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Effect of partially replacing corn with sugar cane molasses on blood parameters and composition of the M. *longissimus thoracis* of growing pigs

Efeito da substituição parcial do milho por melaço de cana-de-açúcar sobre parâmetros sanguíneos e a composição do músculo *longissimus thoracis* de suínos em crescimento

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Abstract
The effect of sugar cane molasses, as a partial replacement to corn in the diet, on blood parameters and composition of the M. *longissimus thoracis* (LT) in growing pigs was explored in this study. Twenty female pigs aged 63 days, and weighing 28.98 ± 3.56 kg, were randomly assigned to either the control or sugar cane molasses treatments. Molasses was included at the 3% level to partially replace corn in their diet. Blood samples were collected at the beginning and end of the experiments. The animals were slaughtered at 110 days of age after 47 days in the experiment, weighing 67.9 ± 5.58 kg, and an LT muscle sample was extracted and evaluated. Each animal was considered an experimental unit. The treatment had no effect on the length and area of the LT muscle. Backfat thickness was reduced when using the sugar cane molasses treatment (5.80 mm) compared to the control treatment (8.90 mm) ($P < 0.05$). Higher enzyme gamma-glutamyl transferase (GGT) levels were observed in animals of the control treatment (67.10 IU/L) compared to animals treated with the sugar cane molasses treatment (49.90 IU/L) ($P < 0.05$). Moreover, the proximal composition, fatty acid profile, and quality were not influenced by treatment. Sugar cane molasses, used as an energy source to partially replace corn in the diet of growing pigs at a level of 3%, reduced the backfat thickness of the pig carcass and improved the serum concentration of the enzyme gamma-glutamyl transferase in pigs.
Key words: eye muscle area; fatty acids; meat; pig; subcutaneous fat thickness

Resumo
Neste estudo foi explorado o efeito do melaço de cana-de-açúcar em substituição parcial ao milho na dieta sobre os parâmetros sanguíneos e a composição do músculo *longissimus thoracis* (LT) de suínos em crescimento. Vinte leitoas com 63 dias de idade, pesando 28,98 ± 3,56 kg foram aleatoriamente distribuídas nos tratamentos controle ou melaço de cana-de-açúcar. O melaço foi incluído ao nível de 3% em substituição parcial ao milho na dieta. Ao início e ao final do experimento foram coletadas amostras de sangue dos animais. Os animais foram abatidos aos 110 dias de idade após 47 dias de experimento pesando 67,9 ± 5,58 kg e uma amostra do músculo LT foi extraída e avaliada. Cada animal foi considerado uma unidade experimental. Não houve diferença entre os tratamentos sobre o comprimento e a área do músculo LT. A espessura de toucinho foi reduzida ao utilizar o tratamento melaço de cana-de-açúcar (5,80 mm) em relação ao tratamento controle (8,90 mm) ($P < 0,05$). Níveis mais elevados da enzima gama-glutamil transferase (GGT) foram observados nos animais do tratamento controle (67,10 UI/L) em comparação aos animais do tratamento melaço de cana-de-açucar (49,90 UI/L) ($P < 0,05$). A composição proximal e o perfil e qualidade dos ácidos graxos não foram influenciados pelo tratamento. O melaço de cana-de-açúcar utilizado como fonte energética em substituição parcial ao milho na dieta de suínos em crescimento ao nível de 3% reduziu a espessura de toucinho da carcaça de suínos e melhorou a concentração sérica da enzima gama-glutamil transferase de suínos.
Palavras-chave: ácidos graxos; área de olho de lombo; carne; espessura de gordura subcutânea; suínos

1. Introduction

The costs associated with the diets of pigs are still a challenge for animal nutritionists who have the task of increasing animal protein production while looking for minimum input costs, thus ensuring sustainable farming[(1)]. Sugar cane molasses (*Saccharum officinarum*), composed of sucrose (32.8%), fructose (21.1%), and glucose (7.4%), is a reliable alternative for cereals because of its availability, high energy value, and low price[(2,3)]. It

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has a lower digestible and metabolizable energy content than corn, despite the high digestibility (approximately 100%) of soluble carbohydrates[4]. However, replacing a higher fraction of cereals with molasses in the diet of pigs causes diarrhea and reduces their growth rate[5]. In addition, the difficulty of mixing limits the use of high levels of molasses in the diet[6]. A previous study showed that sugar cane molasses can be used to replace corn in the diet of finishing pigs up to 5% without affecting performance, nutrient digestibility, blood metabolites, fecal noxious gas emission, and meat quality[7].

Pig meat products have been associated with unhealthy images because of their relative proportions of polyunsaturated and saturated fatty acids[8]. In general, pig meat contains predominantly oleic (C18:1n9), palmitic (C16:0), linoleic (C18:2), stearic (C18:0), and arachidonic (C20:4) fatty acids[9,10] due to fatty acid synthesis (Novo Synthesis). The conversion of glucose into triglycerides, called lypogenisys, provides at least 80% of the fatty acids deposited in pigs[11]. However, one of the main factors influencing the deposition of fatty acids, as well as their profiles, is the nutrition that animals receive during the rearing process[7]; consequently, changes in the nutrition of pre-slaughtered animals can modify this scenario, thereby changing the fatty acid composition of the meat[9].

Both corn and sugar cane molasses are sources of polyunsaturated fatty acids, with linoleic (47.50%), oleic (30.96%), palmitic (14.28%), stearic (4.16%), and α-linolenic (1.75%) acids being the most abundant fatty acids in corn[12], meanwhile, linoleic (39.20%), palmitic (24.39%), oleic (19.96%), and α-linolenic (7.07%) acids are the most abundant fatty acids in sugar cane molasses[13]. Therefore, we hypothesized that sugar cane molasses, as a partial replacement for corn in the diet of growing pigs, does not influence the blood parameters, the fatty acid profiles, and the quality of the M. *longissimus thoracis* of pigs. Therefore, the aim of this study was to evaluate the effect of sugar cane molasses (*Saccharum officinarum*), as a partial replacement for corn in the diet, on the blood parameters and composition of the M. *longissimus thoracis* in growing female pigs.

2. Material and methods

2.1 Animals and experimental diets

The procedures performed in this study were approved by the Ethics Committee on the Use of Animals of the Instituto Federal Catarinense (IFC), under protocol number 247/2018. The experiment was carried out on an experimental farm located in Araquari City (26°22'12" S and 48°43'20" W, with an altitude of 9 m) in southern Brazil. The climate is Cfa (wet mesothermal with hot summers) according to the Koppen classification system. A total of 20 recently nursered female pigs, crossbred between Large White × Landrace females and EMBRAPA MS 115 males, were used. The experiment lasted for the duration of the growing phase, which was from the nursery age at 63 days to the slaughter age at 110 days, totaling a period of 47 days. The female pigs, 63 days of age and weighing 28.98 ± 3.56 kg, were identified using ear tags and distributed homogeneously according to their weight between the two experimental treatments. The animals were housed in two pens of an area of 15.5 m² with a solid floor. There were 10 animals per pen. Each animal was considered an experimental unit. Feed was supplied in semi-automatic feeders and water was given from nipple drinkers; both were given *ad libitum*. The individual intake of the pigs was not recorded.

The animals received a pelleted, isoenergetic, and isoproteic commercial diet (Polinutri Alimentos SA, São Paulo, Brazil) formulated to meet the apparent ileal digestible amino acid requirements of the pigs during the growing phase. The experimental dietary treatments consisted of a control treatment and a sugar cane molasses treatment, where sugar cane molasses was included at the 3% level as a substitute for corn in the diet (Table 1). In the control treatment, refined sugar was added to keep both diets isoenergetic. The refined sugar cane was added during the pelleting process, while liquid sugar cane molasses was automatically added in the post-pelleting process via spraying.

2.2 Blood parameter analysis

Blood samples of all the animals were collected through venipuncture of the jugular vein after 12 h of fasting at the beginning and the end of the experiment. The samples were then centrifuged at 7,000 *g* for 5 min. The resulting serum was frozen at -20°C in microtubes (Eppendorf, Hamburg, Germany) for further blood parameter analysis[7,14]. The levels of high-density cholesterol (HDL), total cholesterol, triglycerides, urea, albumin, and gamma-glutamyl transferase (GGT) in the serum were analyzed in duplicate using a colorimetric method with commercial kits (Labtest, Lagoa Santa, MG, Brazil). The intra- and inter assay coefficients of variation for the assays were less than 10%.

Table 1. Ingredients, as well as the chemical and fatty acid compositions, of the experimental diets of growing pigs

	Treatment	
	Control	**Sugar cane molasses**
Feed Ingredients, %		
Ground corn[1]	59.09	57.35
Soy bean meal 45.5%	19.30	19.44
Wheat bran	6.60	6.60
Meat and bone meal 40%	5.24	5.24
Refined sugar[2]	4.00	-
Sugar cane molasses[3] + Antimold	-	4.00
Flash dry blood flour	2.00	2.00
Gluten	1.80	1.80
Ground salt	0.54	0.54
Soybean oil	0.42	0.90
Premix[4]	0.45	0.45
Total amino acids	0.55	1.67
Chemical composition of feed, % of DM		
Dry matter (DM)	88.73	87.82
Crude protein	20.00	20.00
Crude fiber	6.00	5.82
Ether extract	5.17	5.89
Ash	4.85	5.50
Calcium	0.84	0.85
Phosphorus	0.62	0.63
Fatty acids, g/100 g of FAME		
14:0	0.78	0.72
14:1	0.19	0.18
15:0	0.19	1.18
16:0	20.54	20.07
16:1n7	2.13	2.15
17:0	0.19	0.18
18:0	5.81	5.73
18:1n9t	0.19	0.18
18:1n9c	32.36	32.80
18:2n6c	34.30	32.59
18:3n3	1.94	1.97
20:0	0.39	0.36
20:1n9	0.39	0.36
20:4n6	0.19	0.18
22:0	0.19	0.18
24:0	0.19	0.18
SFA	28.49	27.78
MUFA	35.08	35.48
PUFA	36.63	36.92
PUFA/SFA	1.29	1.33
n-6/n-3	17.90	17.73
n-6	34.69	34.95
n-3	1.94	1.97
Energy, MJ/kg		
Metabolizable energy	13.50	13.50
Aminoacids, %		
Arginine	1.167	1.167
Glycine + Total Serine	1.895	1.894
Isoleucine	0.720	0.720
Lysine	1.594	1.581
Methionine	0.383	0.392
Methionine + Cysteine	0.695	0.695
Threonine	0.771	0.762
Tryptophan	0.217	0.217
Valine	0.941	0.941
Total aminoacids	8.383	8.369

[1]92.60% dry matter; 8.80% crude protein; 4.08% ether extract; 1.35% ash; 0.02% calcium; 0.19% phosphorus; 14.19 MJ/kg metabolizable energy. [2]99.00% dry matter; 0.00% crude protein; 0.00% ether extract; 0.14% ash; 0.00% calcium; 0.00% phosphorus; 15.65 MJ/kg metabolizable energy. [3]73.90% dry matter; 3.66% crude protein; 0.10% ether extract; 8.75% ash; 0.76% calcium; 0.06% phosphorus; 9.82 metabolizable energy.[4]9.400 mg/kg manganese; 14.000 mg/kg iron; 13.700 mg/kg zinc; 1.800 mg/kg copper; 275 mg/kg iodine; 24 mg/kg selenium; 4.000 mg/kg nicotinamide; 1.600.000 IU vitamin A; 3.000 mcg vitamin B12; 442 mg/kg vitamin B6; 400 mg/kg vitamin B2; 320.000 IU vitamin D3; 400 mg vitamin K3; 1.600 IU vitamin E; 90 mg/kg pantothenic acid; 2.400 mg/kg ethoxyquin. IU: international units; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; FAME: Fatty acid methyl esters n-3, n-6, and n-9: fatty acids of the omega 3, omega 6, and omega 9 families, respectively.

2.3 Backfat thickness evaluation and muscle sample collection

The animals were slaughtered at the weight of 67.90 ± 5.58 kg in a local abattoir where before bleeding, the pigs were electrically stunned. Backfat thickness (FT) was measured between the 12th and 13th rib of the left side of the carcass using a caliper, with one end placed above the hide and the other at the line of separation between the backfat and meat. Measurements were performed at the height of the last rib, which is in the region of insertion of the last thoracic vertebra with the first lumbar vertebra.

A 300 g sample of M. *longissimus thoracis* (LT) was extracted from between the 12th and 13th rib of the left side of each carcass. The depth of the M. *longissimus thoracis* was defined with the aid of a caliper measured perpendicular to the opposite end of the muscle, six centimeters from the midline of the carcass cut. The length of the M. *longissimus thoracis* was defined using a caliper, and the length of the longest muscle was measured. Images of M. *longissimus thoracis* were captured using a camera with a resolution of 4,000 × 3,000 pixels. Each sample was photographed over a blank surface, and a ruler was placed over the meat cut to obtain the pixel-to-mm ratio for further image analysis[15]. Eye muscle area was determined via image processing using ImageJ® software (NIH, Maryland, USA) and Bio7® editor (https://bio7.org/)[16,17]. Subsequently, six ribeye steaks were fabricated from each LT. These samples were identified, covered in aluminum foil, packed in plastic bags, and frozen for up to two months at -20°C for further analysis.

2.4 Chemical composition and fatty acid profile analysis

Thirty grams of one M. *longissimus thoracis* (LT) steak was lyophilized (Terroni, LS3000B, Brazil) under ideal conditions[14] for chemical composition and total lipid analyses. Chemical determination of moisture, crude protein, and ash followed the AOAC[18] methods. The total lipid[19] and transesterification of the fatty acid profile[20] were also analyzed. Fatty acid methyl esters (FAME) were obtained via gas chromatography (GC) (Agilent, 45,813–01, CA, USA) using a 0.25 mm × 60 m fused silica capillary column (Supelco SP™-2362, PA, USA). The temperature of the oven ranged from 100°C to 240°C, while the temperatures of the injector and detector were 250°C and 280°C, respectively. Nitrogen, with a flow rate of 0.6 mL/min, was used as a carrier gas. Individual fatty acids were identified by comparing their retention times to that of a standard (Supelco Mix 37 components FAME), and they were quantified by the incorporation of C23:0 standard prior to methylation. Methyl esters were transformed into fatty acids using both the theoretical correction factor and the conversion factor proposed by Tonial et al.[21].

From the fatty acids the saturated fatty acids (SFA),

monounsaturated fatty acid (MUFA), polyunsaturated fatty acid (PUFA), PUFA/SFA ratio, and omega 6 (n-6) to omega 3 (n-3) polyunsaturated fatty acids ratio (n-6/n-3) were calculated. Furthemore, the proportion of desirable fatty acids (DFA) DFA = (MUFA + PUFA + C18:0) was calculated according to the method described by Rhee[22]. The atherogenicity index (AI): AI= [(C12:0 + (4 × C14:0) + C16:0)] / (ΣMUFA + C18:1+ Σn-6 + Σn-3) and the thrombogenicity index (TI): TI = (C14:0 + C16:0 + C18:0) / [(0.5 × ΣMUFA) + (0.5 × C18:1) + (0.5 × Σn-6) + (3 × Σn-3) + (Σn-3/ Σn-6)] were calculated according to the method of Ulbricht and Southgate[23], and were used to evaluate the nutritional quality of the lipid fraction.

The hypocholesterolemic (h) to hypercholesterolemic fatty acid (H) ratio h/H= [(C18:1cis-9 + C18:2n6 + C20:4n6 +C18:3n3+ C20:5n3 + C22:5n3 + C22:6n3) / (C14:0 + C16:0)] was calculated as described by Santos-Silva et al.[24].

2.5 Statistical analysis

Data were analyzed using Statistical Analysis System software (SAS Inst. Inc., Cary, NC, USA, v.9.4), as a completely randomized design. Data normality and residual homogeneity were evaluated using the Shapiro-Wilk and Levene tests, respectively. The MIXED procedure was used to test the effect of treatment on the length, depth, and area of the LT, as well as the chemical composition, fatty acid profile, and quality of M. *longissimus thoracis*. Animal was considered a random effect. The following statistical model was used:

$$Yijk = \mu + \alpha i + \gamma j + \varepsilon ijk,$$

where Yijk represents dependent variables; μ is the overall mean of the observations; αi is the fixed effect of the treatment (i = 1, 2); γj is the random effect of the animal (j = 1 to 10); and εijk is the random residual experimental error.

Blood parameter data (except that of GGT) were analyzed as repeated measures over time using the following statistical model:

$$Yijkl = \mu + \alpha i + \gamma j + \tau k + \alpha\tau ik + \varepsilon ijkl,$$

where Yijkl represents dependent variables; μ is the overall mean of the observations; αi is the fixed effect of the treatment (i = 1, 2); γj is the random effect of the animal (j = 1 to 10); τk is the fixed effect of time ((k =); ατik is the treatment × time interaction effect; and εijkl is the random residual experimental error.

The main effect of the treatment was evaluated at a 5% significance level. Using the Akaike Information Criterion, the CS (composite symmetry) structure was considered the best model for the residual covariance structure.

Backfat thickness and GGT variables were analyzed using the Kruskal-Wallis (NPAR1WAY) test at a 5% significance level. Differences were considered statistically significant when $P < 0.05$. The following statistical model was used:

$$Yij = \mu + \alpha i + \varepsilon ij,$$

where Yij represents dependent variables; μ is the overall mean of the observations; αi is the fixed effect of the treatment (i = 1, 2); and εi is the random residual experimental error.

3. Results

When the sugar cane molasses partially replaced corn in the diet of growing pigs, there was no significant effect on the length, depth, and area of M. *longissimus thoracis* (Table 2). However, the animals that received the control treatment had greater backfat thickness than the animals that received sugar cane molasses (P = 0.0223, Table 2).

Table 2. Effect of the sugar cane molasses, as a partial replacement for corn in the diet, on M. *longissimus thoracis* parameters and the backfat thickness of growing pigs

Parameter	Treatment		Mean	SEM	Pr>F
	Control	Sugar cane molasses			
Length of LT, cm	8.54	8.76	8.65	0.190	0.578
Depth of LT, cm	5.62	5.41	5.70	0.146	0.488
Area of LT, cm²	65.91	68.06	66.98	2.155	0.632
Backfat thickness, mm	8.90	5.80	7.35	0.646	0.022

SEM, standard error of the mean; Pr>F, probability; LT, *longissimus thoracis*.

Except for the enzyme GGT, the blood parameters were not influenced by sugar cane molasses as a replacement for corn in the diet (Table 3). The animals that received the control treatment had higher values of GGT than the animals that received sugar cane molasses in the diet (P = 0.0123).

Table 3. Effect of the sugar cane molasses, as a partial replacement for corn in the diet, on the blood parameters of growing pigs

Parameter	Treatment		Mean	SEM	Pr>F
	Control	Sugar cane molasses			
HDL, mg/dl	54.19	56.04	41.10	1.279	0.475
Total cholesterol, mg/dl	100.90	100.25	100.57	2.817	0.909
Triglyceride, mg/dl	55.71	50.18	33.65	2.193	0.218
Urea, mg/dl	34.12	37.86	32.07	1.332	0.165
Albumin, g/dl	4.00	3.66	3.75	0.250	0.564
GGT, IU/l	67.10	49.90	58.50	3.159	0.012

SEM, standard error of the mean; Pr>F, probability; HDL, high-density cholesterol; GGT, gamma-glutamyl transferase; IU, international units.

The chemical composition of M. *longissimus thoracis*, as well as the fatty acid profile, atherogenicity (AI) and thrombogenicity (TI) indices, ratio of hypocholesterolemic to hypercholesterolemic (h/H) fatty acids, and desirable fatty acids (DFA) were not influenced by the partial replacement of corn with sugar cane molasses corn in the diet (Table 4).

Table 4. Effect of sugar cane molasses, as a partial replacement for corn in the diet, on the chemical composition, fatty acid profile, and quality of M. *longissimus thoracis* in growing pigs

Parameter	Treatment		Mean	SEM	Pr>F
	Control	Sugar cane molasses			
Chemical composition, g/100 g					
Moisture	74.65	74.35	74.50	0.143	0.306
Ash	1.34	1.32	1.33	0.023	0.512
Crude protein	23.80	24.12	22.77	0.119	0.179
Total lipids	1.35	1.27	0.81	0.033	0.241
Fatty acids, mg/100 g of FAME					
10:0	1.50	1.40	1.45	0.005	0.649
12:0	1.00	1.00	1.00	0.003	0.139
14:0	14.80	14.50	14.60	0.029	0.577
16:0	256.40	253.30	254.90	0.155	0.342
16:1n7	36.00	32.10	34.00	0.120	0.117
17:0	2.70	2.10	2.40	0.017	0.106
17:1n7	1.90	1.90	1.90	0.009	0.916
18:0	132.0	124.10	128.10	0.270	0.148
18:1n9	408.30	406.90	407.60	0.244	0.777
18:2n6	105.90	105.00	105.40	0.085	0.621
18:3n6	1.20	1.10	1.10	0.011	0.444
20:0	1.60	1.60	1.60	0.006	0.936
18:3n3	5.10	4.80	4.90	0.015	0.376
20:1n9	8.20	8.20	8.20	0.017	0.910
20:2n6	5.10	4.50	4.80	0.023	0.191
20:3n6	3.90	3.50	3.70	0.0285	0.5096
20:4n6	20.00	19.20	19.60	0.1274	0.7487
22:1n9	1.10	0.90	1.00	0.0081	0.2386
24:1n9	4.60	3.90	4.30	0.0296	0.2560
SFA	407.40	403.50	405.50	0.2894	0.5180
MUFA	457.50	452.70	455.10	0.2996	0.4339
PUFA	140.10	139.50	139.80	0.2097	0.8945
PUFA/SFA	0.34	0.34	0.34	0.0062	0.8191
n-6/n-3	28.36	26.69	27.52	0.7044	0.2470
n-6	135.30	134.50	134.90	0.2012	0.8450
n-3	5.10	4.80	4.90	0.0153	0.3765
Quality of fatty acids, mg/100 g of FAME					
AI	3.20	3.10	3.15	0.0025	0.1656
TI	7.80	7.60	7.70	0.0090	0.5580
h/H	20.00	19.80	19.90	0.0191	0.6512
DFA	724.90	721.30	723.10	0.1687	0.3006

SEM, standard error of the mean; Pr>F, probability; SFA, saturated fatty acids; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; n-3, n-6, and n-9: fatty acids of the omega 3, omega 6, and omega 9 families, respectively; AI, atherogenicity index; TI, thrombogenicity index; h/H, hypocholesterolemic to hypercholesterolemic ratio; DFA, desirable fatty acid; FAME, fatty acid methyl esters.

4. Discussion

In current swine breeds, the goals of genetic selection have resulted in a strong reduction in potential lipogenesis, creating animals with less intramuscular fat deposition and a higher percentage of lean meat in the carcass. Consequently, this affects the quality of the final product, mainly in relation to technological and sensory aspects[10,25,26]. Female pigs that received sugar cane molasses in the diet showed reduced backfat thickness compared to those that received the control diet. This effect could be due to a decrease in energy and protein utilization efficiency[13]. This reduction in energy utilization can be explained by both the incomplete digestion of sucrose and incomplete intestinal absorption of fructose[3,13]. In this context, Mordenti et al.[13] stated that the use of molasses in pig diets could also improve the meat to fat ratio of the carcass by reducing the incidence of fat cuts. Therefore, this reduction in fat content can be a good indicator of lean meat yield on the carcass and as a result may meet the demand from the consumer market, which prefers leaner meat [27]. On the other hand, the covering fat associated with marbling fat

is a factor that positively affects the tenderness of the meat, especially in the perception of its juiciness[26,28].

In pigs, the fat deposition rate is influenced by several factors including nutrition, sex, age, slaughter weight, room temperature, and animal genotype[28]. Although the polygenic architecture of backfat thickness and the role of the genes involved in energy homeostasis, adipogenesis, fatty acid metabolism, and insulin, signaling pathways for fat deposition in pigs[25]. Because fat is a tissue that increases in percentage with increasing animal maturity, resulting in lower feed efficiency[29], it is expected that the current pigs will have a lower deposition of fat in the carcass at this time of slaughter. Dutra Jr et al.[30] reported that female pigs (Camborough 22) slaughtered at 120 kg had an average backfat thickness of 16.4 mm, and for those slaughtered at 70 kg, the average value was 12.4 mm, which is higher than the values observed in this study of 5.80 mm and 8.90 mm for female pigs slaughtered at 67.90 kg from the sugar cane molasses and control groups, respectively. This is a very promising result, considering that current genotypes of pigs used for industrial lean meat production are being slaughtered at an older age[31,32]. Furthermore, Aymerich et al.[33] found that females had greater backfat thickness than males.

The area of the M. *longissimus thoracis* (LT) is a measure used to predict the amount of muscle in the carcass, and is the most reliable measure to assess the development and size of muscle tissue[34]. In this study, the area of the LT muscle was not influenced by the partial replacement of corn with sugar cane molasses, possibly because the experimental diets were isoenergetic and isoproteic, and the animals reached similar slaughter weights. However, Brooks and Iwanaga[35] observed that pigs fed a diet containing sugar cane molasses and fat had a higher LT muscle area than those on the basal corn diet. The differences between these studies may be related to the growth phase of the animals, the amount of sugar cane molasses in the diet, and feed conversion. Furthermore, the LT muscle area is directly related to the total muscle content of the carcass[36] and is inversely related to the fat content[37]. The increase in the production of muscle mass resulted in carcasses with improved quality, which is an important indicator of the yield of cuts of a high commercial value.

The female pigs from the control treatment had a concentration of GGT (67.10 IU/L) that was above the reference values for pigs, ranging from 10 to 52 IU/L[38], which may be indicative of acute injury of the liver, which causes immediate serum increases in most animal species[39]. Nevertheless, the female pigs that received sugar cane molasses that had partially replaced corn in the diet maintained GGT levels (49.90 IU/L) within the reference values for the species. The higher serum GGT in the control treatment may be due to diet-induced hepatic procoagulant and proinflammatory conditions[40] as molasses is transformed into glucose faster than starch[41] with less hepatic overload in gluconeogenesis.

Muñoz et al.[42] found a positive correlation between blood lipid indicators, such as HDL, LDL, and total cholesterol, in Duroc castrated pigs as the slaughter age increased; the opposite was observed for serum triglyceride levels. However, they showed a weak correlation with fat deposition in the carcasses. In the present study, the indicators of lipid metabolism were kept constant at the basal level and were not influenced by sugar cane molasses partially replacing corn in the diet. This is possibly because of the slaughter age and weight of the female pigs.

The body fat of pigs is dependent on the composition of the dietary fat supply; these fatty acids are deposited directly in the body fat. Thus, it is possible to obtain the fat profile by the supplied feed[43]. Although in this study, sugar cane molasses partially replacing corn in the diet had no effect on the lipid profile, the fatty acids present in the meat at higher concentrations were C18:1, C16:0, C18:0, and C18:2n6, with the monounsaturated fatty acids (MUFA) presenting higher levels, followed by the saturated (SFA) and polyunsaturated fatty acids (PUFA). This corroborates the findings of Poklukar et al.[11] who observed that most swine breeds had higher levels of MUFA and lower PUFA levels in their composition. While stearic acid (C18:0) reduces serum cholesterol in humans by rapidly converting it to C18:1[29], palmitic acid (C16:0) increases cholesterol synthesis, which favors LDL accumulation and is a risk factor for cardiovascular disease[44,45].

When consumed in high quantities, saturated fats can predispose an individual to the onset of cardiovascular disease and cancer, whereas PUFAs, when consumed in high quantities, are beneficial to human health because they are associated with a lower risk of death[29]. In the present study, the PUFA/SFA ratio of 3.40 mg/100 g of FAME was lower than the maximum value of 4.00 mg per 100 g recommended by the World Health Organization (WHO), which is beneficial in human diets. Among polyunsaturated fatty acids, the consumption of omega-6 (n-6) and omega-3 (n-3) fatty acids is considered essential in the diet of mammals. The concentration of n-6 in pig meat is high, as the base of animal feed rations is rich in soybean oil and corn, and contributes to increased levels of this fatty acid in adipose tissue, consequently increasing the n-6/n-3 ratio in meat[46]. Therefore, as expected, the n-6/n-3 ratio in the present study was above the value of 4:1 recommended by the WHO being considered a risk factor for the development of coronary, allergic, inflammatory, and cardiovascular diseases, in addition to cancer[47].

Although pig meat has a lower concentration of PUFA than marine oily fish, it is an important source of n-3 and n-6 fatty acids for most of the population, as the

consumption of such fish is proportionally lower. The possibility of increasing the levels of PUFAs in pig meat helps to reduce the negative image linked to it, that is attributed to the amount of saturated fat, which is actually lower in pig meat than the amount of polyunsaturated fat, as observed in the present study. Thrombogenicity (TI) and atherogenicity (AI) indices are used to assess the lipid quality of meat and its potential effect on the development of coronary heart disease, as their calculations consider SFA, MUFA, and PUFA fatty acids[22]. In the present study, the mean values of AI and TI were below the maximum recommended values of 6.00 mg/100 g and 13.70 mg/100 g of FAME, respectively, for pig meat, according to Ulbricht and Southgate[23] who suggested that these indices are more suitable for assessing the atherogenicity of foods than the PUFA/SFA ratio.

The h/H ratio allows for a better nutritional assessment of the lipid profile in addition to considering the beneficial effects of monounsaturated fatty acids in this ratio, thus being useful in the assessment of the cholesterolemic effect of lipids[29,48]. Thus, the higher the h/H ratio, the more suitable the oil or fat from a nutritional point of view. The mean h/H ratio observed in this study was 19.90 mg/100 g of FAME. In Pulawska and Polish Landrace pigs the h/H ratio ranged from 28.30 mg/100 g to 29.10 mg/100 g of FAME[49]. The mean value of the desirable fatty acids (DFA) observed in the present study was 723.10 mg/100 g of FAME. It has been suggested that DFA levels be used as a risk indicator for cardiovascular disease, and is useful in the evaluation of meat quality as it considers MUFA and PUFA in addition to C18:0; consequently, the higher the DFA value, the lower the risk of cardiovascular disease[50].

5. Conclusion

Sugar cane molasses used as an energy source to partially replace corn in the diet of growing pigs at the level of 3% resulted in animals with smaller backfat thickness and better serum concentration of the enzyme gamma-glutamyl transferase. Furthermore, this treatment did not affect the chemical composition, fatty acid profile, and quality of M. *longissimus thoracis*. Therefore, sugar cane molasses can be used in the diet of growing pigs to reduce the backfat thickness of the carcass and to improve blood parameters of pigs.

Conflict of interest

The authors declare that they have no conflicts of interest with respect to the work described in this manuscript.

Author contributions

Conceptualization: V. Peripolli, J.M. Oliveira Júnior, and F. Moreira; *Data curation:* V. Peripolli, G. Caillouel, and J.H. Montes; *Formal analysis:* V. Peripolli; *Funding acquisition:* V. Peripolli and F. Moreira; *Investigation:* V. Peripolli, G. Caillouel, F.A. Pace, J.H. Montes, M.G. Philippe, L.L. Nörnberg, J.M. Oliveira Júnior, I. Bianchi, E. Schwegler, and F. Moreira; *Methodology:* V. Peripolli, J.L. Nörnberg, J.M. Oliveira Júnior, I. Bianchi. E. Schwegler, and F. Moreira; *Project administration:* F. Moreira; *Writing (original draft and review & editing):* V. Peripolli, G. Caillouel, L.L. Nörnberg, J.M. Oliveira Júnior, I. Bianchi, E. Schwegler, and F. Moreira.

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References

1. Sahu S, Patel BHM, Sarangi A, Kumar D, Malesh MS, Upadhyay D, Dutt T. Sun-dried sugarcane press mud could be a prospective feedstuff for swine production. Sugar Tech. 2022; 24(3):788-797. https://doi.org/10.1007/s12355-021-01061-8.

2. Palmonari A, Cavallini D, Sniffen CJ, Fernandes L, Holde P, Fagioli L, Fusaro I, Biagi G, Formigoni A, Mammi L. Short communication: Characterization of molasses chemical composition. Journal of Dairy Science. 2020;103(7):6244-6249. http://doi.org/10.3168/jds.2019-17644.

3. Bayley HS, Figueroa V, Ly J, Maylin A, Perez A. Utilization of sugarcane final molasses by the pig: energy metabolism. Canadian Journal of Animal Science. 1983;63:455-462. https://doi.org/10.4141/cjas83-054.

4. Rostagno HS, Albino LFT, Donzele JL, Gomes PC, Oliveira RF, Lopes DC, Ferreira AS, Barreto SLT, Euclides RF. Tabelas Brasileiras para aves e suínos: Composição de alimentos e exigências nutricionais. 3st ed.Viçosa: Editora da UFV; 2011. 252p. Portuguese.

5. Diaz CP, Marrero L. Broken rice and final molasses for pig fattening. Cuban Journal of Agricultural Science. 1978; 12(2):177-134.

6. Singh NM, Singh LA, Kumari LV, Kadirvel G, Patir M. Effect of supplementation of molasses (*Saccharum officinarum*) on growth performance and cortisol profile of growing pig in north eastern hill ecosystem of India. Journal of Entomology and Zoology Studies. 2020; 8(2): 302-305.

7. Sureshkumar S, Lee SI, Nam DS, Kim IH. Effect of substitution of corn for molasses in diet on growth performance, nutrient digestibility, blood characteristics, fecal noxious gas emission, and meat quality in finishing pigs. Revista Brasileira de Zootecnia. 2017;45(3):107-112. http://doi.org/10.1590/S1806-92902016000300004.

8. Morgan CA, Noble RC, Cocchi M, McCartney R. Manipulation of the fatty acid composition of pig meat lipids by dietary means. J. Sci. Food Agric.,1992, 58: 357-368. https://doi.org/10.1002/jsfa.2740580310

9. Chen J, Li J, Liu X, He Y. Effects of dietary fat saturation level on growth performance, carcass traits, blood lipid parameters, tissue fatty acid composition and meat quality of finishing pigs. Animal Biosciences. 2021;34(5):895-903. http://doi.org/10.5713/ajas.20.0247.

10. Albuquerque TMNC, Ramos EM, Machado IFM, Borges PC, Bolleta AC, Marçal JO, Carvalho FP, Faria PB. Lipid profile

and quality of meat from finishing pig supplemented with minerals. Food Science and Technology. 2019;39(3):721-728. http://doi.org/10.1590/fst.06118.

11. Poklukar K, Čandek-Potokar M, Batorek Lukač N, Tomažin U, Škrlep M. Lipid deposition and metabolism in local and modern pig breeds: A review. Animals. 2020;10(3):424. https://doi.org/10.3390/ani10030424.

12. Jiménez JJ; Bernal JL, Nozal MJ, Toribio L, Bernal J. Profile and relative concentrations of fatty acids in corn and soybean seeds from transgenic and isogenic crops. Journal of Chromatography A. 2009; 1216(43): 7288-7295. https://doi.org/10.1016/j.chroma.2009.08.015.

13. Mordenti AL, Giaretta E, Campidonico L, Parazza P, Formigoni A. A Review regarding the use of molasses in animal nutrition. Animals. 2021; 11: 115. https://doi.org/10.3390/ani11010115.

14. Pace FA, Montes JH, Philippe MG, Ramos LFP, Clementino FMM, Oliveira Júnior JM, Moreira F, Bianchi I, Peripolli, V. Interactive effects between sugar source and pelleting temperature on processing, digestibility and blood metabolites in nursery piglets. Livestock Science. 2020;240:104182. http://doi.org/10.1016/j.livsci.2020.104182.

15. Giaretta E, Mordenti AL, Canestrari G, Brogna N, Palmonari A, Formigoni A. Assessment of muscle Longissimus thoracis et lumborum marbling by image analysis and relationships between meat quality parameters. PLoS ONE. 2018;13(8): e0202535. https://doi.org/ 10.1371/journal.pone.0202535

16. Junior FMV, Fernandes T, de Matos AT, Fernandes ARM, Alves LGC, Rossatti JA, Britez GDV, Zagonel NGT. Evaluator effect on the ultrasound measurement of subcutaneous fat deposition and loin eye area from weaning to slaughter lambs. Veterinary World Journal. 202;14(1):259-264. doi: http://doi.org/10.14202/vetworld.2021.259-264.

17. Carpentier SC, Dens K, Houwe IVD, Swennen R, Panis B. Lyophilization, a practical way to store and transport tissues prior to protein extraction for 2DE analysis? Proteomics. 2007;7: 64-69. http://doi.org/10.1002/pmic.200700529.

18. AOAC - Association of Official Analytical Chemists. Official Methods of Analysis of AOAC International. 16th ed. Washington: Association of Official Analytical Chemists; 1995. 1200p.

19. Hara A, Radin NS. Lipid extraction of tissues of low toxicity solvent. Analytical Biochemistry. 1978;90(1):420-426. https://doi.org/10.1016/0003-2697(78)90046-5.

20. Christie WW. A simple procedure for rapid transmethylation of glycerolipids and cholesterol esters. Journal of Lipid Research. 1982;23(7):1072-1075. https://doi.org/10.1016/S0022-2275(20)38081-0.

21. Tonial IB, Oliveira DF, Coelho AR, Matsushita M, Coró FAG, Souza NE, Visentainer JV. Quantification of essential fatty acids and assessment of the nutritional quality indexes of lipids in tilapia alevins and juvenile tilapia fish (Oreochromis niloticus). Journal of Food Research. 2014;3(3):105-114. https://doi.org/10.5539/jfr.v3n3p105.

22. Rhee KS. Fatty acids in meats and meat products. In: Chow CK. Fatty acids in foods and their health implications. New York: CRC Press; 1992. p. 65-93.

23. Ulbricht TLV, Southgate DAT. Coronary heart disease: seven dietary factors. Lancet. 1991; 338(8773):985-992. https://doi.org/10.1016/0140-6736(91)91846-m.

24. Santos-Silva J, Bessa RJB, Santos-Silva F. Effect of genotype, feeding system and slaughter weight on the quality of light lambs: II. Fatty acid composition of meat. Livestock Production Science. 2002;77(2-3):187-194. https://doi.org/10.1016/S0301-6226(02)00059-3.

25. Gozalo-Marcilla M, Buntjer J, Johnsson M, Batista L, Diez F, Werner CR, Chen C-Y, Gorjanc G, Mellanby RJ, Hickey JM, Ros-Freixedes R. Genetic architecture and major genes for backfat thickness in pig lines of diverse genetic backgrounds. Genetics Selection Evolution. 2021;53:76. https://doi.org/10.1186/s12711-021-00671-w.

26. Zhang Z, Zhang Z, Oyelami FO, Sun H, Xu Z, Ma P, Wang Q, Pan Y. Identification of genes related to intramuscular fat independent of backfat thickness in Duroc pigs using single-step genome-wide association. Animal Genetics. 2021;52(1):108-113. https://doi.org/10.1111/age.13012.

27. Ngapo TM, Rubio Lozano MS, Braña Varela, D. Mexican consumers at the point of meat purchase. Pork choice. Meat Science. 2018;135:27-35. https://doi.org/10.1016/j.meatsci.2017.08.005.

28. Malgwi IH, Halas V, Grünvald P, Schiavon S, Jócsák I. Genes related to fat metabolism in pigs and intramuscular fat content of pork: a focus on nutrigenetics and nutrigenomics. Animals. 2022;12(2):150. https://doi.org/10.3390/ani12020150.

29. Esteves GIF, Peripolli V, Costa Jr, JBG, Tanure CB, Menezes AM, Souza JR, Kindlein L, Bergmann GP, Louvandini H, McManus C. Effects of genetic group, pregnancy and age on carcass traits, meat quality and fatty acid profile in female sheep. Revista Colombiana de Ciencias Pecuarias. 2019;32(1):21-33. https://doi.org/10.17533/udea.rccp.v32n1a03.

30. Dutra Jr WM, Ferreira AS, Tarouco JU, Donzele JL, Euclydes RF, Albino LFT, Cardoso LL, Fernandes SP. Predição de características quantitativas de carcaças de suínos pela técnica de ultra-sonografia em tempo real. Revista Brasileira de Zootecnia. 2001;30(4):1251-1257. https://doi.org/10.1590/S1516-35982001000500018. Portuguese.

31. Auqui SM, Egea M, Peñaranda I, Garrido MD, Linares MB. Rustic Chato Murciano pig breed: Effect of the weight on carcass and meat quality. Meat Science. 2019;156:105-110. https://doi.org/10.1016/j.meatsci.2019.05.022.

32. Ba HV, Seo H-W, Seong P-N, Cho S-H, Kang S-M, Kim Y-S, Choi Y-M, Kim J-H. Live weights at slaughter significantly affect the meat quality and flavor components of pork meat. Animal Science Journal. 2019;90(5):667-679. http://doi.org/10.1111/asj.13187.

33. Aymerich P, Gasa J, Bonet J, Coma J, Solà-Orio D. The effects of sire line, sex, weight and marketing day on carcass fatness of non-castrated pigs. Livestock Science. 2019; 228:25-30. https://doi.org/10.1016/j.livsci.2019.07.021.

34. Santos L, Caldara F, Santos R, Nääs I, Foppa L, Garcia R, Paz I. Comparison of methodologies for assessment of pork loin eye area. Boletim da Indústria Animal, 2014;71(3): 211-216. https://doi.org/10.17523/bia.v71n3p211.

35. Brooks CC, Iwanaga II. Use of cane molasses in swine diets. Journal of Animal Science. 1967;26(4):741-745. https://doi.org/10.2527/jas1967.264741x.

36. Apple JK. Swine Nutrition and Pork Quality. In: Chiba LI. Sustainable Swine Nutrition. New Jersey: Wiley-Blackwell; 2012. p.413-438

37. Pietruszka A, Jacyno E, Kawęcka M, Biel W. The relation between intramuscular fat level in the longissimus muscle and the quality of pig carcasses and meat. Annals of Animal Science. 2015;15(4):1031-1041. https://doi.org/10.1515/aoas-2015-0046.

38. González FHD, Silva SC. Introdução à bioquímica clínica veterinária. Porto Alegre: Editora da UFRGS; 2022. Portuguese. (http://hdl.handle.net/10183/237269)

39. Moreira CN, Souza NS, Barini AC, Araújo EG, Fioravanti MCS. γ-glutamiltransferase como indicador de lesão hepática crônica em bovinos sem sinais clínicos. Arquivo Brasileiro de Medicina Veterinária e Zootecnia. 2012;64(6):1403-1410. https://doi.org/10.1590/S0102-09352012000600001. Portuguese.

40. Nanizawa E, Otsuka S, Hatayama N, Tamaki Y, Hayashi Y, Ishikawa T, Hirai S, Naito M. Short-term high-fat and high-carbohydrate diets increase susceptibility to liver injury by inducing hepatic procoagulant and proinflammatory conditions with different balances. Nutrition. 2022;101:111710. https://doi.org/10.1016/j.nut.2022.111710.

41. Ferreira DS, Bertachini DL, Negreiros Filho L, Ferreira RCV. Metabolismo da frutose e a sua relação com a sindrome metabólica e esteatose hepática não alcoólica. Revista Saúde UniToledo. 2018;2(1):93-103. Portuguese.

42. Muñoz R, Tor M, Estany J. Relationship between blood lipid indicators and fat content and composition in Duroc pigs. Livestock Science. 2012;148(1-2):95-102. https://doi.org/10.1016/j.livsci.2012.05.015.

43. Bertol TM. Estratégias nutricionais para melhoria da qualidade da carne suína. Brasília: Embrapa; 2019. 296p. Portuguese. (http://www.alice.cnptia.embrapa.br/alice/handle/doc/1115146)

44. Praagman J, Jonge EA, Kiefte-de Jong JC, Beulens JW, Sluijs I, Schoufour JD, Hofman A, van der Schouw YT, Franco OH. Dietary saturated fatty acids and coronary heart disease risk in a dutch middle-aged and elderly population. Arteriosclerosis, Thrombosis, and Vascular Biology. 2016;36(9):2011-2018. https://doi.org/10.1161/ATVBAHA.116.307578.

45. Zong G, Li Y, Wanders A, Alssema M, Zock P, Willett W, Hu F, Sun, Q. Intake of individual saturated fatty acids and risk of coronary heart disease in US men and women: Two prospective longitudinal cohort studies. The British Medical Journal. 2016;355:i5796. https://doi.org/10.1136/bmj.i5796.

46. Alonso V, Muela E, Gutiérrez B, Calanche JB, Roncalés P, Beltrán JA. The inclusion of Duroc breed in maternal line affects pork quality and fatty acid profile. Meat Science. 2015; 107:49-56. https://doi.org/10.1016/j.meatsci.2015.04.011.

47. Huerta-Yépez S, Tirado-Rodriguez AB, Hankinson O. Role of diets rich in omega-3 and omega-6 in the development of cancer. Boletín Médico del Hospital Infantil de México. 2016; 73(6):446-456. https://doi.org/10.1016/j.bmhimx.2016.11.001.

48. Chen J, Liu H. Nutritional indices for assessing fatty acids: a mini-review. International Journal of Molecular Sciences. 2020; 21: 5695. https://doi.org/10.3390/ijms21165695.

49. Kasprzyk A, Tyra M, Babicz M. Fatty acid profile of pork from a local and a commercial breed. Archives Animal Breeding; 21015; 58: 379-385. https://doi.org/10.5194/aab-58-379-2015.

50. Costa RG, Santos NM, Queiroga RCRE, Sousa WH, Madruga MS, Cartaxo FQ Physicochemical characteristics and fatty acid profile of meat from lambs with different genotypes and diets. Revista Brasileira de Zootecnia. 2015; 44(7): 248-254. https://doi.org/10.1590/S1806-92902015000700003.