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Physicochemical, antioxidant and fatty acid quality in Mexican hairless pork fed with *Moringa oleifera* and *Brosimum alicastrum*

Calidad fisicoquímica, antioxidante y ácidos grasos en carne de cerdo pelón Mexicano alimentado con *Moringa oleifera* y *Brosimum alicastrum*

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ABSTRACT

This study aimed to evaluate the effects of diets with *Moringa oleifera* and *Brosimum alicastrum* leaf meal on the physicochemical characteristics, antioxidant capacity and fatty acid composition of meat from Mexican Hairless Pigs. Eighteen (18) Mexican Hairless Pigs pigs were used in the study. The pigs were randomly divided into three dietary groups: control diet and two experimental diets supplemented with 10 % *Moringa oleifera* and *Brosimum alicastrum* leaf meal, respectively. The results indicated that intramuscular fat was higher (P < 0.05) in meat from Mexican Hairless Pigs fed control diet. Meat from Mexican Hairless Pigs fed *Brosimum alicastrum* diets presented higher (P < 0.001) α-tocopherol (48.33 µg/g of fat). The 2,2-diphenyl-1-picrylhydrazyl concentration was higher (P < 0.05) in the meat of pigs supplemented with *Moringa oleifera* (450.48 µM Trolox/g of DW). Pigs fed *Brosimum alicastrum* leaf meal were characterized by a higher content of 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) in their meat (P < 0.05) (471.89 µM Trolox/g of DW). Regarding the fatty acid composition, meat from Mexican Hairless Pigs fed *Moringa oleifera* and *Brosimum alicastrum* presented higher values (P < 0.001; P < 0.05) of saturated fatty acids and atherogenic and thrombogenic indices. In contrast, the concentrations of monounsaturated fatty acids and polyunsaturated fatty acids, unsaturated fatty acids, the polyunsaturated fatty acids/saturated fatty acids ratio and the monounsaturated fatty acids/saturated fatty acids ratio were higher (P < 0.001; P < 0.05) in meat from the control group. The nutritive value index did not differ (P > 0.05) between treatments. It is concluded that *Moringa oleifera* and *Brosimum alicastrum* leaf meal could be used as an Mexican Hairless Pigs feed resource to reduce intramuscular fat in meat.

Key words: Meat quality; 2,2-diphenyl-1-picrylhydrazyl; 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); α-tocopherol

RESUMEN

Este estudio tuvo como objetivo evaluar los efectos de las dietas con harina de hojas de *Moringa oleifera* y *Brosimum alicastrum* sobre las características fisicoquímicas, la capacidad antioxidante y la composición de ácidos grasos en carne de Cerdos Pelón Mexicanos. En el estudio, se utilizaron dieciocho Cerdos Pelón Mexicanos. Los cerdos se dividieron aleatoriamente en tres grupos dietéticos: dieta control y dos dietas experimentales suplementadas con 10 % de harina de hojas de *Moringa oleifera* y *Brosimum alicastrum*, respectivamente. Los resultados indicaron que la grasa intramuscular fue mayor (P < 0.05) en la carne de Cerdos Pelón Mexicanos alimentados con dieta control. La carne de Cerdos Pelón Mexicanos alimentados con dietas *Brosimum alicastrum* presentó mayor (P < 0,001) α-tocopherol (48,33 µg/g de grasa). La concentración de 2,2-difenil-1-picrilhidrazilo fue mayor (P < 0,05) en la carne de los cerdos suplementados con *Moringa oleifera* (450,48 µM Trolox/g de PS). Los cerdos alimentados con harina de hojas de *Brosimum alicastrum* se caracterizaron por un mayor contenido de Ácido 2,2′-azino-bis(3-etilbenzotiazolina-6-sulfónico) en la carne (P < 0,05) (471,89 µM Trolox/g de PS). En cuanto a la composición de ácidos grasos, la carne de Cerdos Pelón Mexicanos alimentada con *Moringa oleifera* y *Brosimum alicastrum* presentó valores más altos (P < 0,001; P < 0,05) de ácidos grasos saturados y de índices aterogénicos y trombogénicos. En cambio, las concentraciones de ácidos grasos monoinsaturados y ácidos grasos poliinsaturados, los ácidos grasos insaturados , la relación ácidos grasos poliinsaturados/ácidos grasos saturados y la relación ácidos grasos monoinsaturados/ácidos grasos saturados fueron mayores (P < 0,001; P < 0,05) en la carne del grupo control. El índice de valor nutritivo no difirió (P > 0,05) entre tratamientos. Se concluye que la harina de hojas de *Moringa oleifera* y *Brosimum alicastrum* podría utilizarse como un recurso alimenticio para el Cerdos Pelón Mexicanos para reducir la grasa intramuscular en la carne.

Palabras clave: Calidad de la carne; 2,2-difenil-1-picrilhidrazilo; Ácido 2,2′-azino-bis(3-etilbenzotiazolina-6-sulfónico); α-tocoferol.

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INTRODUCTION

The main characteristics by which pork (*Sus scrofa domesticus*) quality is evaluated include intramuscular fat (IMF) content, drip loss, meat color, pH, juiciness, tenderness, flavor, and fatty acid composition. In this sense, polyunsaturated fatty acids (PUFAs) supplementation has been widely discussed as a strategy for improving meat quality in pig production [1]. However, technological quality is a complex property of pork meat, which is influenced by multiple intrinsic and extrinsic factors. [2]. Dietary supplementation is one of the most common methods to improve the meat quality of pigs. Therefore, it is of great significance to improve pork quality via seeking effective feed strategies [1].

The Mexican hairless pig (MHP) is an important animal genetic resource in southeastern Mexico, capable of exploiting foods with very low nutritional value. Its meat is prized for its flavor and is essential in many traditional Mayan dishes [3]. The MHP's diet is highly diversified due to its good foraging capacity and digestive capacity for fibrous diets. It can exploit a wide variety of grains, fruits, tubers, agricultural byproducts, and household waste. It has been suggested that tropical forages feed for monogastric animals can play a role in improving the sustainability of animal production within farming traditional systems [4].

Previous studies have found that forages resources can be included in pig diets to reduce feed cost and improved productive performance [5], as well as improved meat quality [6]. Among the forages most used in livestock production, *Moringa oleífera* (MO) leaf has attracted great interests as an unconventional feed source because of its unique nutrional values in terms of crude protein, energy, vitamins, minerals, and essential amino acids [7]

The positive effects of dietary MO supplementation on productive performance and carcass traits have been observed in chickens (*Gallus gallus domesticus*) [8], buffalo calves (*Bubalus bubalis*) [9], and goat (*Capra hircus*) kids [10]. in addition, *Brosimum alicastrum* (BA) leaf is a forage resource which is commonly used in animal feed in tropics. Because of its nutritional characteristics as animals and human food, it is considered to have potential for the livestock feed agro-industry [11]. In addition, BA contains soluble fiber can favorably stimulate the microbial community of the gastrointestinal tract and decrease digestive disorders in monogastrics [12].

Therefore, MO and BA could be used as a supplementation feed strategy to animals raised under tropical conditions. In addition, due to its nutritional composition and bioactive compounds such as polyphenols, the incorporation of these forages in pig diets may represent an attractive alternative as a source of natural antioxidants [13,14].

Therefore, the objective of this study was to examine the effects of dietary supplementation with MO and BA leaf meal on physicochemical characteristics, antioxidant capacity and fatty acid composition in *Biceps femoris* of Mexican hairless pigs. These findings would contribute to the application of MO and BA as unconventional feed and to explore the potential benefits of these forage resources in the diet of pigs traditionally reared under tropical conditions.

MATERIALS AND METHODS

Study area

The study was conducted at the Agricultural and Livestock Production Unit at Conkal Technological Institute, Yucatan, Mexico, located at the geographic coordinates of 21° 04´26” N and 89° 31´17” W. The agroecological characteristics include flat terrain typical of the Yucatán Peninsula, with rocky plains and mostly uniform topography. The prevailing climate is warm, sub-humid with summer rains, with an average annual temperature above 26 °C and rainfall between 700 and 1,100 mm per year.

Animals, diets and experimental design

A total of 18 male castrated MHP, with an average initial live weight of 22.0 ± 1.11 kg and age of 4 months were used. The initial live weight was recorded with a digital scale (Torrey, model EQB 100, Mexico). The animals were randomly divided into three groups (each group had six repetitions), that were housed in individual pens of 2.1 × 1.1 m with slated floors and were given, *ad libitum* access to feed and clean water for 82 days (d).

The pigs were also fed at 07:00 h and 14:00 h. The quantity of feed administered to the pigs was adjusted daily according to the quantity rejected the previous day.

The treatments were three experimental feeding regimens corresponding to: Control diet (CO) was based on corn, soybean meal, and wheat bran; MO leaf meal diet at 10 %, and BA leaf meal at 10 %. Leaves and stems of were collected in a forage bank, cut after 55 d of re-growth from. The leaves were separated from the stems and both plant materials were placed in a convection oven (Terlab, TE-H80DM, USA) at 50 ºC for 48 h. After drying, leaves and stems were ground in an hammer mill grinder with a sieve size of 3 mm (Verde Turbo, model 610300, Mexico)

The composition and chemical analysis of experimental diets are presented in TABLES I and II, respectively.

The experimental diets were formulated according to Nutrient Requirements for Swine (NRC) guidelines [15] to fulfill. After feeding period, all pigs were humanely slaughter when they reached an average live weight of 50.1 ± 1.65 kg (Torrey, model EQB 100, Mexico), following the Official Mexican Standards (NOM-008-ZOO-1994, NOM-009-ZOO-1994, and NOM-033-ZOO-995).

Samples of the *Biceps femoris* muscle were obtained from the left carcass of each animal.

TABLE I
Composition and nutrient levels of experimental diets to Mexican hairless pigs

Dietary components	Diets		
	CO	MO	BA
Corn (%)	35.96	38.37	37.95
Soybean meal (%)	11.52	11.28	11.73
Bran (%)	48.07	35.91	36.50
Sunflower oil (%)	2.00	2.00	2.00
Moringa olifera leaf meal (%)	0.00	10.00	0.00
Brosimun alicastrum leaf meal (%)	0.00	0.00	10.00
Calcium phosphate (%)	1.08	1.13	1.11
Calcium carbonate (%)	0.75	0.72	0.00
Vitamin Premix (%)	0.05	0.05	0.05
Mineral Premix (%)	0.10	0.10	0.10
Lysine 98 (%)	0.22	0.16	0.28
Methionine (%)	0.00	0.03	0.03
Sodium chloride (%)	0.25	0.25	0.25

CO: control diet, MO: *Moringa olifera* leaf meal diet, BA: *Brosimun alicastrum* leaf meal diet.

TABLE II
Composition of fatty acid profile (%) and antioxidant capacity of experimental diets supplemented with meal from the arboreal offered to Mexican hairless pigs

Chemical composition	Diets		
	CO	MO	BA
Fatty acids			
C14:0	1.88	6.87	5.59
C15:0	3.07	0.52	0.20
C16:0	2.38	3.36	3.29
C17:0	0.04	0.23	0.10
C18:0	6.00	12.17	5.12
C20:0	1.62	0.15	1.84
C14:1 n-5	2.29	7.08	7.11
C15:1c10	2.60	0.18	0.07
C16:1 n-7	6.81	6.38	5.91
17:1c10	0.04	0.45	0.11
C18:1 n-9	46.98	38.01	41.55
C20:4 n-6	2.01	0.53	0.55
C22:1 n-9	0.83	0.84	0.31
C18:2 n-6	11.05	17.14	24.19
C18:3 n-3	5.32	4.89	3.60
C20:3 n-6	0.04	1.00	0.12
C20:5 n-3	3.22	0.04	0.16
C22:6 n-3	3.82	0.16	0.15
ABTS*	450.51	1059.23	1096.12
DPPH*	413.26	1038.48	817.33
α-tocopherol (mg/g fat)	27.50	29.34	33.25

CO: control diet, MO: *Moringa olifera* leaf meal diet, BA: *Brosimun alicastrum* leaf meal diet. *µMTrolox/g of DW. ABTS: 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid). DPPH:2,2-difenil-1-picrilhidrazilo

Proximate composition of meat

The chemical composition analysis (moisture, crude protein, intramuscular fat and ash) of meat samples from the *Biceps femoris* muscle was carried. The determination of proximal components was performed according to the official methodologies described by the Association of Official Analytical Chemists (AOAC, 2019). In this regard, the moisture, raw protein, ash, and intramuscular fat content of meat samples were quantified using the standardized methods AOAC 950.46, AOAC 981.10, AOAC 920.153, and AOAC 991.36, respectively.

Fatty acid profile analyses

Diet and tissue lipids were extracted following the procedure described by Hanson and Olley [16], which were converted to fatty acid methyl esters with methanolic KOH and BF3 [17]. Fatty acid composition was carried out on a gas chromatograph (TRACE GC Ultra, Thermo scientific Inc®. Milan, Italy) according to the conditions described by Dzib-Cauich *et al*. [18].

The percentages of Unsaturated fatty acids (UFA) were the sum of monounsaturated fatty acids (MUFAs) and PUFAs. Desirable fatty acids (DFA) were the sum of C18:0 and UFAs. Additionally, nutritional indices of lipids were calculated as follows: thrombogenic index y atherogenic index [19], and nutritive value index [20].

DPPH assay

The antioxidant capacity of the meat was evaluated using the DPPH (2,20-diphenyl-1-picrylhydrazyl) according to the technique by Brand *et al*. [21] The results were expressed as µM Trolox equivalents/100 g of dry weight (DW).

ABTS+ assay

The antioxidant capacity of the meat was evaluated using the DPPH (2,20-diphenyl-1-picrylhydrazyl) according to the technique by Brand *et al*. [21] The results were expressed as µM Trolox equivalents/100 g of dry weight (DW).

α-tocopherol quantification

Before the analysis, 500 mg of intramuscular fat and crude fat were diluted in 1 mL of 2-propanol. The determination of α-tocopherol was carried out with HPLC (Thermo Fischer Scientific, USA). Separation was performed on a reverse phase Nucleosil C18 column (250 mm x 4.6 mm, 5 µm particle size). The mobile phase was acetonitrile:methanol:dichlorometha ne (60:38:2 v/v). The system was operated isocratically at a flow rate of 1 mL/min – 1, and peaks were recorded at 285 and 335 nm as excitation and emission wavelengths, respectively. The injection volume was 50 µL. The identification and quantification of the peaks were performed by comparison with the α-tocopherol standard. The results were expressed as µg of α-tocopherol/g.

Statistical analysis

All statistical analyses were performed using the SAS Version 9.4 statistical package (SAS Institute Inc., Cary, NC, USA). A Shapiro-Wilk test was performed to evaluate the normality of data. The results of the physicochemical characteristics, antioxidant capacity and fatty acid composition of meat were analyzed using a simple one-way analysis of variance (ANOVA). The linear model was as follows:

$$Yij = \mu + Ti + \varepsilon ij$$

where:

Yij is the response variable;

µ is the overall mean common to all observations;

Ti = is the effect of the ith experimental diet;

εij is the random error with mean 0 and variance σ2.

The means were compared by Tukey's *post hoc* test (α = 0.05). For statistical analyses, the individual pig was the experimental unit.

RESULTS AND DISCUSSION

The effects of dietary supplementation with MO and BA leaf meal on proximate composition and oxidative characteristics in *Biceps femoris* muscle of MHP are presented in TABLE III.

TABLE III
Effect of dietary supplementation with Moringa oleifera and Brosimum alicastrum leaf meal characteristics in Biceps femoris muscle of Mexican hairless pigs (n=6).

Dietary components	Diets			*P*-value
	CO	MO	BA	
Moisture (g 100 g^{-1} of meat)	70.61	70.89	70.79	0.439
Crude protein (g 100 g^{-1} of meat)	21.78	21.60	21.98	0.904
IMF (g 100 g^{-1} of meat)	10.19^{a}	7.27^{b}	7.02^{b}	0.010
Ash (g 100 g^{-1} of meat)	3.91	4.01	3.96	0.872
α-tocopherol (µg/g of fat).	4.34^{c}	14.55^{b}	48.33^{a}	0.001
DPPH (µM Trolox/g of DW)	262.68^{c}	450.48^{a}	354.70^{b}	0.001
ABTS (µM Trolox/g of DW)	193.39^{b}	471.89^{a}	329.79^{ba}	0.006

^{a,b,c} Means within the same row showing different letters are significantly different at *P* <0.05 and *p* <0.001. CO: control diet, MO: *Moringa olifera* meal diet, BA: *Brosimun alicastrum meal diet*, IMF: intramuscular fat, DW: dry weight.

There were no significant differences (P > 0.05) in the moisture, crude protein, and ash content of meat between treatments (P= 0.439-0.904). However, dietary supplementation had a significant (P < 0.05) effect on intramuscular fat. Pigs fed with the control diet were characterized by a higher intramuscular fat proportion in meat (10.19 g/100 g of meat), compared to pigs supplemented with MO and BA leaf meal (7.27 and 7.02 g/100 g of meat, respectively).

These results confirmed the findings by Pieszka *et al*. [23] who did not find significant differences in chemical parameters of meat (dry matter, crude protein, and crude fat) between control diet and experimental diets based on dietary supplementation with dried apple, chokeberry, black currant, strawberry and carrot pomaces. In the study by Chu and Park [24], although substituted fermented carrot by-product diets showed no effect on the contents of moisture, protein, and ash, it did affect ether extract.

According to the cited authors, when the intramuscular fat is distributed more evenly throughout the meat, the tissue is more relaxed, which ultimately affects meat tenderness. In addition, fat is also a carrier of flavor and juiciness, which affects the technological value and taste of meat and meat products [25]. In their research, Tomović *et al*. [26] observed an inverse relationship of moisture, protein and ash levels with increasing percentages of fat. The authors justify the variation in the intramuscular fat content by the high lipid synthesis capacity of the autochthonous pig breed. In general, analytical results of the proximate composition of meat were similar to those reported by Kim and Kim [27] in standard and sow pork.

However, dietary MO and BA supplementation increased significantly (P < 0.001) the concentration of oxidative characteristics. Meat of pigs fed with BA leaf meal presented higher α-tocopherol content (48.33 µg/g of fat), while pigs fed with the control diet had lower α-tocopherol content (4.34 µg/g of fat). The forages contain high levels of vitamin E (α-tocopherol); therefore, the increase in α-tocopherol concentration of pigs that were fed BA and MO diets can be explained by forage consumption. These same findings were reported by Rey *et al*. [28] in pigs fed with grass. α-Tocopherol is the most potent form of vitamin E that acts as an antioxidant. Therefore, results suggest that it is possible to protect MHP meat from oxidative deterioration through the consumption of these forage resources.

The DPPH concentration was higher in the meat of pigs supplemented with MO (450.48 µM Trolox/g of DW). Meanwhile, pigs fed with BA leaf meal were characterized by a higher ABTS content in meat (471.89 µM Trolox/g of DW) compared to pigs fed with CO diet (193.39 µM Trolox/g of DW), the results of the DPPH and ABTS+ assays in meat could be attributed to the phenolic compounds present in MO and BA [13, 14]. Similarly, Qwele *et al*. [29] reported that by including MO in the diet of goats, the meat had higher DPPH and ABTS+ activity, which is beneficial for human consumption.

The effects of dietary supplementation with MO and BA leaf meal on fatty acid composition of meat from *Biceps femoris* muscle of MHP are given in TABLE IV. Fatty acid concentrations were significantly affected (P < 0.05) by dietary supplementation type. The meat of the pigs supplemented with BA presented a higher percentage of myristic acid (C14:0), pentadecylic acid (C15:0), margaric acid (C17:0), myristoleic acid (C14:1c9), pentadecenoic acid (C15:01c10), and palmitoleic acid (C16:1c7), but the percentage of stearic acid (C18:0) was similar that those obtained in meat from pigs fed MO leaf meal. While the concentrations of behenic acid (C22:0), oleic acid (C18:1c9), erucic acid (C22:01), and docosahexaenoic acid (C22:6n-3) were higher in the meat of pigs fed with CO diet.

TABLE IV

Effect of dietary supplementation with Moringa oleifera and Brosimum alicastrum leaf meal on fatty acid composition (% of total fatty acids) in Biceps femoris muscle of Mexican hairless pigs (n=6).

Chemical composition	Diets			*P*-value
	CO	MO	BA	
C14:0	2.29^{b}	1.52^{c}	3.33^{a}	0.001
C15:0	0.57^{b}	0.47^{b}	1.71^{a}	0.003
C16:0	19.25	21.79	19.15	0.175
C17:0	0.29^{b}	0.29^{b}	0.60^{a}	0.048
C18:0	4.96^{b}	19.55^{a}	16.32^{a}	0.001
C20:0	0.55	0.59	0.68	0.820
C21:0	0.42	0.19	0.46	0.143
C22:0	2.11^{b}	0.82^{b}	1.46^{ba}	0.006
C23:0	0.04	0.01	0.04	0.287
ΣSFA	30.50^{b}	45.24^{a}	43.78^{a}	0.001
C14:1c9	1.01^{ba}	0.39^{b}	1.74^{a}	0.018
C15:01c10	1.02^{ba}	0.60^{b}	1.97^{a}	0.042
C16:1c7	4.63^{b}	5.06^{b}	6.19^{a}	0.009
C17:1c10	0.71	0.38	0.77	0.380
C18:1t9	4.50	5.09	5.31	0.542
C18:1c9	41.39^{a}	29.74^{b}	24.56^{c}	0.001
C20:1c-9	0.23	0.17	0.34	0.315
C22:01	0.93^{a}	0.06^{b}	0.09^{b}	0.048
ΣMUFA	54.46^{a}	41.52^{b}	41.00^{b}	0.001
C18:2 n-6	9.12	11.62	11.68	0.078
C20:3 n-6	0.23	0.17	0.34	0.315
C20:4 n-6	1.10	0.25	0.46	0.060
Σ n-6 PUFA	10.55	12.06	12.49	0.277
C18:3n-3	0.54	0.41	0.54	0.673
C20:3 n-3	0.70^{a}	0.20	0.65^{a}	0.003
C20:5 n-3	0.07	0.16^{a}	0.13^{b}	0.001
C22:6 n-3	2.73^{a}	0.31^{b}	1.13^{b}	0.005
Σn-3 PUFA	4.05^{a}	1.10	2.46^{b}	0.009
ΣPUFA	14.61^{c}	13.17	14.96	0.426
ΣUFA	69.08^{a}	54.69^{b}	55.97^{b}	0.001
ΣDFA	74.04	74.24	72.29	0.138
n-6/n-3	2.73^{b}	11.33^{a}	5.09^{b}	0.001
ΣPUFA/ΣSFA ratio	0.48^{a}	0.29^{b}	0.34^{ba}	0.018
ΣMUFA/ΣSFA ratio	1.80^{a}	0.91^{b}	0.93^{b}	0.001
Nutritive value	2.44	2.26	2.13	0.210
Atherogenic index	0.41^{b}	0.51^{a}	0.58^{a}	0.006
Thrombogenic index	0.59^{c}	1.42^{a}	1.13^{b}	0.001

[a,b,c] Means within the same row showing different letters are significantly different at p <0.05 and p <0.001. SFA: saturated fatty acids, MUFA: monounsaturated fatty acids, PUFA: polyunsaturated fatty acids, UFA: unsaturated fatty acids, DFA: desirable fatty acids, CO: control diet, MO: *Moringa olifera* meal diet, BA: *Brosimun alicastrum* meal diet.

On the other hand, these results were consistent with those reported by Kim and Kim [27] in meat from standard and sow pork, as well as by Luo *et al*. [30] in meat from lambs fed pastures. The results showed that the levels of SFAs in the meat of pigs supplemented with MO and BA leaf meal were higher than in control group. The concentration of saturated fatty acids (ΣSFA) was significantly higher in meat from pigs fed with MO and BA leaf meal. Instead, the monounsaturated fatty acids (ΣMUFA), polyunsaturated fatty acids (n-3PUFA). However, the excessively high PUFAs contents can impair meat pork processing because PUFA-rich fat is softer and greasier. Also, oxidation stability and thus product shelf life is reduced [31].

The higher concentration of PUFAs in the control group could be due to higher intramuscular fat content [1]. On the other hand, the pastures are naturally high in PUFAs, especially linolenic acid, which is reflected in muscle tissue. The Unsaturated fatty acids (ΣUFA), ΣPUFA/ΣSFA ratio, and ΣMUFA/ΣSFA ratio were higher in the meat of pigs fed with CO diet. Meat of pigs fed with MO and BA diets had higher atherogenic and thrombogenic index values compared to the meat of pigs fed with control diet the nutritive value index in the meat of pigs did not differ ($P > 0.05$) between treatments.

Likewise, ΣPUFA/ΣSFA ratio is considered as an indicator of the nutritional quality of meat [30]. In this study, the ΣPUFA/ΣSFA and ΣMUFA/ΣSFA ratios were higher in meat from pigs fed control diet than in pigs fed with MO and BA leaf meal. These results were consistent with those reported by Baerley *et al*. [25], who reported that the SFA/PUFA ratio identified in the meat was significantly higher in lambs from the control diet and the same was observed in the MUFA/PUFA ratio, compared to lambs fed diets based on yerba mate.

According to the authors, it was possible to observe that the inclusion of natural antioxidants in the diet, as yerba mate, reduced the concentration of total saturated fat present in meat. Likewise, Luo *et al*. [30] reported that antioxidant capacity contributes to oxidative stability in lamb muscles, because natural antioxidants found in herbage improve meat quality to make meat more desirable. According to Russo [32], the appropriate PUFA/SFA ratio recommended for the human diet is between 0.40 and 0.45. Therefore, the PUFA/SFA ratios for meat of pigs suplemented with MO and BA leaf meals were slightly below the recommended values. Similar results were reported by Chernukha *et al.* [33] in backfat from four pig breeds: Livny (0.28), Duroc (0.30); Altai meat breed (0.77), and Mangalitsa (0.46).

The results of this study indicate a higher nutritive value index for pigs fed control diet, although this index value was not significantly affected. According to Cañeque *et al*. [20], the nutritive value indicates the healthiness of the diet with regard its lipid content; therefore, higher nutritive value is desirable since cholesterol levels in the blood are negatively affected by stearic acid and positively affected by palmitic acid. The dietary supplementation with MO and BA leaf meals significantly affected the index atherogenic (AI) and thrombogenic index (TI) values.

Meat from pigs fed MO and BA had higher atherogenic and thrombogenic index values compared to the meat from pigs fed with control diet. According to Güngör *et al*. [34], for the healthy human diet, low atherogenic and thrombogenic indices were recommend. Low AI values (< 1) indicate a good nutritional quality of the lipid fraction of the food, since the proportion of unsaturated fatty acids (considered anti-atherogenic) is greater than that of saturated fatty acids (considered pro-atherogenic). For its part, the TI estimates the thrombogenic capacity of all the lipids present in the food through the ratio between the SFA and the UFA. The difference with the AI is that in the calculation of the TI, more weight is given to n-3 PUFAs, which are the most recognized in the maintenance of cardiovascular health. Therefore, foods with low TI values (< 1.15) are considered beneficial for cardiovascular health [35]. The results were in the range 0.41 to 0.58 and 0.59 to 1.42 for AI and TI, respectively. These values were similar than those reported by Chernukha *et al*. [33] in backfat samples of different pig breeds, as Duroc (AI = 0.52 and TI = 1.44), Livny (AI = 0.51 and TI = 1.21), Altai (AI = 0.43 and TI = 1.05), and Mandalitsa (AI = 0.53 and TI = 1.15). Čitek *et al*. [36] also reported a significant decline in atherogenic and thrombogenic indexes in relation to dietary changes. These authors determined that corn and lineseed supplementation increases the content of myristic, linoleic, α-linolenic, and eicosapentaenoic acids and reduces the amount of palmitic, palmitoleic, oleic, eicosenoic, and arachidonic acids, improving atherogenic and thrombogenic indexes.

The results obtained in this study coincide with those reported by Zhang *et al*. [37] who evaluated the effect of including different levels of *Moringa oleifera* leaf meal (0, 3, 6 and 9 %) in diets for pigs at completion, analyzing productive performance, the meat quality, fatty acid composition and amino acid profile of *Longissimus thoracis* muscle. These authors observed that the inclusion of 6 % of moringa meal (M6) significantly modified the lipid profile, by reducing saturated fatty acids (C10:0, C12:0, C14:0 and C16:0) and increasing C18:1n9c, C20:3n3, C20:5n3 and total polyunsaturated fatty acids (PUFA n-3). There was also an increase in the content of total unsaturated fatty acids (TUFA) and monounsaturated fatty acids (MUFA) ($P < 0.05$), accompanied by a decrease in the rates of atherogenicity (AI) and thrombogenic (TI) as well as in the ratio n-6/n-3 (from 18.6 to 16.6). Taken together, these results show that *Moringa oleifera* meal improves the lipid profile of meat, favouring a higher proportion of unsaturated fatty acids and a lower n-6/n-3 ratio, conditions considered beneficial for human health.

The change in lipid profile seen after supplementation with *Moringa oleifera* leaf meal has significant nutritional and public health importance. Reducing SFA and increasing monounsaturated and MUFA, especially those in the n-3 series, are highly beneficial because they help lower plasma LDL cholesterol and triglycerides while raising HDL cholesterol, which supports cardiovascular health [38]

CONCLUSIONS

In conclusion, MO and BA leaf meals could be used as a local feed resource for MHP traditionally reared under tropical conditions to decrease intramuscular fat in meat. Likewise, dietary supplementation with MO and BA exhibited greater potential as a source of α-tocopherol, DPPH and ABTS+, which are essential to protect meat from oxidative problems that occur in the postmortem period and during maturation of the meat, improving their quality. In addition, the use of these forages does not affect the physicochemical properties (dry matter, crude protein, and crude fat) and nutritional value of meat.

The inclusion of MO and BA leaves in the diet of Mexican pigs significantly changed the profile of intramuscular fatty acids compared to the CO. In particular, the moringa diet increased the proportion of MUFAand reduced the proportion of SFA, suggesting that these plant supplements contribute to improving meat lipid quality and increase consumer health benefits. Despite this, further studies are needed to determine the slaughter weight and the optimal level of inclusion of MO and BA in the diet of these animals so as not to affect the lipid profile.

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Conflicts of interest

The authors declare no conflicts of interest.

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