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ANIMAL SCIENCE

Meat quality of pigs fed grape pomace in different production systems

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Abstract: The main objective of this study was to evaluate the effects of supplementation the diet of pigs with grape pomace preserved in silage form (GPS) and its interaction with indoor and outdoor production systems, with and without access to vegetation, on the attributes of meat quality produced. Analyzes of proximal composition, cholesterol content, fatty acid profile, shear force, texture profile and sensory analysis were performed. During cold storage, oxidative stability and objective color were analyzed. Statistical analysis was performed in a 3x2 factorial design (production systems (S) x GPS-feed (F)) and the interaction between them (S*F). The results showed that there was no interaction between the production system and GPS feeding for the attributes evaluated. The proximate composition and fatty acid profile of the muscle remained unchanged. Additionally, it provides higher subjective and objective tenderness, higher red color intensity, and reduces lipid oxidation under refrigeration. The supplementation of pig feed with GPS improve the quality of the meat and constitute a sustainable alternative for the winemaking residue.

Key words: agro-industrial waste, antioxidant, fatty acid profile, lipid oxidation, sensory analysis, tenderness.

INTRODUCTION

Vinification residues, as a source of bioactive compounds, such as phenolic compounds, have attracted attention in several sectors such as the cosmetic, pharmaceutical, and food industries (Beres et al. 2017). Grape pomace is the main solid residue of the wine industry, composed of large amounts of phenolic compounds (Perra et al. 2022). During the production of wine, large quantities of grape pomace are generated, consisting of husks, seeds, and stalks. These components, rich in bioactive compounds, act as antimicrobials, anti-inflammatories and have high antioxidant potential (Yu & Ahmedna 2013, Sirohi et al. 2020).

The use of natural antioxidants can be suitable preservatives for the meat industry (Salami et al. 2019). Recent studies have shown the possibility of developing healthier meat and meat products for consumers, introducing bioactive compounds beneficial to human health through animal nutrition, with emphasis on those with antioxidant properties (Kotsampasi et al. 2014, Francisco et al. 2015, Trombetta et al. 2019).

Studies show that supplementation with grape pomace and its components improves meat quality. Bertol et al. 2013 when adding up to 10% dehydrated grape pomace to the feed of confined pigs, observed improvements in the

meat color, with a high intensity of red color. Dietary supplementation with grape compounds, in this case, resveratrol, improved the quality of confined pig meat in the amounts of 300 mg and 600 mg per kg of feed (Zhang et al. 2015). Cheng et al. 2020 when evaluating pigs raised in groups and supplemented with resveratrol, observed that the grape component can inhibit muscle oxidative stress. Trombetta et al. 2019 concluded that the inclusion of 3.5% and 7% grape pomace silage on a dry basis in the feed of confined pigs improved meat quality.

In recent years, there has been an increase in the exploration for organic foods, concern for animal welfare, and an increasing appreciation of welfare parameters in relation to other meat quality attributes (Alonso et al. 2020). There is a growing demand from the population for sustainable methods of meat production. Conventional production is challenged by environmental and animal welfare issues and, therefore, outdoor swine farming becomes an alternative that aims at the welfare and sustainability of production (Therkildsen et al. 2021). Song et al. 2021 concluded in their research that meat from pigs raised outdoors had better nutritional quality, with higher mineral contents compared to meat from pigs raised in a conventional system.

Studies with grape pomace in swine feed are scarce, and no studies have been found with the use of this residue conserved in the form of silage at the level of supplementation proposed, as well as associated with the production system. Therefore, the objective of the present study was to evaluate the effects of supplementation the diet of pigs with grape pomace preserved in silage form and its interaction with indoor and outdoor production systems, with and without access to vegetation, on the attributes of meat quality.

MATERIALS AND METHODS

Local description, grape pomace, and diets

The research was conducted in accordance with the provisions of Law 11,794 of October 8, 2008, with Decree 6,899 of July 15, 2009, as well as with the rules issued by the National Council of the Control of Animal Experimentation (CONCEA), and it was approved by the Ethics Committee on the Use of Animals of the Farroupilha Federal Institute (CEUA/IFFar), number 5418040518. The experiment was conducted at the Farroupilha Federal Institute, *Campus* São Vicente do Sul (IFFar-SVS), Brazil, located in the physiographic region denominated Central Depression of Rio Grande do Sul, coordinates 29º41'30 "S and 54º40'46" W, with an altitude of 129 m. The average temperature and relative humidity of the air during the experimental period were 12.45 ± 5.40 ºC and 81.26 ± 15.41%, respectively.

The grape pomace was obtained at a winery of Rural Cooperative São José, located in the city of Jaguari, approximately 30 km from the trial site, originating from red grapes (*Vitis vinifera* cv. Bordeaux), after a cold-pressing process and stored in plastic bags of approximately 40 kg (Sinuelo, Brazil) with dimensions of 51 cm x 110 cm and a thickness of 200 microns, called grape pomace silage (GPS). The bags were stored in a warehouse for about four months. At the time of inclusion of the GPS in the animal diet, the material was directed to the passage in the stainless steel mesh of 8 mm for unpacking and, thus, allowing a homogeneous mixture with the other ingredients of the diet. The diets were formulated using corn and soybean meal, and a premix with minerals, vitamins, and amino acids (Suipremium CT - Tortuga®), according to the requirements of the category reported by Rostagno et al. 2005, similar in protein, but with variation in the ether extract and carbohydrates contents due to the inclusion of GPS (Table I).

Table I. Ingredients, nutritional composition and fatty acid profile of growth and finishing diets.

	Diets			
	Growth		Finishing	
Ingredients (g/kg/DM)	Without	With	Without	With
Corn grain	724	550	804	630
Soybean meal	230	200	150	120
Premix (vitamins, minerals and amino acids)*	46	45	46	45
Grape pomace silage (GPS)	-	205	-	205
Nutritional composition (g/100g/DM)				
Moisture**	12.00	34.00	12.00	34.00
Ash	2.45	3.66	2.04	3.26
Crude Protein	16.10	16.10	13.30	13.30
Ether extract	2.68	3.33	2.82	3.47
Neutral Detergent Fiber corrected for ash and protein (NDFap)	11.95	19.99	11.69	19.65
Acid Detergent Fiber corrected for ash (ADFa)	4.58	12.93	4.12	12.48
Non-fiber Carboydrates	66.82	56.92	70.45	60.32
Phenolic compounds (mg/g GAE)	0.64	12.92	0.43	13.25
Anthocyanins (mg/g malvidine 3-glycoside)	-	38.34	-	38.37
Fatty acid profile (g/100g fatty acid methyl esters)				
C10:0	0.47	0.52	0.51	0.56
C12:0	1.02	0.95	1.12	1.05
C14:0	0.04	0.14	0.03	0.12
C16:0	17.54	16.62	17.47	16.55
C16:1n7	0.30	2.58	0.31	2.60
C18:0	3.24	3.37	3.16	3.29
C18:1n9	24.76	21.40	25.92	22.54
C18:2n6	45.01	42.95	44.26	42.20
C18:3n3	2.01	2.65	1.67	2.30
C20:0	0.49	0.50	0.53	0.54
C20:3n3	-	0.13	-	0.13
SFA	22.79	22.09	22.80	22.10
MUFA	25.06	23.98	26.23	25.14
PUFA	47.28	49.14	46.20	48.07
Σ n-6	45.27	48.56	44.54	47.84
Σ n-3	2.01	2.78	1.67	2.43

***Minerals (Mg, Mn, Fe, Cu, Zn, Se), Vitamins (A, B1, B2, B6, B12, D, K, Biotin (B3)), Amino Acids (Lysine, Methionine, Tryptophan, Histidine, Isoleucine, Leucine, Threonine, Valine, Arginin, Phenylalanine); **Natural basis; DM = dry matter; GAE = gallic acid equivalents; SFA (saturated fatty acids = C10:0; C12:0; C14:0; C16:0; C18:0; C20:0); MUFA (monounsaturated fatty acids = C16:1n7; C18:1n9); PUFA (polyunsaturated fatty acids = C18:2n6c; C18:3n6; C18:3n3; C20:3n3).**

The animals received growth ration up to 80 kg and finishing ration until slaughter.

Animals, management, and experimental design

48 animals (24 castrated males and 24 females) from the crossing of F1 matrices (50% Large White x 50% Landrace) were used with EMBRAPA MS115 breeder, with an average age of 89.5 ± 2.15 days and average body weight of 28.81 ± 5.92 kg, were randomly distributed in six treatments: SYSCON: animals confined with conventional ration, SYSCON + GPS: confined animals receiving conventional ration with 20% grape pomace silage, SYSOUT A: free animals in an area provided with vegetation with conventional ration, SYSOUT A + GPS: free animals in an area provided with vegetation receiving conventional ration with 20% grape pomace silage, SYSOUT B: free animals without vegetation with conventional feed, SYSOUT B + GPS: free animals without vegetation receiving conventional ration with 20% grape pomace silage. The animals in the confined system were maintained in concrete stalls with a water depth of 1.2 m^2 per animal, while in the free-range system the animals had an area of 800 m^2/animal, with 3 m^2/animal covered area for shelter and rest, with free access to food and drinking water.

A completely randomized design was used, with eight animals per treatment, totaling 48 experimental units. Pigs, after an adaptation period of 10 days, were weighed, this weight was considered as the initial weight and the final weighing with 84 days of experiment when they were conducted to a water diet for 12 hours and then slaughtered according to humane slaughter standards. The animals were slaughtered with an average weight of 100.84 ± 13.24 kg. At slaughter, portions of the *Longissimus thoracis* (LT) muscle were collected, vacuum packed in film with low oxygen permeability, and stored at -18 ºC for later analysis.

Chemical composition, fatty acid profile, phenolic compounds and anthocyanins of the diets

The chemical composition of the main ingredients of the diets was carried out according to AOAC 2005 for moisture, ash or mineral matter (MM), crude protein (CP), and ether extract (EE). The fibrous fraction was determined as neutral detergent fiber (NDF) and acid detergent fiber (ADF) according to Van Soest et al. 1991. NDF was obtained using thermostable α-amylase (Termamyl 120L, Novozymes Latin America LTDA) but without the addition of sodium sulfite, with a subsequent correction for ash and protein (NDFap) and ADF has been correted for ash (ADFa). The fraction of non-fibrous carbohydrates was obtained by difference, according to the equation: (NFC = 100 - (CP + EE + MM + NDFap)) (Table I).

The fatty acid profile, after extraction of the lipid fraction (Bligh & Dyer 1959) and respective esterification (Hartman & Lago 1973), was determined in a gas chromatography apparatus (Agilent model 6890N), equipped with a flame ionization detector (FID) with capillary column DB-23 attached (length of 60 meters, internal diameter 0.25 mm and film thickness 0.25 µm). Nitrogen was used as the carrier gas at a flow rate of 1 mL/min and a sample injection volume of 1 µL in 1/50 split mode, with an injection and detection temperature of 250 °C. Fatty acids were identified by comparing the retention period of previous determined methyl ester standards (Sigma: Supelco Mix 37) and the esterified samples.

The determination of phenolic compounds was performed by the method proposed by Zielinski & Kozłowska 2000, in a spectrophotometer model V-M5 (BEL

Engeneering®), using Folin-Ciocalteu reagent and gallic acid as standard. The results obtained were expressed as gallic acid equivalents in mg/100g of sample on a natural basis.

Anthocyanins were extracted according to Wu et al. 2004 and the purification of the content was performed according to Bochi et al. 2014 and Rodriguez-Saona et al. 2001. Anthocyanins were removed from the SPE with 0.35% methanol formic acid followed by evaporation of the solvent by rotary evaporator (10 min/38 ± 2 ° C). The contents were recovered with 2 ml of acidified ultrapure water (0.35% formic acid) and refrigerated in the absence of light. The determination of anthocyanin was performed on High Performance Liquid Cromatography (HPLC) (CBM-20A, LC-20AT, DGU-20A, model CTO-20A, Shimadzu, Columbia, MD, USA) with visible UV-28 detector (SPD-20AV, Shimadzu). The separation was carried out on a reverse phase C-18 Core-Shell Kinetex column (particle size of 2.6 µm, 100 mm, 4.6 mm, Phenomenex, Torrance, CA) at 38 °C using the chromatographic method described by Treptow et al. 2017. The elution and separation of the anthocyanins used acidified ultrapure water (3% formic acid) as mobile phase A and acetonitrile grade HPLC-UV as mobile phase B. The chromatograms analysis was performed with the aid of the LC solutions software (version 3, Shimadzu, Columbia, USA).

Proximal composition, fatty acid profile, and cholesterol of the meat

The moisture, ash, and protein determinations were performed according to AOAC 2005, in lyophilized samples (Terroni, LS3000B, BR) until constant pressure. The extraction and quantification of lipids were performed according to the technique proposed by Bligh & Dyer 1959 and the esterification and quantification of fatty acids according to Hartman & Lago 1973.

The fatty acid profile was determined in a Varian 3600 gas chromatograph (CA, USA) with flame ionization detector (GC-FID) and Varian 8100 automatic sampler (CA, USA). The injection volume was 1 µL in a split/splitless injector, operating in split mode, with a ratio of 20:1 to 250 °C. Hydrogen with a constant pressure of 35 psi was used as carrier gas. The column used was HP-88 (Agilent Technologies, USA) (100 m × 0.25 mm, 0.2 µm) with an initial temperature of 50 °C for 1 min, increasing to 185 °C at a rate of 15 °C min^{-1}, increasing again to 195 °C at a rate of 0.5 °C min^{-1} and, finally, to 230 °C at 15 °C min^{-1} remaining for 5 min. The detector was maintained at 250 °C. The identification was carried out by comparing the retention times of the FAME Mix 37 standards (P/N 47885-U, Supelco, USA). The results were expressed as a percentage of the total area of the chromatograms and considering the FID correction factors and conversion of ester to acid, according to Visentainer 2012. Cholesterol levels were determined using an enzymatic method with a laboratory kit (VIDA Biotecnologia®, Belo Horizonte, Minas Gerais, Brazil) according to the methodology proposed by Saldanha et al. 2004.

Lipid oxidation and color evaluation

After the unfreeze process at 4 ºC, samples of meat from the LT muscle remained refrigerated with evaluations performed at 0, 3, 6, 9, and 12 days. Oxidative stability was achieved by determining substances reactive to thiobarbituric acid (TBARS) according to the method described by Raharjo et al. 1992. The results were calculated from a standard curve of 1,1,3,3-tetraethoxypropane (TEP) (T9889, Sigma-Aldrich, St. Louis, USA), and expressed in milligrams of malondialdehyde (MDA) per kg of sample. The objective evaluation of muscle color was performed using a Minolta spectrophotometer (model CM-700d, Konica Minolta, Japan) with illuminant A, included

specular component (SCI) and 10º observer angle. For each repetition, eight evaluations were performed at different points, considering the values of luminosity (L*), redness (a*), and yellow (b*). The total color difference (ΔE) was calculated, which aims to assess the color change in relation to the difference between the initial and final storage times (AMSA 2012). The calculation of the total color difference was performed using the following equation:

$$\Delta E = [(L^* - L^*_0)^2 + (a^* - a^*_0) + (b^* - b^*_0)^2]^{1/2}$$

Where: L^*_0, a^*_0 e b^*_0 are the sample values on the first day of storage.

pH24h, water losses, shear force, texture profile, and sensory analyses

The pH_{24h} *postmortem* was measured in the LT muscle, in the left side of the carcass, at the height of the 12th rib, using a manual digital potentiometer (TESTO 205) equipped with a penetration probe thermometer. Samples of 2.5 cm thick from the LT muscle were evaluated. The samples were placed in polyethylene bags and frozen at -18 ºC until the analysis. The frozen samples were weighed and stored under refrigeration for 24 hours at 4 ºC during the unfreezing process. After 24 hours the samples were weighed, and the percentage of water loss was determined through the initial weight and final weight of the sample. To evaluate the loss of water in the cooking process, the muscle was weighed after thawing for 24 hours at 4 ºC and afterward, it was cooked on a grill until it reached an internal temperature of 71 ºC, as proposed by AMSA 2015 and quantified by weight difference between the unfrozen and cooked samples. From the cooked samples, the evaluation of shear force and texture profile was performed using a texturometer model TA. XT (Texture Analyzer TA. XT Plus, Stable MicroSystems®, United Kingdom). The shear force was performed by taking six samples in the longitudinal direction of the muscle fibers, with a diameter of 2.54 cm, using the Warner Bratzler Blade probe with a test speed of 3.30 mm/s and 30 mm. To determine the texture profile, the samples were cut into 1 cm³ cube and analyzed through the P36 probe, with a height of 36 mm, speed test of 5 mm/s, with double compression, with a speed pre-test of 1.5 mm/s and speed post-test of 10 mm/s. The attributes of hardness, elasticity, cohesiveness, chewability, and resilience were evaluated. The evaluation of sensory characteristics was performed through quantitative descriptive analysis (QDA) (Stone & Sidel 2004), with a panel of 15 members, trained according to the AMSA 2015 guidelines, in four sessions. For each session, 12 samples of the LT muscle were served to the panelists (two steaks per pig, two pigs per treatment, six treatments per session). After the removal of subcutaneous fat, the steaks were prepared to 71 ºC of internal temperature and cut into cubes of 2.5 cm³. The samples were served individually to each member, under red light to avoid visual differences. Water and salt-free biscuits were prepared for the panelists to consume to clean the taste of the different samples. The evaluated attributes were succulence (1 = extremely dry to 7 = extremely juicy), initial tenderness (1 = extremely hard to 7 = extremely soft), global tenderness (1 = extremely hard to 7 = extremely soft), flavor (odor + flavor) (1 = extremely weak to 7 = extremely intense), and off-flavor (0 + no off-flavor at 8 = extremely intense).

Statistical analysis

Data were analyzed as 3 × 2 factorial design using the general linear model procedure of RStudio® statistical program (R Core Team 2018), with ExpDes, MASS, lsmeans, multcompView packages. Animal was the experimental unit for all analysis. The model included fixed effects of

production systems (S), GPS-feed (F) treatment and the interaction between them (S*F). The random terms were pen and experimental error. The effect of the animal genre was studied, but since it did not significantly influence responses, it was excluded from the model. The residuals were checked for the assumptions of normality of the error distribution by the Shapiro-Wilk test ($p > 0.05$) and homogeneity of variances by the Bartlett test ($p > 0.05$). The variables with disagreement of the assumptions of normality and homogeneity were transformed by the methodology of Box & Cox 1964. When P values of were < 0.05, differences among the treatments were examined by one-way ANOVA using Tukey's test. Data were expressed as means ± SEM.

RESULTS AND DISCUSSION

Proximal composition, fatty acid profile, and cholesterol

The results showed no interaction effect between the production and feeding system and there were no significant differences in the proximal composition (Table II), fatty acid profile (Table III) and cholesterol levels (Table II) in the meat produced. Experiments with grape pomace in swine feed are scarce especially as silage. For comparative purposes, Trombetta et al. 2019 evaluated the use of GPS, at the levels of 3.5 and 7.0% on a dry basis, associated with flaxseed oil, obtaining results similar to this study according to the effects of grape pomace, in spite of the highest level employed. Thus, it can be observed that even the level of 20% of GPS in the pig diets based on corn and soybean meal does not change the proximal composition and the cholesterol content, as well as the fatty acid profile, of the meat produced.

Yan & Kim 2011 when adding 3% and 10% of fermented grape pomace to the feed of

Table II. Proximal composition, cholesterol, pH 24h, water loss, texture profile, and shear force of pig meat in different production systems supplemented with GPS.

	Treatments								
	System (S)			GPS-Feed (F)			p-value		
Parameters	SYSCON	SYSOUT A	SYSOUT B	Without	With	SEM	S	F	S*F
[1]Moisture	73.36	73.47	73.49	73.40	73.49	0.120	0.898	0.733	0.671
[1]Ashes	1.23	1.25	1.19	1.21	1.24	0.011	0.092	0.295	0.580
[1]Crude protein	23.13	23.12	22.87	23.00	23.09	0.110	0.566	0.722	0.518
[1]Lipids	1.70	1.69	1.87	1.79	1.71	0.041	0.129	0.323	0.097
[2]Cholesterol	58.90	54.93	53.03	56.25	54.99	1.17	0.110	0.579	0.181
ph_{24h}	5.53[b]	5.64[ab]	5.76[a]	5.63	5.66	0.03	0.014	0.636	0.172
[1]DL	8.57[b]	9.18[ab]	12.61[a]	9.50	10.74	0.669	0.027	0.314	0.650
[1]CL	25.70	26.50	25.55	26.13	25.71	0.584	0.789	0.732	0.697
[3]SF	25,79[a]	28,53[b]	25,49[a]	27,65	26,08	0.049	0.012	0.183	0.518
[3]Hardness	174.52	145.06	149.39	176.50[a]	136.15[b]	8.477	0.282	0.017	0.852
[1]Elasticity	0.58	0.57	0.55	0.59	0.56	0.006	0.943	0.569	0.125
Cohesiveness	0.54	0.56	0.54	0.54	0.55	0.004	0.194	0.236	0.204
Chewability	53.70	43.47	46.95	52.69[a]	43.39[b]	2.341	0.169	0.041	0.330
[1]Resilience	0.22	0.23	0.21	0.22	0.22	0.004	0.486	0.751	0.713

Means followed by different letters on the same line are statistically different ($p < 0.05$); SYSCON (confined animals); SYSOUT A (free-range animals); SYSOUT B (free animals without pasture); GPS-feed (conventional feed without or with GPS); SEM (standard error of mean); S*F (system x feed interaction); DL (drip loss); CL (cooking loss); [1]values expressed as a percentage; [2]values expressed in mg/100g of sample; SF (shear force); [3]value expressed in Newton (N).

confined pigs found alterations in the fatty acid profile in the subcutaneous fat specifically, not observing differences in the *Longissimus* muscle. Trombetta et al. 2019 when adding flaxseed oil and grape pomace silage to confined pigs, did not observe any alterations in the fatty acid profile concerning to grape pomace supplementation. The results can be explained by the relatively low participation of the grape pomace lipid fraction (6.13 x 0.20 = 1.23%) in the diets and by the relative similarity in the fatty acid profile in relation to the main ingredients (corn and soybean meal) used in experimental diets.

Lipid oxidation and color evaluation

The results showed linear behavior ($p < 0.05$) in the analysis of TBARS (Figure 1), where the values increased during storage in all

Table III. ***Longissimus thoracis*** **(LT) fatty acid profile of pigs in different production systems supplemented with GPS.**

[1]Fatty acids	Treatments						p-value		
	System (S)			GPS-feed (F)					
	SYSCON	SYSOUT A	SYSOUT B	Without	With	SEM	S	F	S*F
C10:0	0.06	0.07	0.08	0.08	0.07	0.011	0.149	0.640	0.137
C12:0	0.05	0.06	0.06	0.05	0.06	0.010	0.194	0.463	0.740
C14:0	1.03	1.05	1.03	1.04	1.05	0.055	0.487	0.764	0.938
C15:0	0.07	0.08	0.08	0.08	0.07	0.008	0.909	0.400	0.255
C16:0	27.10	27.24	27.64	27.17	27.42	0.181	0.320	0.473	0.111
C16:1n7	2.64	2.53	2.73	2.71	2.55	0.068	0.518	0.288	0.601
C17:0	0.24	0.24	0.20	0.22	0.23	0.011	0.135	0.665	0.347
C17:1n7	0.35	0.33	0.39	0.36	0.35	0.018	0.408	0.768	0.344
C18:0	13.64	13.27	13.23	13.25	13.74	0.184	0.601	0.584	0.474
C18:1n9c	42.97	42.21	43.23	42.66	42.15	0.568	0.253	0.661	0.707
C18:2n6c	7.72	7.56	7.75	7.76	7.53	0.160	0.731	0.487	0.314
C20:0	0.20	0.23	0.22	0.21	0.22	0.006	0.093	0.483	0.439
C18:3n6	0.07	0.08	0.08	0.08	0.07	0.007	0.803	0.427	0.464
C18:3n3	0.21	0.24	0.22	0.22	0.24	0.007	0.073	0.079	0.694
C20:1n9	0.75	0.76	0.72	0.74	0.73	0.019	0.413	0.884	0.909
C20:2n6	0.24	0.24	0.22	0.23	0.24	0.005	0.132	0.592	0.652
C20:3n6	0.21	0.21	0.20	0.21	0.21	0.007	0.829	0.781	0.122
C22:1n9	0.04	0.05	0.04	0.05	0.05	0.001	0.061	0.599	0.517
C20:4n6	1.15	1.10	1.11	1.14	1.10	0.041	0.867	0.563	0.145
C20:5n3	0.03	0.04	0.04	0.03	0.04	0.002	0.284	0.780	0.845
C24:1n9	0.29	0.26	0.25	0.29	0.25	0.011	0.215	0.081	0.710
C22:6n3	0.04	0.03	0.04	0.03	0.03	0.001	0.186	0.792	0.197
SFA	42.39	42.24	42.54	42.10	42.86	0.189	0.189	0.096	0.969
MUFA	47.04	46.14	47.36	46.81	46.08	0.412	0.463	0.682	0.936
PUFA	9.66	9.50	9.66	9.70	9.46	0.291	0.361	0.775	0.681
PUFA/SFA	0.23	0.22	0.23	0.23	0.22	0.004	0.180	0.582	0.323
Σ n-6	9.39	9.19	9.36	9.42	9.15	0.244	0.734	0.562	0.993
Σ n-3	0.28	0.31	0.30	0.28	0.31	0.006	0.820	0.371	0.644
Σ n-6/n-3	33.53	29.65	31.20	33.64	29.51	1.363	0.579	0.749	0.696

[1]values expressed as a percentage of the total area of the chromatograms; Values of p> 0.05 do not differ at the 5% level of significance. SYSCON (confined animals); SYSOUT A (free-range animals); SYSOUT B (free animals without pasture); GPS-Feed (conventional feed without or with GPS); SEM (standard error of mean); S*F (system x feed interaction). SFA (saturated fatty acids = C10:0; C14:0; C15:0; C16:0; C17:0; C18:0; C20:0); MUFA (monounsaturated fatty acids = C16:1n7; C17:1n7; C18:1n9; C20:1n9; C22:1n9; C24:1n9); PUFA (polyunsaturated fatty acids = C18:2n6c; C18:3n6; C18:3n3; C20:3n6; C20:5n3; C22:6n3).

treatments, showing lipid oxidation. However, the treatments with the inclusion of GPS showed the lowest TBARS values during storage, showing less lipid oxidation in meats. It was observed that during storage, the SYSOUT B treatment showed the highest TBARS values, indicating higher oxidation. Ahmad & Srivastava 2007 reported that TBARS values between 0.5 and 1.0 mg of MDA/kg of meat samples do not make it possible to identify the odor. Nevertheless, the authors reported that values between 1 and 2 mg of MDA/kg of sample stimulated the sensory detection of lipid oxidation. The TBARS values established during the nine days of evaluation were below 1 mg. However, after 12 days of storage, the values were approximately 1 and 1.8 mg of MDA/kg of sample, indicating the lipid oxidation, which could cause damage to the consumer health.

The inclusion of GPS was able to reduce lipid oxidation until the ninth day of cold storage, regardless of the production system, whose effects can be attributes to the compounds with the antioxidant activity present in the GPS as shown in Table I, the inclusion of GPS in diet of pigs provided increased in phenolic compounds (13 mg/g GAE) and anthocyanins (38 mg/g malvidine 3-glycoside).

Yan & Kim 2011 evaluated the supplementation of 3% and 10% fermented grape pomace in confined pigs and observed TBARS values of 0.049 mg MDA/kg in the control diet, 0.026 mg MDA/kg with 3% grape pomace and 0.09 mg MDA/kg with 10% grape pomace, with a reduction in lipid oxidation. The main phenolic compounds present in grape pomace are catechins, epicatechins, gallic acid, and other phenolic acids (Lafka et al. 2007). The results indicated that GPS is an important source of antioxidants with the potential for use in pig feed, constituting an alternative to increasing the meat shelf life.

The instrumental color analysis (Figure 2) indicated a decreasing linear behavior ($p < 0.05$) for the values of L* (luminosity) and a* (redness). It is possible to observe that, initially, the values of L* are lower for the groups fed with GPS and that the values of a* are higher in these groups, indicating a high intensity of the red color in these meats (AMSA 2012). According to the American Meat Science Association (AMSA 2001), L* values between 49 and 60 are related

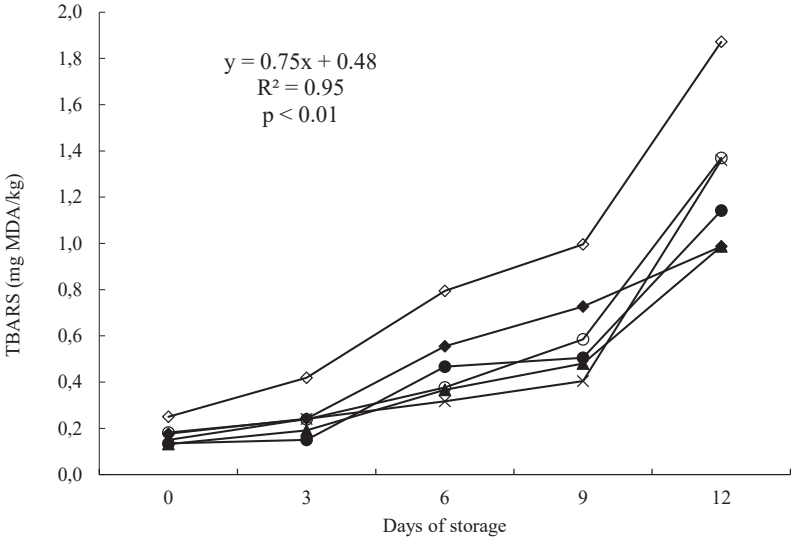

Figure 1. Oxidative stability of GPS-fed pig meat in different production systems during refrigerated storage: (○) SYSCON, (○) SYSCON + GPS, (◆) SYSOUT A, (×) SYSOUT A + GPS, (◊) SYSOUT B, (○) SYSOUT B + GPS.

to the quality standards of pigs, demonstrating that the meat was conforming to the standards considered normal for the species.

The higher intensity of the red color in the groups fed with GPS may be due to the phenolic compounds in the diets with grape pomace, preventing the myoglobin oxidation. Yan & Kim 2011 and Bertol et al. 2017 also observed an increase in the redness of pigs meat fed with grape pomace extract and dehydrated grape residue, respectively. Increasing linear behavior ($p < 0.05$) is observed for the values of b* (yellow). The treatments SYSCON and SYSOUT B indicated a higher content of b* during storage. The higher b* value in meat indicates the formation of metmyoglobin (AMSA 2012). According to Rodríguez et al. 2007 the reduction in the red color is associated with the oxidation rate of oxymyoglobin to metmyoglobin. The color difference (ΔE), calculated in relation to the zero-day of cold storage (Figure 2 (d)) showed an increasing linear behavior ($p < 0.05$), representing a global change in color over time. According to Heck et al. 2019, ΔE values above 2 are noticeable by consumers. The animals fed with GPS showed a lower value of ΔE up to the sixth day of storage. At nine and 12 days, the treatments SYSCON and SYSOUT B demonstrated the highest values compared to the other treatments, probably since the animals did not consume GPS. At 12 days, all values exceeded the limit, with the discoloration noticeable to human vision. Substances such as anthocyanins and phenolic acids increase resistance to oxidizing agents and improve color stability (Pieszka et al. 2017), confirmed by this

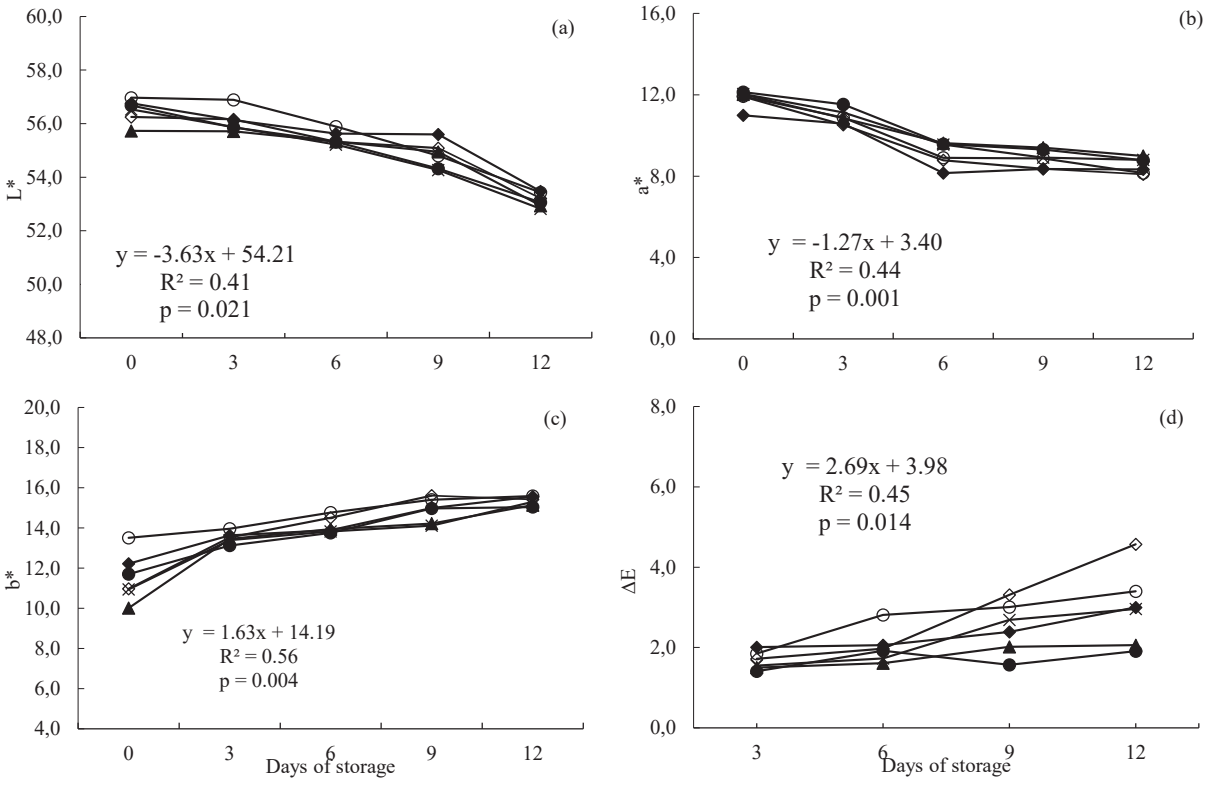

Figure 2. Effect of inclusion of grape pomace (GPS) and the production system on the parameters of L* (a), a* (b), b* (c), and ΔE (d) in pigs during refrigerated storage: (○) SYSCON, (○) SYSCON + GPS, (◆) SYSOUT A, (×) SYSOUT A + GPS, (◊) SYSOUT B, (○) SYSOUT B + GPS.

study, where the phenolic compounds present in GPS provided beneficial effects on the color and oxidative stabilities of pig meat.

pH_{24h}, water loss, shear force, texture profile, and sensory analyses

There was no interaction between the production system and feeding in the evaluated attributes. However, there was an effect of the production system on the percentage of water loss during thawing, which was higher in the SYSOUT B treatment (free range animals). Differences in the water loss on thawing may be related to different parameters affected by the production system, such as, the pH_{24h} value (Gandemer et al. 1990, López & Carballo 1991), confirmed by this study in which the final pH value was also higher in the SYSOUT B treatment. Other authors have also connected the pH_{24h} value with water loss (Monin 1991, Santos-Silva & Portugal 2001). The cooking losses did not show significant differences. Similar results were noticed by Tejerina et al. 2012, in which it was evaluated the water retention and loss capacity in pigs in different production systems.

According to the shear force test, there was a significant difference for the production system, with the highest average in the SYSOUT A treatment. The SYSCON and SYSOUT B treatments showed no differences (Table II). Enfält et al. 1997 observed that the shear force was higher in the meat of pigs raised in free-range. Tejerina et al. 2012 also observed higher shear force in animals raised in free-range, corroborating with this study. For the analysis of the texture profile (Table II), the attributes of hardness and chewability showed a significant difference in the diet, when the animals fed with GPS showed lower values, characterizing a soft meat. This result is confirmed by the sensory analysis since the members considered higher tenderness for this meat. There was no effect of the production system for the attributes evaluated in the texture profile, nor interaction. Lopez-Bote et al. 2008 also indicated no differences in texture attributes in pigs submitted to exercise and confinement. Sensory analysis (Table IV) showed no interaction between production system and feeding, but revealed a significant effect on feeding for the attribute initial tenderness and overall tenderness when the animals fed with GPS showed higher values. Results confirmed by the analysis of the texture profile since the less hard and chewable meat was considered tender by the sensory evaluation. The other attributes did not present effects of production,

Table IV. Sensory analysis of pig meat in different production systems supplemented with GPS.

Attributes	Treatments						p-value		
	System (S)			GPS-feed (F)					
	SYSCON	SYSOUT A	SYSOUT B	Without	With	SEM	S	F	S*F
Juiciness	4.17	3.97	4.37	3.98	4.36	0.130	0.460	0.151	0.487
Initial tenderness	5.25	4.83	5.17	4.89[b]	5.28[a]	0.108	0.196	0.005	0.063
Global ternderness	5.0	4.90	4.80	4.67[b]	5.14[a]	0.110	0.742	0.031	0.069
Meat *flavor*	3.87	3.77	3.97	3.80	3.94	0.124	0.812	0.599	0.409
Off-flavor	0.64	0.60	0.80	0.69	0.67	0.122	0.782	0.929	0.562

Means followed by different letters on the same line are statistically different (p <0.05); SYSCON (confined animals); SYSOUT A (free-range animals); SYSOUT B (free animals without pasture); GPS-Feed (conventional feed without or with GPS); SEM (standard error of mean); S*F (system x feed interaction).

feeding, and interaction system. Trombetta et al. 2019 when adding GPS to the pig feed, did not detect significant differences in the sensory attributes, possibly due to the reduced level of supplementation (3.5 and 7.0%).

CONCLUSIONS

The grape pomace conserved as silage when used for growing-finishing swine diet, does not alter the proximal composition, cholesterol content, fatty acid profile, juiciness, and flavor of meat. Additionally, it promotes improvement in pork quality, such as greater objective and subjective tenderness, higher red color intensity, and retarded the lipid oxidation, regardless of the production system, constituting a sustainable alternative for a waste that needs to be reused.

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