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Carcass characteristics and pork quality of pigs fed diets containing crude glycerin and ractopamine

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Abstract

An experiment was conducted to evaluate the effects of increasing concentrations of crude glycerin, with or without ractopamine, in the diet of finishing barrows on carcass characteristics and pork quality. The experimental design was a randomized complete block, in a 4 x 2 factorial scheme, with four concentrations of crude glycerin (0, 100, 150, or 200 g/kg) and two concentrations of ractopamine (0 or 10 mg/kg). There was no interaction between the crude glycerin concentrations and the ractopamine use as well as there was no isolated effect of the dietary crude glycerin concentration for all the evaluated traits. However, the dietary ractopamine increased the hot (p = 0.021) and cold (p=0.020) carcass weight, the hot carcass yield (p = 0.038), the shear force (p = < 0.0001), lightness (L* index) (p = 0.043), hue angle (h*) (p = 0.026), and C16:1 (p = 0.023) concentration in the loin. Moreover, the dietary ractopamine decreased the red content (a* value) (p = 0.043), the activity of C16-C18 elongase (p = 0.037) and the C18:0 (p = 0.021) concentration in the loin. The inclusion of up to 200 g/kg crude glycerin in the diet of finishing pigs may be used as a partial substitute for dietary corn, combined or not with 10 mg/kg ractopamine, without impair the evaluated carcass characteristics and the quality of the loin.

Keywords: ß-adrenergic agonist, biodiesel, coproduct, fatty acid profile, nutrition, swine.

Practical Application: The inclusion of crude glycerin with ractopamine on swine production does not compromise the meat quality.

1 Introduction

The main energy source in pig diets is corn. However, in addition to its use in human and animal diets, corn is used in various industrial processes, this contributes to an increase in its price, especially in times of lesser production. It is also important to emphasize that corn prices oscillate greatly in the national and international markets because it is a commodity. Thus, alternative sources of energy are pursued in animal diets to achieve optimal meat production.

Brazil is one of the largest producers and consumers of biodiesel in the world, and crude glycerin is a byproduct of biodiesel production. As the production of this biofuel has been increasing in recent years, the supply of crude glycerin in the market has also increased. In 2018, 5.3 billion liters of biodiesel and, consequently, 530 million liters of crude glycerin were produced in Brazil (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, 2019). However, the supply of glycerin has exceeded its demand, mainly from the chemical, pharmaceutical and food industries, and therefore, finding new alternatives for its use (Egea et al., 2016). Considering the high glycerol content in crude glycerin, -usually between 80 and 95%-, and its high energy value similar to corn, it has been considered as an alternative energy source in pig diets for swine production (Hanczakowska et al., 2010; Faria et al., 2015).

Addition of ractopamine in pig diets reduces the body fat content and increases the meat deposition in the carcass (Araújo et al, 2014). This makes the meat production more competitive as consumers demand high-quality, and healthy food. Individual usage of crude glycerin (Egea et al., 2016), or ractopamine (Rickard et al., 2017) in the pig diet at the finishing period leads to improvements in carcass and meat quality. However, it is necessary to assess the effects of combined usage in pig diets at the finishing period. This is the knowledge gap that we want to cover regarding the usage of glycerol, from dietary glycerin, and its metabolic potential for the triacylglycerols synthesis (Lee et al., 2001; Montell et al., 2002). We hypothesized that glycerol impacts directly on the fat deposition in the carcass and meat, while the ractopamine can modulate the lipid metabolism decreasing the lipogenesis in pigs (Ferreira et al., 2013). Thus, dietary glycerin could favor lipid deposition while ractopamine would modulate it without affecting the carcass characteristics and meat quality traits. Therefore, the objective of this study was to evaluate carcass characteristics, pork quality, and fatty acid

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profile of the loin of pigs fed with combined diets using crude glycerin and ractopamine at the finishing period.

2 Material and methods

2.1 Animals, experimental design, diet and feeding

The experiment was carried out at the Experimental Swine Center of the Animal Science Department of the Federal University of Lavras (UFLA). All experimental procedures used in this study were approved by the Ethics Committee on Animal Use of UFLA under protocol n.040/15.

Sixty-four barrows of genetic line Agroceres PIC 337 X Camborough 25, with initial average weights of 77.2 ± 6.0 kg, were used. The animals were distributed in a randomized complete block design, in factorial scheme 4 x 2, corresponding to four concentrations of crude glycerin inclusion (0, 100, 150, or 200 g/kg) in diets without or with ractopamine (10 mg/kg). Therefore, eight treatments were evaluated, each with eight replicates of one pig (experimental unit). The criterion used for the formation of the blocks was the initial weight of the animals. The animals were individually housed in pens with concrete floors (2.3 x 1.5 m), with a semi-automatic feeder and nipple drinker. The minimum temperature of the barn during the experimental period was 19.5 °C, the maximum was 29.1 °C, and the average temperature was 24.3 °C.

The crude glycerin evaluated in this study was derived from the production of biodiesel made using soybean oil and animal fat (60% and 40%, respectively) as raw materials. Its chemical composition was determined in the laboratory (Table 1), and the composition was considered in the formulation of the experimental diets (Table 2).

Experimental diets were formulated with corn and soybean meal and supplemented with minerals, vitamins, and amino acids to the nutritional requirements recommended by Rostagno et al. (2011) for barrows of high genetic potential and weighing from 70 to 100 kg. All diets were isonutritive and isocaloric. Crude glycerin was included as substitution for corn, considering its metabolizable energy value of 3,475 kcal/kg (Melo et al., 2014). The ractopamine was added to the mix in substitution to kaolin. The Concentration used was 0.5 g/kg in the form of ractopamine hydrochloride (Ractosuin®, Ouro-Fino Saúde Animal, São Paulo, Brazil). The experimental period lasted 28 days and the pigs received water and diet *ad libitum*.

2.2 Carcass characteristics

At the end of the experimental period, the pigs were fasted for eight hours. Subsequently, they were sent to a slaughterhouse where they were desensitized by electronarcosis and slaughtered according to current Brazilian legislation.

After bleeding and evisceration, the carcasses were weighed to determine the hot carcass weight. After cooling for 24 h, the following variables were evaluated: cold carcass weight, carcass length, fat area, loin eye area, backfat thickness and loin depth, at the position of the last rib, according to Bridi & Silva (2009). The hot and cold carcass yields were estimated based in the equation: % Carcass yield = (Carcass weight x 100)/Live weight.

Table 1. Chemical composition of crude glycerin[1] (as-fed basis).

Characteristics	*Analyzed composition*[2]
Moisture and volatiles (g/kg)	132.9
Glycerol (g/kg)	803.0
Crude protein (g/kg)	0.35
Sodium (g/kg)	19.7
Potassium (g/kg)	0.5
Ash (g/kg)	52.4
Methanol (g/kg)	*12.0*
pH	*7.0*

[1]Crude glycerin (CG) obtained from soybean oil and animal fat; [2]Chemical analyses were performed by the CBO Analysis Laboratory (Campinas, São Paulo, Brazil).

Table 2. Ingredients and chemical composition of the experimental diets (as-fed basis).

	Crude glycerin concentration in the diet			
Item	0 g/kg	100 g/kg	150 g/kg	200 g/kg
Ingredients (g/kg)				
Corn	763.0	654.5	599.0	541.5
Crude glycerin	0.0	100.0	150.0	200.0
Soybean meal, 45%	191.5	210.6	220.4	230.7
Soybean oil	14.0	9.1	7.0	5.6
Dicalcium phosphate	8.5	8.5	8.6	8.7
Limestone	5.8	5.7	5.7	5.6
Sodium chloride	9.8	4.9	2.5	0.0
Vitamin-mineral supplement[1]	2.0	2.0	2.0	2.0
L-Lysine HCl, 99%	2.5	2.2	2.0	1.8
DL-Methionine, 99%	0.3	0.4	0.5	0.5
L-Threonine	0.5	0.5	0.5	0.5
Kaolin[2]	2.1	1.6	1.8	3.0
Calculated nutritional composition (g/kg)				
Glycerin	*0.0*	*100.0*	*150.0*	*200.0*
Glycerol[3]	*0.0*	*80.3*	*120.5*	*160.6*
Crude protein (N x 6,25)	*150*	*150*	*150*	*150*
Metabolizable energy (MJ/kg)	*13.8*	*13.8*	*13.8*	*13.8*
Calcium	*5.0*	*5.0*	*5.0*	*5.0*
Available phosphorus	*2.4*	*2.4*	*2.4*	*2.4*
Sodium	*4.1*	*4.1*	*4.1*	*4.1*
Methionine + cystine	*4.8*	*4.8*	*4.8*	*4.8*
Digestible lysine	*8.3*	*8.3*	*8.3*	*8.3*
Digestible threonine	*5.6*	*5.6*	*5.6*	*5.6*

[1]Qualitec S. Acabamento® (Trouw Nutrition, São Paulo, Brasil). Composition (per kg): vitamin A, 2500000 IU; vitamin B1, 250 mg; vitamin B12, 5,000 mcg; vitamin B2, 1200 mg; vitamin B6, 400 mg; vitamin D3, 300,000 IU; vitamin E, 4,000 IU; vitamin K3, 500 mg; biotin, 5 mg; choline, 32.5 g; niacin, 7,500 mg; pantothenic acid, 3600 mg; cobalt, 100 mg; copper, 22.5 g; iron, 40 g; iodine, 100 mg; manganese, 21 g; selenium, 75 mg; zinc, 40 g; lysine, 113.1 g; *Bacillus subtillis* 75 x 10^9 UFC; [2]Kaolin is an inert ingredient. For the experimental diets, the ractopamine was added in substitution to kaolin in the inclusion level of 0.5 g/kg. Ractopamine hydrochloride 2% (Ouro-fino Saúde Animal, Cravinhos, Brasil) was used; [3]Estimated according to the glycerin concentration in the diet and the glycerol content determined in glycerin (803 g/kg; Table 1).

2.3 Physical and chemical traits

PH and temperature were measured in the *Longissimus thoracis* portion, i.e. the last rib, using a pH meter (Hanna Instruments® HI 99163, Romania). The initial pH and temperature

were measured 45 min after slaughter, while the final pH and temperature were measured 24 h after slaughter.

Color evaluation was measured at 24 h *post mortem*, using a colorimeter (Konica Minolta® CM-700, Singapore), with a CIELAB system, and D65 illuminant, at an observer angle of 10º, MAV (11 mm) and Specular Component Excluded (SCE) to obtain the indexes lightness (L*), redness (a*) and yellowness (b*). Saturation (C*) and hue angle (h*) were calculated using equations proposed by Ramos & Gomide (2012) in which C* = (a* 2 + b* 2) 1/2 and h* = tan-1 (b*/a*).

Cooking loss was evaluated according to the technique described by Bridi & Silva (2009). Meat samples were wrapped in aluminum foil and broiled on a preheated electric grill of 170ºC (Mega Grill; Britânia, Curitiba, PR, Brazil), to an internal temperature of 72 °C. Drip loss determination was performed using the suspension technique described in Ramos & Gomide (2012) with a 48-hour duration at 5 ºC. Results were reported as a percentage of the initial weight. Shear force determination was performed in samples with a cross-section of 1.0 cm × 1.0 cm using a Warner Bratzler probe coupled to a texturometer (Extralab, model TA.XT plus, Jarinu, SP, Brazil), gauged to cut at the speed of 2 mm/s, and the SF results were expressed by Newtons (N).

Loin samples were also used to determine the centesimal composition (moisture, crude protein, ether extract and ash) and were evaluated, respectively, according to the methods 950.46, 991.36, 726.08, and 923.03 respectively of the Association of Official Analytical Chemists (Latimer, 2016).

2.4 Lipid profile

The fatty acids profile in the loin was performed by the extraction method described by Folch et al. (1957) and esterification as described by Hartman & Lago (1973). The extracts were submitted to gas chromatography on a Shimatzu CG 2010 chromatograph (Agilent Technologies Inc., Palo Alto, CA, USA), equipped with an AOC 20 I split injector in a ratio of 1:100 split, and capillary column Supelco SPTM-2560, 100 m X 0.25 mm X 0.20 μm (Supelco Inc., Bellefonte, PA, USA). The chromatographic conditions were as follows: initial column temperature of 140º C/5 min, elevation from 4 ºC/min to 240 ºC and maintenance for 30 min, for a total of 60 min. The temperatures of the injector and the sampler were maintained at 260 °C. The carrier gas used was helium. The linear velocity was 28 cm/sec, and the column flow was 2 ml/min.

Fatty acids were identified by comparison with the retention times presented by the chromatography standard Supelco™ 37 standard FAME Mix 47885-U (Supelco Inc., Bellefonte, PA, USA) and expressed as a percentage of total identified fatty acids. Later, fatty acids were grouped as total saturated fatty acids (SFA), total monounsaturated fatty acids (MUFA), total polyunsaturated fatty acids (PUFA), total omega 6 and omega 3 fatty acids, and their ratios.

The rates of atherogenicity and thrombogenicity, considered health indicators related to the risk of cardiovascular disease, were calculated according to Ulbricht & Southgate (1991) using the following equations: the atherogenicity index = [4 (C14:0) + C16:0] / (ΣMUFA + ΣPUFA), and the thrombogenicity index = (C14:0 + C16:0 + C18:0) / [(0.5 x ΣMUFA) + (0.5 x Σω-6) + (3 x Σω-3) + (Σω-3 / ω-6)]. The activity indexes of the Δ9-desaturase, elongase, and thioesterase enzymes were estimated according to Malau-Aduli et al. (1997). The cholesterol content in the loin was determined colorimetrically according to the method of Bohac & Rhee (1988).

2.5 Statistical analysis

All variables measured were tested for normality by the Shapiro–Wilk test before analysis, and any variable that failed to follow a normal distribution was transformed through the RANK procedure of SAS (SAS Inst. Inc., Cary, NC). The PROC RANK statement with the NORMAL option was used to produce a normalized transformed variable. All data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC, USA) as a randomized complete block design (initial weight of the pigs) in a factorial scheme with inclusion of crude glycerin (0, 100, 150 or 200 g/kg), inclusion or not of ractopamine (0 or 10 mg/kg) and interaction effect between glycerin level and ractopamine inclusion. Each pig was considered an experimental unit. Initial analyses found no significant interactions, and consequently these were deleted from the model. The effect of ractopamine inclusion was determined using an F test. Non-significant effects were found for the glycerin levels, and no regression analysis was performed. Results include least squares means, and the greatest standard errors (SEM). Significant differences were reported considering $\alpha = 0.05$.

3 Results

There was no interaction ($p > 0.05$) between ractopamine and crude glycerin nor an isolated effect ($p > 0.05$) of the crude glycerin concentrations in the diet for all carcass characteristics evaluated (Table 3). The dietary ractopamine increased ($p < 0.05$) the hot carcass weight, hot carcass yield, and cold carcass weight but did not affect ($p > 0.05$) cold carcass yield, carcass length, fat area, loin depth, and backfat thickness.

No significant interaction ($p > 0.05$) between dietary ractopamine and glycerin was observed. Isolated effects ($p > 0.05$) of crude glycerin concentrations on all pork quality traits (pH, Temperature, Color, Cooking/Drip Loss, Shear Force, Centesimal composition and Cholesterol) of the loin (Table 4) were not significant either. The use of ractopamine increased ($p < 0.05$) the shear force, the indexes L* (lightness) and h* (hue angle), and decreased ($p < 0.05$) the value of a* (red content) in the loin.

No significant interaction ($p > 0.05$) between ractopamine and glycerin was computed. There was no effect of crude glycerin ($p > 0.05$) on the loin fatty acid profile and other traits of the lipid composition (Table 5). The dietary ractopamine increased ($p < 0.05$) the C16:1 concentration and decreased ($p < 0.05$) the C18:0 concentration and the activity estimate of the elongase$^{C16\text{-}C18}$ in the loin. There were no differences ($p > 0.05$) among the dietary treatments for the atherogenicity and thrombogenicity rates.

Table 3. Carcass characteristics of finishing pigs fed diets formulated with different crude glycerin concentrations, without or with addition of ractopamine.

Characteristics	Ractopamine (mg/kg)		Crude glycerin (g/kg)				SEM	p-value[1]	
	0	10	0	100	150	200		RAC	CG
Hot carcass weight (kg)	81.2[b]	83.2[a]	82.0	82.8	82.2	81.8	2.35	0.021	0.831
Hot carcass yield (%)	78.7[b]	79.6[a]	78.9	78.9	79.3	79.5	0.51	0.038	0.720
Cold carcass weight (kg)	79.0[b]	80.9[a]	79.9	80.4	79.9	79.7	2.35	0.020	0.918
Cold carcass yield (%)	76.6	77.4	76.8	76.6	77.0	77.5	0.55	0.061	0.774
Carcass length (cm)	95.3	94.4	95.8	94.1	94.4	95.2	0.76	0.222	0.375
Loin eye area (cm^2)	51.8	52.5	52.7	52.3	51.8	51.9	1.15	0.425	0.869
Backfat thickness (mm)	13.9	13.1	13.6	13.6	13.2	13.5	0.70	0.228	0.987
Loin depth (mm)	73.6	73.5	74.7	75.1	72.2	72.2	1.23	0.935	0.198
Fat area (cm^2)	17.5	17.1	17.1	18.6	16.5	17.2	0.95	0.674	0.462

SEM, mean standard error; RAC, ractopamine; CG, crude glycerin. [a-b]Means followed by different lowercase letters in the same row differ from each other at a 5% significance level; [1]For all evaluated characteristics, there was no interaction ($p > 0.05$) between crude glycerin and ractopamine in the diet.

Table 4. Quality traits, color, and centesimal composition of the loin (*Longissimus lumborum*) of finishing pigs fed diets formulated with different crude glycerin concentrations, without or with addition of ractopamine.

Traits	Ractopamine (mg/kg)		Crude glycerin (g/kg)				SEM	p-value[1]	
	0	10	0	100	150	200		RAC	CG
pH 45 min	6.2	6.2	6.1	6.2	6.2	6.2	0.06	0.944	0.462
pH 24 h	5.7	5.6	5.8	5.5	5.7	5.7	0.12	0.471	0.054
Temperature 45 min (°C)	33.6	32.8	33.8	33.6	32.9	32.4	0.82	0.113	0.353
Temperature 24 h (°C)	5.8	6.2	5.9	6.1	6.0	5.9	0.56	0.338	0.995
Cooking loss (%)	33.4	33.1	34.4	32.5	32.9	33.2	0.96	0.745	0.517
Drip loss 24 h (%)	4.6	4.8	4.5	4.7	5.0	4.5	0.40	0.849	0.840
Drip loss 48 h (%)	6.0	6.1	6.1	5.8	6.4	5.8	0.40	0.688	0.765
Shear force (N)	47.0[b]	58.8[a]	55.9	51.9	48.0	56.8	2.84	<0.0001	0.120
Lightness - L*	57.2[b]	58.0[a]	57.2	57.7	57.6	57.9	0.41	0.043	0.683
Redness - a*	0.7[a]	0.4[b]	0.7	0.7	0.5	0.3	0.16	0.043	0.142
Yellowness - b*	11.5	11.2	11.5	11.4	11.3	11.0	0.18	0.125	0.234
Saturation index - C*	11.5	11.2	11.6	11.4	11.4	11.1	0.13	0.106	0.221
Hue angle - h*	86.3[b]	88.2[a]	86.0	86.5	87.5	88.9	0.58	0.026	0.085
Moisture (%)	73.2	73.1	73.1	73.2	73.2	73.0	0.46	0.787	0.992
Ether extract (%)	1.6	2.0	1.8	1.6	2.0	1.8	0.20	0.109	0.339
Crude protein (%)	24.0	23.5	23.4	23.6	23.9	24.2	0.40	0.218	0.486
Ash (%)	1.3	1.3	1.3	1.3	1.3	1.3	0.03	0.385	0.726
Cholesterol (mg/100 g)	93.1	91.1	90.3	90.6	96.1	91.5	5.59	0.914	0.851

SEM, mean standard error; RAC, ractopamine; CG, crude glycerin. [a-b]Means followed by different lowercase letters in the same row differ from each other at a 5% significance level; [1]For all evaluated traits, there was no interaction ($p > 0.05$) between crude glycerin and ractopamine in the diet.

4 Discussion

Our results regarding the carcass characteristics are in accordance to those reported by other authors (Mendoza et al., 2010; Egea et al., 2016) for backfat thickness, since the energy value of glycerin is similar to that of corn (Melo et al., 2014).

The increases in hot and cold carcass weight corroborated the results found by Silva et al. (2013), and the increase in the hot carcass yield in this study agrees with those observed by Rickard et al. (2017) in pigs fed diets containing ractopamine. Ractopamine can increase the proportion of nutrients deposited in the carcass relative to that deposited in organs or non-carcass components (Mills, 2002), as no significant differences were observed in else carcass characteristics (loin eye area, backfat, thickness, loin depth, and fat area).

The addition of ractopamine to the diet did not alter the pH or temperature of the pork, as found in another study (Amin et al., 2015). The dietary crude glycerin also did not alter the pH of the pork, as shown in the research of Egea et al. (2016) with the use of glycerin at up to 10 mg/kg of diet. Moreover, the results obtained for pork loin quality corroborate the reports of Melo et al. (2014), who concluded that the dietary glycerin did not promote changes in the traits of lightness, redness, yellowness, color saturation index, hue angle, pH at 45 min, pH at 24 h, cooking loss, and shear force.

Table 5. Fatty acids profile in the loin (*Longissimus lumborum*) of finishing pigs fed diets formulated with different crude glycerin concentrations, without or with addition of ractopamine.

Fatty acids (%)	Ractopamine (mg/kg)		Crude glycerin (g/kg)				SEM	p-value[1]	
	0	10	0	100	150	200		RAC	CG
C10:0	0.09	0.10	0.10	0.09	0.09	0.10	0.003	0.316	0.978
C12:0	0.09	0.10	0.10	0.10	0.10	0.10	0.002	0.536	0.458
C14:0	1.16	1.19	1.21	1.17	1.17	1.17	0.012	0.261	0.554
C14:1	0.02	0.03	0.03	0.02	0.02	0.02	0.001	0.323	0.059
C15:0	0.09	0.10	0.10	0.10	0.09	0.10	0.003	0.609	0.369
C16:0	24.92	25.22	25.37	24.98	25.13	24.83	0.120	0.242	0.409
C16:1	3.21[b]	3.46[a]	3.35	3.27	3.43	3.28	0.053	0.023	0.757
C17:0	0.43	0.42	0.38	0.44	0.45	0.44	0.012	0.622	0.137
C17:1	0.83	0.86	0.79	0.86	0.85	0.90	0.025	0.585	0.530
C18:0	11.49[a]	11.07[b]	11.22	11.35	11.30	11.25	0.083	0.021	0.916
C18:1ω9t	0.15	0.15	0.13	0.15	0.16	0.15	0.004	0.667	0.068
C18:1ω9c	44.07	43.73	43.20	43.30	44.67	44.43	0.312	0.453	0.337
C18:2ω6c	9.36	9.41	9.92	9.87	8.80	8.95	0.246	0.828	0.286
C20:0	0.16	0.17	0.16	0.16	0.18	0.15	0.003	0.240	0.085
C18:3ω6	0.08	0.07	0.07	0.08	0.08	0.08	0.003	0.719	0.343
C20:1	0.76	0.78	0.75	0.73	0.79	0.80	0.014	0.690	0.200
C18:3ω3	0.01	0.01	0.01	0.01	0.02	0.01	0.007	0.977	0.243
C21:0	0.04	0.05	0.04	0.04	0.04	0.06	0.004	0.334	0.355
C20:2	0.27	0.26	0.28	0.26	0.25	0.26	0.005	0.812	0.258
C20:3ω6	0.29	0.28	0.28	0.31	0.26	0.30	0.010	0.763	0.455
C20:3ω3	0.04	0.04	0.04	0.04	0.04	0.03	0.003	0.710	0.645
C20:4ω6	2.15	2.06	2.08	2.25	1.96	2.12	0.077	0.691	0.733
C20:5ω3	0.05	0.05	0.05	0.05	0.05	0.04	0.002	0.896	0.692
C22:6ω3	0.05	0.05	0.05	0.06	0.05	0.04	0.002	0.771	0.078
SFA[2]	38.32	38.15	38.48	38.22	38.38	37.86	0.161	0.628	0.556
MUFA[3]	48.80	48.72	48.01	48.12	49.48	49.42	0.321	0.759	0.292
PUFA[4]	12.50	12.39	12.98	13.02	11.73	12.07	0.326	0.973	0.505
∑ω3[5]	0.41	0.40	0.43	0.41	0.40	0.38	0.009	0.812	0.254
∑ω6[6]	11.88	11.76	12.34	12.37	11.10	11.45	0.315	0.956	0.490
∑ω6/∑ω3[7]	28.55	28.96	29.11	29.37	27.05	29.49	0.484	0.670	0.394
PUFA/SFA[8]	0.32	0.33	0.34	0.33	0.30	0.32	0.009	0.604	0.516
[9]Δ9-desaturase^{C16}	0.11	0.12	0.12	0.12	0.12	0.12	0.002	0.098	0.911
[10]Δ9-desaturase^{C18}	0.79	0.80	0.80	0.79	0.80	0.80	0.002	0.340	0.707
[11]Elongase$^{C16\text{-}C18}$	0.66[a]	0.65[b]	0.65	0.66	0.66	0.66	0.001	0.037	0.060
[12]Thioesterase$^{C16\text{-}14}$	0.96	0.98	0.95	0.96	0.96	0.90	0.018	0.980	0.828
Atherogenicity	0.58	0.57	0.55	0.58	0.60	0.59	0.012	0.796	0.715
Thrombogenicity	8.64	8.59	8.99	8.93	8.20	8.34	0.189	0.970	0.399

SEM, mean standard error; RAC, ractopamine; CG, crude glycerin. [a-b]Means followed by different lowercase letters in the same row differ from each other at a 5% significance level; [1]For all evaluated traits, there was no interaction ($p > 0.05$) between crude glycerin concentration and ractopamine in the diet; [2]Sum of the saturated fatty acids (SFA) (C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0); [3]Sum of the monounsaturated fatty acids (MUFA) (C14:1 cis-9+C16:1 cis-9+ C17:1 cis-9+C18:1 cis-9+C20:1 cis-9 + C22:1 cis-9); [4]Sum of the polyunsaturated fatty acids (PUFA) (C18:2ω-6 + C18:3ω-6 + C18:3ω-3 + C20:4ω-6 + C20:3ω6 + C20:3ω3 + C20:5ω3 + C22:6ω-3). [5]Sum of the n-3 series PUFA (C18:3ω-3 + C20:3ω3 + C20:5ω3 + C22:6ω-3); [6]Sum of the n-6 series PUFA (C18:2ω-6 + C18:3ω-6 + C20:4ω-6 + C20:3ω6); [7]Ratio ω-6/ω-3 (Σω-6/Σω-3); [8]Ratio PUFA/SFA (SumPUFA / SumSFA); [9]Desaturase activity index C16 = 100 [(C16:1 cis-9)/(C16:1 cis-9 + C16:0)]; [10]Desaturase activity index C18 = 100 [(C18:1 cis-9)/(C18:1 cis-9 + C18:0)]; [11]Elongase activity index C16 to C18 = 100 [(C18:0 + C18:1 cis-9)/(C16:0 + C16:1cis-9 + C18:0 +C18:1 cis-9)]; [12]Thioesterase activity index C16 to C14 = 100 [(C16:0)/(C16:0 + C14:0)].

The levels of ash, moisture, protein, and ethereal extract in the loin determined in this work were not influenced by crude glycerin concentrations, as reported by Melo et al. (2014) and Egea et al. (2016). In its turn, the influence of dietary ractopamine on the increase in the shear force of the loin may be related to a reduction in the activity of calpain proteases (Xiong et al., 2006)

due to the greater gene expression related to calpastatin isoforms (Parr et al., 2004), and may be associated with increased muscle fiber diameter (Li et al., 2015).

The mean values observed in the present study for yellowness (11.34) and saturation index or chroma (11.37) are in accordance with the values reported in the literature (Silva et al., 2013). Pigs fed ractopamine (10 mg/kg) during the finishing phase may exhibit lighter meat due to a reduction in red content and a concomitant increase in lightness. The decrease in redness suggests that in the presence of this additive, there is a reduction in the oxymyoglobin concentration resulting in a lighter meat because of the decreased amount of iron present in the tissue (Lindahl et al., 2001). As verified in the present study, Agostini et al. (2011) also found that pork has a lower red intensity when ractopamine is added to the pig diet.

The constancy of the fatty acid profiles in the loin of pigs fed with different glycerin concentrations is contrary to the results reported by Faria et al. (2015). They found changes in fatty acid deposition with higher amounts of glycerin in pig diet. These results are important as the meat flavor is influenced by the intramuscular composition of fatty acids (Muriel et al., 2004). Moreover, in this study, no changes were observed in concentrations of MUFA, PUFA, or linoleic acid in the loin of pigs fed diet containing ractopamine. However, there was a decrease in stearic acid and increase in palmitoleic acid with the addition of ractopamine in the pig diets. In contrast to our study, Apple et al. (2008) observed an increase in PUFA and linoleic acid concentrations and a decrease in the concentrations of SFA and MUFA in the pork of pigs fed ractopamine. Pork fat composition in pigs fed with ractopamine and glycerin could be variable due to the actual input of these ingredients, i.e. the contents of glycerol, and ractopamine in the diets.

The decrease in the estimated activity of the enzyme elongase$^{C16\text{-}C18}$ in the loin caused by dietary ractopamine may be related to a decrease in the synthesis of triacylglycerols in the pork (Nakamura & Nara, 2004). Already the atherogenicity and thrombogenicity indexes are related to the amounts of fatty acids saturated, polyunsaturated, ω-3, and ω-6, being health indicators associated with the risk of cardiovascular disease (Ulbricht & Southgate, 1991). Thus, the lower the atherogenicity and thrombogenicity indexes of a given food are, the better the health benefits. The mean rates of atherogenicity and thrombogenicity found in this study were higher than those found in the study by Faria et al. (2015) for barrows. These discrepancies may be the result of different dietary lipid profiles among studies, as the addition of ractopamine and glycerin in the diet did not increase the atherogenicity and thrombogenicity indexes.

Our results showed that these ingredients, and their association, have potential application in swine meat production if their usage could reduce costs and caused no detrimental effects on pork quality.

5 Conclusion

The inclusion of up to 200 g/kg crude glycerin in the diet of finishing pigs may be used as a partial substitute for dietary corn, combined or not with 10 mg/kg ractopamine, without impair the evaluated carcass characteristics and the quality of the loin.

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