	23,678 ± 112.6	23,576 ± 107.4	23,825 ± 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	12,434 ± 170.8	12,193 ± 255.9	11,909 ± 185.0	12,021 ± 178.0	12,362 ± 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	37,917 ± 198.7	38,141 ± 334.0	37,583 ± 223.9	37,586 ± 201.8	38,209 ± 204.9	0.372	0.020	0.549	0.466	0.222
Monounsaturated fatty acids (MUFAs)										
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	37,298 ± 395.5	37,411 ± 261.6	37,341 ± 143.5	37,081 ± 253.9	37,636 ± 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	41,963 ± 436.4	42,357 ± 258.8	42,323 ± 170.3	41,905 ± 293.8	42,536 ± 175.8	0.569	0.084	0.059	0.481	0.445
Polyunsaturated fatty acids (PUFAs)										
C18:2n6c	13,995 ± 464.7	13,504 ± 238.9	13,983 ± 189.2	14,412 ± 236.7	13,200 ± 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	15,718 ± 480.3	15,102 ± 248.5	15,693 ± 184.3	16,106 ± 251.6	14,856 ± 211.5	0.249	0.001	0.186	0.926	0.100
Σω-6	14,742 ± 474.9	14,216 ± 245.5	14,686 ± 189.4	15,151 ± 237.2	13,901 ± 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

[ab] 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 24 h, 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 the 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, and 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 their 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 Σω-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 the 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, ΣSFAs, and ΣMUFAs.

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.

Author Contributions: Conceptualization, T.M.B. and J.V.L.; methodology, T.M.B., J.V.L., M.d.C.M.M.L., B.C.d.S.A., D.M.B. and A.C.J.; validation, T.M.B., J.V.L. and A.C.; formal analysis, A.C., T.M.B. and B.C.d.S.A.; investigation, T.M.B., B.C.d.S.A., J.V.L., D.M.B. and A.C.J.; resources, T.M.B.; data curation, T.M.B., A.C. and B.C.d.S.A.; writing—original draft preparation, B.C.d.S.A. and T.M.B.; writing—review and editing, T.M.B., J.V.L., M.d.C.M.M.L. and D.M.B.; visualization, T.M.B., B.C.d.S.A. and M.d.C.M.M.L.; supervision, T.M.B. and M.d.C.M.M.L.; project administration, T.M.B.; funding acquisition, T.M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This study is part of a research project funded and conducted by the Embrapa Swine and Poultry Research Unit (project 03.17.00.025.00.00) with partial financial support from Vinery Scortegagna Limited Company (Flores da Cunha/RS, Brazil) (technical cooperation contract nº 210001200341) and CAPES—Coordination for the Improvement of Superior Level Education Personnel—Brazil, (grant number 1248057).

Institutional Review Board Statement: This research was approved by the Committee of Ethics in the Use of Animals (CEUA/CNPSA) under protocol number 003/2014 by following the Ethical Principles in Animal Experimentation (CFMV Resolution 879, 2008) adopted by the Brazilian College of Animal Experimentation (COBEA).

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available at: www.figshare.com/account/home (accessed on 12 July 2024).

Acknowledgments: The growth performance experiment and the analytical procedures were completed at the Embrapa Swine and Poultry facilities (Embrapa Suínos e Aves, Br 153, Km 110, District Tamanduá, ZIP Code: 89715-899, PO box: 321, Concórdia-SC, Brazil). The authors thank the Embrapa Swine and Poultry Unit crew for their input on this study. Bárbara Cristina da Silveira de Almeida partially carried out the research through a postgraduate scholarship from the CAPES—Coordination of Superior Level Staff Improvement (Brasilia-DF, Brazil) linked to the postgraduate course in Animal Science at the Federal Rural University of Pernambuco (UFRPE).

Conflicts of Interest: All the authors declare that the resources from Vinery Scortegagna Limited Company were used only to cover part of the costs of feeding the animals, laboratory analyses and travel necessary for the project. The funder was not involved in the study design, collection, analysis, interpretation of data, the writing of this article or the decision to submit it for publication.

References

1. de Campos, R.; Hierro, E.; Ordóñez, J.; Bertol, T.; de la Hoz, L. A note on partial replacement of maize with rice bran in the pig diet on meat and backfat fatty acids. *J. Anim. Feed Sci.* **2006**, *15*, 427–433. [CrossRef]
2. Decker, E.A.; Akoh, C.C.; Wilkes, R.S. Incorporation of (n-3) Fatty Acids in Foods: Challenges and Opportunities. *J. Nutr.* **2012**, *142*, 610S–613S. [CrossRef] [PubMed]
3. Ahn, D.U.; Lutzb, S.; Sim, J.S. Effects of dietary α-linolenic acid on the fatty acid composition, storage stability and sensory characteristics of pork loin. *Meat Sci.* **1996**, *43*, 291–299. [CrossRef] [PubMed]
4. Musella, M.; Cannata, S.; Rossi, R.; Mourot, J.; Baldini, P.; Corino, C. Omega-3 polyunsaturated fatty acid from extruded linseed influences the fatty acid composition and sensory characteristics of dry-cured ham from heavy pigs. *J. Anim. Sci.* **2009**, *87*, 3578–3588. [CrossRef] [PubMed]
5. Juárez, M.; Dugan, M.E.R.; Aldai, N.; Aalhus, J.L.; Patience, J.F.; Zijlstra, R.T.; Beaulieu, A.D. Increasing omega-3 levels through dietary co-extruded flaxseed Supplementation negatively affects pork palatability. *Food Chem.* **2011**, *126*, 1716–1723. [CrossRef]
6. Larick, D.K.; Turner, B.E.; Schoenherr, W.D.; Coffey, M.T.; Pilkington, D.H. Volatile compound content and fatty acid composition of pork as influenced by linolenic acid content of the diet. *J. Anim. Sci.* **1992**, *70*, 1397–1403. [CrossRef]
7. Lauridsen, C.; Nielsen, J.H.; Henckel, P.; Sorensen, M.T. Antioxidative and oxidative status in muscles of pigs fed rapeseed oil, vitamin E, and copper. *J. Anim. Sci.* **1999**, *77*, 105–115. [CrossRef]
8. Xu, M.; Chen, X.; Huang, Z.; Chen, D.; Li, M.; He, J.; Chen, H.; Zheng, P.; Yu, J.; Luo, Y.; et al. Effects of dietary grape seed proanthocyanidin extract supplementation on meat quality, muscle fiber characteristics and antioxidant capacity of finishing pigs. *Food Chem.* **2022**, *367*, 130781. [CrossRef]
9. Pinelo, M.; Arnous, A.; Meyer, A.S. Upgrading of grape skins: Significance of plant cell-wall structural components and extraction techniques for phenol release. *Trends Food Sci. Technol.* **2006**, *17*, 579–590. [CrossRef]

10. Yilmaz, Y.; Toledo, R.T. Major Flavonoids in grape seeds and skins: Antioxidant capacity of catechin, epicatechin, and gallic acid. *J. Agric. Food Chem.* **2004**, *52*, 255–260. [CrossRef]
11. Amico, V.; Napoli, E.M.; Renda, A.; Ruberto, G.; Spatafora, C.; Tringali, C. Constituents of grape pomace from the Sicilian cultivar Nerello Mascalese. *Food Chem.* **2004**, *88*, 599–607. [CrossRef]
12. Lafka, T.I.; Sinanoglou, V.; Lazos, E.S. On the extraction and antioxidant activity of phenolic compounds from winery wastes. *Food Chem.* **2007**, *104*, 1206–1214. [CrossRef]
13. Pazos, M.; Gallardo, J.M.; Torres, J.L.; Medina, I. Activity of grape polyphenols as inhibitors of the oxidation of fish lipids and frozen fish muscle. *Food Chem.* **2005**, *92*, 547–557. [CrossRef]
14. Brewer, S. Natural Antioxidants: Sources, Compounds, Mechanisms of Action, and Potential Applications. *Compr. Rev. Food Sci. Food Saf.* **2011**, *10*, 221–247. [CrossRef]
15. Chamorro, S.; Viveros, A.; Rebolé, A.; Rica, B.D.; Arija, I.; Brenes, A. Influence of dietary enzyme addition on polyphenol utilization and meat lipid oxidation of chicks fed grape pomace. *Food Res. Int.* **2015**, *73*, 197–203. [CrossRef]
16. Yan, L.; Kim, I.H. Effect of Dietary Grape Pomace Fermented by Saccharomyces boulardii on the Growth Performance, Nutrient Digestibility and Meat Quality in Finishing Pigs. *Asian Australas. J. Anim. Sci.* **2011**, *24*, 1763–1770. [CrossRef]
17. Romero, C.; Arija, I.; Viveros, A.; Chamoro, S. Productive performance, egg quality and yolk lipid oxidation in laying hens fed diets including grape pomace or grape extract. *Animals* **2022**, *12*, 1076. [CrossRef]
18. Bertol, T.M.; Ludke, J.V.; de Campos, R.M.L.; Kawski, V.L.; Cunha, A., Jr.; Figueiredo, E.A.P. Inclusion of grape pomace in the diet of pigs on pork quality and oxidative stability of omega-3 enriched fat. *Cienc. Rural* **2017**, *47*, e20150358. [CrossRef]
19. Trombetta, F.; Fruet, A.P.B.; Stefanello, F.S.; Fonseca, P.A.F.; Souza, A.N.M.; Tonetto, C.J.; Rosado Júnior, A.G.; Nörnberg, J.L. Effects of the dietary inclusion of linseed oil and grape pomace on weight gain, carcass characteristics, and meat quality of swine. *Int. Food Res. J.* **2019**, *26*, 1741–1749. Available online: http://www.ifrj.upm.edu.my (accessed on 16 April 2024).
20. Bernardi, D.M.; Bertol, T.M.; Coldebella, A.; Cunha, A., Jr.; Silveira, B.C.A.; Rodrigues, J.B.; Barrera-Arellano, D.; Godoy, H.; Meinhart, A.D.; de Paris, L.D.; et al. Effects of dietary flaxseed oil with or without products with antioxidant properties on pig performance, carcass characteristics, meat quality, and oxidative stability. *Anim. Prod. Sci.* **2022**, *62*, 1789–1804. [CrossRef]
21. NRC. National Research Council. *Nutrient Requirements of Swine*; Eleventh Revised Edition; The National Academies Press: Washington, DC, USA, 2012; p. 420. [CrossRef]
22. AOAC. *Official Methods of Analysis*, 16th ed.; Association of Official Analytical Chemists: Gaithersburg, MD, USA, 1995.
23. Singleton, V.L.; Rossi, J.A., Jr. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Vitic.* **1965**, *16*, 144–158. [CrossRef]
24. Kähkönen, M.P.; Hopia, A.I.; Vuorela, H.J.; Rauha, J.P.; Pihlaja, K.; Kujala, T.S.; Heinonen, M. Antioxidant activity of plant extracts containing phenolic compounds. *J. Agric. Food Chem.* **1999**, *47*, 3954–3962. [CrossRef] [PubMed]
25. Kim, D.O.; Jeong, S.W.; Lee, C.Y. Antioxidant capacity of phenolic phytochemicals from various cultivars of plums. *Food Chem.* **2003**, *81*, 321–326. [CrossRef]
26. Folch, J.; Lees, M.; Stanley, G.H.S. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* **1957**, *226*, 497–509. [CrossRef]
27. Hartman, L.; Lago, R.C.A. Rapid preparation of fatty acid methyl esters from lipids. *Lab. Pract.* **1973**, *22*, 475–476.
28. Associação Brasileira de Criadores de Suínos. *Método Brasileiro de Classificação de Carcaças*; Publicação Técnica No. 2; ABCS: Estrela, Brazil, 1973; p. 17.
29. *RHINOCEROS*, versão 4.0; McNeel North America: Seatle, WA, USA, 2007.
30. NPPC. Official Color and Marbling Standards. In *Composition & Quality Assessment Procedures*; NPPC: Urbandale, IA, USA, 1999.
31. Correa, J.A.; Méthot, S.; Faucitano, L. A modified meat juice container (EZ-DRIP LOSS) procedure for a more reliable assessment of drip loss and related quality in pork meat. *J. Muscle Foods.* **2007**, *18*, 67–77. [CrossRef]
32. Honikel, K.O. Reference methods for the assessment of physical characteristics of meat. *Meat Sci.* **1998**, *49*, 447–457. [CrossRef] [PubMed]
33. AMSA. *Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat*, 2nd ed.; version 1.02; American Meat Science Association: Champaign, IL, USA, 2016; p. 106. Available online: https://www.meatscience.org/docs/default-source/publications-resources/amsa-sensory-and-tenderness-evaluation-guidelines/research-guide/amsa-research-guidelines-for-cookery-and-evaluation-1-02.pdf (accessed on 15 December 2015).
34. Vyncke, B.W. Direct determination of the thiobarbituric acid value in trichloracetic acid extracts of fish as a measure of oxidative rancidity. *Fette Seifen Anstr.* **1970**, *72*, 1084–1087. [CrossRef]
35. Overholt, M.F.; Arkfeld, E.K.; Mohrhauser, D.A.; King, D.A.; Wheeler, T.L.; Dilger, A.C.; Shackelford, S.D.; Boler, D.D. Comparison of variability in pork carcass composition and quality between barrows and gilts. *J. Anim. Sci.* **2016**, *94*, 4415–4426. [CrossRef]
36. Woodworth, J.; Bohrer, B.; Faccin, J. *Characterizing the Differences between Barrow and Gilt Growth Performance, Carcass Composition, and Meat Quality*; KSU Applied Swine Nutrition Department: Manhattan, KS, USA, 2021; p. 4.
37. Zhang, S.; Knight, T.J.; Stalder, K.J.; Goodwin, R.N.; Lonergan, S.M.; Beitz, D.C. Effects of breed, sex, and halothane genotype on the fatty acid composition of pork Longissimus muscle. *J. Anim. Sci.* **2007**, *85*, 583–591. [CrossRef]
38. Erinle, T.J.; Oladokun, S.; MacIsaac, J.; Rathgeber, B.; Adewole, D. Dietary grape pomace—Effects on growth performance, intestinal health, blood parameters, and breast muscle myopathies of broiler chickens. *Poult. Sci.* **2022**, *101*, 101519. [CrossRef] [PubMed]

39. Ospina-Romero, M.A.; Medrano-Vázquez, L.S.; Pinelli-Saavedra, A.; Sánchez-Villalba, E.; Valenzuela-Melendres, M.; Martínez-Téllez, M.A.; Barrera-Silva, M.A.; González-Ríos, H. Productive Performance, Physiological Variables, and Carcass Quality of Finishing Pigs Supplemented with Ferulic Acid and Grape Pomace under Heat Stress Conditions. *Animals* **2023**, *13*, 2396. [CrossRef] [PubMed]
40. Costa, M.M.; Alfaia, C.M.; Lopes, P.A.; Pestana, J.M.; Prates, J.A.M. Grape by-products as feedstuff for pig and poultry production. *Animals* **2022**, *12*, 2239. [CrossRef]
41. Zhang, C.; Luo, J.; Yu, B.; Zheng, P.; Huang, Z.; Mao, X.; He, J.; Yu, J.; Chen, J.; Chen, D. Dietary resveratrol supplementation improves meat quality of finishing pigs through changing muscle fiber characteristics and antioxidative status. *Meat Sci.* **2015**, *102*, 15–21. [CrossRef]
42. Brenes, A.; Viveros, A.; Goñi, I.; Centeno, C.; Sáyago-Ayerdy, S.G.; Arija, I.; Saura-Calixto, F. Effect of grape pomace concentrate and vitamin E on digestibility of polyphenols and antioxidant activity in chickens. *Poult. Sci.* **2008**, *87*, 307–316. [CrossRef] [PubMed]
43. Romero, C.; Nardoia, M.; Arija, I.; Viveros, A.; Rey, A.I.; Prodanov, M.; Chamorro, S. Feeding broiler chickens with grape seed and skin meals to enhance α- and γ- tocopherol content and meat oxidative stability. *Antioxidants* **2021**, *10*, 699. [CrossRef]
44. O'Grady, M.N.; Carpenter, R.; Lynch, P.B.; O'Brien, N.M.; Kerry, J.P. Addition of grape seed extract and bearberry to porcine diets: Influence on quality attributes of raw and cooked pork. *Meat Sci.* **2008**, *78*, 438–446. [CrossRef]
45. Bordiga, M.; Travaglia, F.; Locatelli, M. Valorisation of grape pomace: An approach that is increasingly reaching its maturity—A review. *Int. J. Food Sci. Technol.* **2019**, *54*, 933–942. [CrossRef]
46. Kafantaris, I.; Stagos, D.; Kotsampasi, B.; Hatzis, A.; Kypriotakis, A.; Gerasopoulos, K.; Makri, S.; Goutzourelas, N.; Mitsagga, C.; Giavasis, I.; et al. Grape pomace improves performance, antioxidant status, fecal microbiota and meat quality of piglets. *Animal* **2018**, *12*, 246–255. [CrossRef]
47. Vitali, M.; Dimauro, C.; Sirri, R.; Zappaterra, M.; Zambonelli, P.; Manca, E.; Sami, D.; Lo Fiego, D.P.; Davoli, R. Effect of dietary polyunsaturated fatty acid and antioxidant supplementation on the transcriptional level of genes involved in lipid and energy metabolism in swine. *PLoS ONE* **2018**, *13*, e0204869. [CrossRef]
48. Rocchetti, G.; Vitali, M.; Zappaterra, M.; Righetti, L.; Sirri, R.; Lucini, L.; Dall'Asta, C.; Davoli, R.; Galaverna, G. A molecular insight into the lipid changes of pig Longissimus thoracic muscle following dietary supplementation with functional ingredients. *PLoS ONE* **2022**, *17*, e0264953. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.