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Posted Date: 17 December 2025

doi: 10.20944/preprints202512.1515.v1

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Article

Influence of Raising System and Dietary Olive Cake Supplementation on the Physicochemical Composition of Bísaro Pork Loins: A Comparative Analysis

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Abstract

This study aimed to: (1) evaluate and compare the effects of two rearing systems—intensive and extensive —on the quality characteristics of loins from Bísaro pigs, a traditional Portuguese breed, and (2) assess the influence of dietary supplementation with olive cake, a by-product of olive oil production, on the physicochemical composition of pork loins. Muscle samples from the *Longissimus thoracis et lumborum* joint were collected from Bísaro pig carcasses raised on farms in the Trás-os-Montes region of northern Portugal. The slaughter and carcass cutting were standardized and performed at the Bragança municipal slaughterhouse, to ensure consistency in sample processing and preparation for laboratory analyses. Comprehensive physicochemical evaluation showed that ash content was the only parameter exhibiting a statistically significant difference ($p = 0.007$) between rearing systems, suggesting that production conditions may affect the mineral content of the meat. No significant differences ($p > 0.05$) were observed between rearing systems for moisture, protein or total fat content. Similarly, dietary inclusion of olive cake in the animals' diet, irrespective of the rearing system, did not significantly affect any of these physicochemical traits. The fatty acid profile - including saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acids (PUFA) – also showed no statistically significant differences ($P > 0.05$) in relation to either rearing system or dietary treatment. Overall, the evidence indicates that olive cake is a sustainable and practical option for Bísaro pork production, without compromising meat quality.

Keywords: *Longissimus thoracis et lumborum*; rearing systems; Bísaro pork; physicochemical composition

1. Introduction

Olive oil production is a key agricultural activity in the European Union, particularly in Spain, Italy, Greece, and Portugal, which together account for approximately 95% of the EU's total output [1]. This high level of production has stimulated interest in valorizing olive oil by-products—such as olive cake—as ingredients in animal feed. Incorporating these by-products into livestock diets has a dual benefit: it can reduce feed while simultaneously enhancing the sustainability of the food production chain.

In pig farming, two main production systems are commonly employed: intensive (conventional) and extensive (alternative). Intensive systems are optimized for high productivity within controlled environments and rely on efficient resource use. Feeding, water supply, manure management, and ventilation are often automated, reducing labor requirements [2]. In contrast, extensive systems place greater emphasis on animal welfare and product quality. Pigs are typically allowed to roam outdoors and access natural forages. Growing consumer demand for meat produced under extensive systems, including organic, free-range, and antimicrobial-free methods, is driven by concerns related to

antibiotic resistance, environmental impact, food safety, and animal welfare. Consumers frequently associate meat from extensive systems with greater naturalness, lower chemical residues, and reduced contamination risk, which has contributed to the increasing popularity of pork products derived from alternative production systems [3].

Differences between intensive and extensive pig production are shaped by factors such as climate, available space, and forage quality. Extensive systems are often associated with improved meat quality and enhanced ethical standards. However, research has shown considerable variability in meat quality traits. This variability occurs not only between intensive and extensive systems but also among distinct types of outdoor systems and even within the same system across different seasons. Key determinants of carcass and meat quality include breed genotype (traditional versus modern breeds), environmental conditions, and dietary management. Conversely, the effects of increased physical activity and behavioral enrichment typical of outdoor systems on meat quality are less consistent and remain the subject of ongoing investigation.

The use of autochthonous pig breeds for meat production is of particular interest, contribute of the valorization, protection, and conservation of zoogenetic heritage [4].

2. Materials and Methods

2.1. Animals and Diets

A total of 47 animals of the autochthonous Bísaro breed were used in this study. Of these, 23 were reared under an indoor production system at the University of Trás-os-Montes and Alto Douro, while the remaining 24 animals were raised under an extensive production system on a typical Bísaro farm located in Castro Vicente – Mogadouro (Portugal). Two experimental groups were therefore defined according to the production system (Indoor vs. Extensive). Within each production system, animals were further allocated to one of two dietary groups. The first group received the traditional diet for this breed (WOC), composed of standard feed formulated for each growth stage. The second group received the same basal diet supplemented with 20% olive cake (OC). The olive cake was provided during the finishing phase for both production systems, corresponding to the last three months prior to slaughter.

All animals were slaughtered at 12 months of age at the Municipal slaughterhouse of Bragança, with an average body weight (BW) of approximately 125 kg and a carcass weight (CW) of about 96 kg. Slaughter and carcass preparation procedures followed the protocol described by Álvarez-Rodríguez and Teixeira [5]. All handling and slaughter practices complied with Regulation [6], on the protection of animals at the time of killing. After 24 hours of chilling, the carcasses were transferred to the cutting facility and sectioned into the respective commercial joints.

Table 1. Ingredient composition of experimental diets (g/kg, as fed basis).

	Diets Indoor and Extensive	
	OC	WOC
Olive cake	20	0
Barley grain	41.20	41.20
Wheat grain	20.40	20.40
Soybean meal 47	11.60	11.60
Rice bran	4.50	4.50
Corn grain	2.20	2.20
DDG’s corn	4.50	4.50
Beet molasses	3.60	3.60
Minerals and vitamins	1.70	1.70
Supplement	0.30	0.30
min+vit+fitase		

Chemical composition of diet		
DM	98.15	98.15
OM	94.16	94.16
NDF	24.04	24.04
ADF	10.50	10.50
ADL	3.09	3.09
Cellulose	7.41	7.41
PB	14.39	14.39
GB	4.30	4.30

DM – dry-matters; OM – organic matter; NDF – neutral detergent fiber; ADF – acid detergent fiber; ADL: acid detergent lignin; PB – crude protein; GB – crude fat. OC – diet with olive cake; WOC – diet without olive cake.

2.2. Chemical Composition and Physicochemical Analysis

The pH was measured immediately after slaughter and again after 24 hours, following the Portuguese standard [7]. Measurements were taken using a portable potentiometer equipped with a penetration electrode, previously calibrated with standard buffer solutions (pH 4.01 and 7.02).

Meat color was assessed on the surface of the *Longissimus thoracis et lumborum* (LTL) muscle using the CIELAB color system, which expresses color parameters as lightness (L*), redness (a*), and yellowness (b*). A Lovibond RT Series Model SP62 (USA) colorimeter was used for this purpose, as described by the CIELAB coordinates L*, a*, and b* [5]. The hue angle (H*) and chroma (C*) values were calculated according to standard equations described by other authors [8].

Water-holding capacity (WHC) was evaluated according to the Honikel procedure [9]. Shear force (SF) was measured using and INSTRON 5543J-3177 equipped with a Warner-Bratzler blade. Muscle samples of LTL (100-120 g) were cooked in plastic bags in a 70 °C water bath until reaching 70 °C in the muscle center. Thirty minutes post-slaughter, muscle subsamples (1 cm² cross-section) were collected for shear force (SF) determination. Eight subsamples were taken from each sample and shear force was expressed as the average peak force (kgf) required to cut perpendicularly to the muscle fiber orientation. All measurements were performed at room temperature, following the procedures described by other authors[10].

The chemical composition of the *Longissimus thoracis et lumborum* (LTL) was analyzed using established procedures. Moisture content was determined according to the Portuguese Institute of Quality [11]. Duplicate 3 g portions of each sample were mixed with 5 mL of ethanol (96% v/v) and dried in an oven (Raypa DO-150, Barcelona, Spain) at 103 °C for 24 hours. Ash content was determined according to the Portuguese Institute of Quality Standard [12]. Approximately 3-5 g of each sample was placed in a crucible, and 1 mL of magnesium acetate solution (15% w/v) and incinerated in a muffle furnace (Vulcan Box Furnace Model 3-550, Yucaipa, CA, USA) at 550 ± 25°C for 5-6h. Protein content was determined according to the Portuguese Institute of Quality Standard [13], using the Kjeldahl sampler system (K370, Flawil, Switzerland) and the digest system (K-437, Flawil, Switzerland). Approximately 2 g of each sample was mineralized tube with two catalyst tablets and 25 mL of sulfuric acid (97 %). After digestion, distillation was performed, and the distillate was titrated with hydrochloric acid solution. The volume of acid required for titration was recorded. All composition parameters were expressed as percentages (g/100g of product). Water activity (a_w) was measured using a water activity probe (HygroPalmAw1 Rotronic 8303, Bassersdorf, Switzerland) in accordance with AOAC International [14].

2.3. Fatty Acid Analysis

Fatty acid analysis of the LTL samples was performed at the Carcass and Meat Quality Laboratory of ESA-IPB. Total lipids were extracted from 25 g of meat sample following the Folch method [15]. The fatty acid profile was determined using 50 mg of extracted fat. Fatty acids were transesterified according to the procedure described by other authors [16] Briefly, 4 mL of sodium

methoxide solution was added, and the mixture was vortexed for 5 min, allowed to stand for 15 min at room temperature, and then 5 mL of sulfuric acid solution in method (50 %) was added. Subsequently, 2 mL of distilled water was added, and the mixture was vortexed again. The organic phase containing the fatty acid methyl esters (FAME) was extracted with 2.35 mL of hexane. Separation and quantification of FAME were carried out using a gas chromatograph (GC-Shimadzu 2010 Plus; Shimadzu Corporation, Kyoto, Japan) equipped with a flame ionization detector (FID) and an automatic sample injector (AOC-20i). A Supelco SPTM-2560 fused silica capillary column (100 m x 0.25mm i.d., 0.2 µm film thickness) was used. Fatty acid contents were calculated from the chromatographic peak areas and expressed as g per 100 g of total FAME. The proportions of saturated (Σ SFA), monounsaturated (Σ MUFA), and polyunsaturated (Σ PUFA) fatty acids, as well as the Σ trans content and the PUFA n-6/n-3 ratio [17]. The atherogenic (AI) and thrombogenic (TI) indices were determined following the equations proposed by other authors [18].

2.4. Statistical Analysis

The Shapiro–Wilk test was used to test data for normal distribution and homogeneity of variance. Next, the effect of diet and raising methods, and the interaction between diet and raising methods, on the physicochemical composition and fatty acid profile were examined using analysis of variance (ANOVA) with the general linear model (GLM) procedure, in which these parameters were defined as dependent variables and diet and raising methods as fixed effects. The results were presented in terms of mean values and standard error of the mean (SEM). When there was a significant effect ($p < 0.05$), the means were compared using Student's t-test.

3. Results and Discussion

3.1. Physical Analysis

Physical measurements are presented in Table 2. No significant differences ($p \geq 0.005$) were observed for either BW or CW. Neither body weight nor carcass weight of Bísaro pig carcasses was influenced by the dietary treatment (with or without olive cake). Likewise, the production system (extensive vs. indoor) did not affect body weight at slaughter or carcass weight. These findings agree with previous studies reporting that the inclusion of olive by-products does not compromise the carcass performance of Apulo-Calabrese pigs [19] or Bísaro pigs [8].

The post-mortem decline in muscle pH and temperature during the first 24 hours is critical for the development of pork meat quality. A rapid drop in pH immediately after slaughter, particularly when combined with high muscle temperatures, can increase the risk of pale, soft, and exudative (PSE) meat. A low ultimate pH further intensifies PSE conditions due to protein denaturation and reduced water-holding capacity (WHC), affecting the visual, textural and processing attributes of meat. properties of meat. Thus, monitoring post-mortem pH is essential, given its substantial influence on overall meat quality [20]. In the present study, carcass pH values exhibited a normal post-mortem decline between slaughter and 24 h of refrigeration with no significant effects of diet or production system. Similar results have been observed by other authors investigating diets containing by-products [8,21]. WHC and SF are important meat quality traits because they influence juiciness and tenderness, respectively. Water-holding capacity (WHC) is a key parameter influencing weight loss, shrinkage, and juiciness during meat cooking [22]. In this study, WHC averaged 10.22% in pigs fed olive-cake diets and 11.96% in pigs fed diets without olive cake. Across production system, WHC ranged from 10.67 % in the extensive system to 11.50 % in the indoor system. Thus, WHC of the LTL muscle was not significantly affected by either the production systems or the diet. Slightly higher WHC values (approximately 13 %) were reported in Bísaro pigs receiving diets without by-product supplementation and reared under a semi-extensive production system [23] as well as in animals fed olive cake supplemented diets [8]. Much higher WHC values have been described in loin muscles of Korean pig breeds [24]. Conversely, some authors have observed lower WHC in pork from pigs with outdoor access compared with indoor systems [25] a tendency not detected in the present study. No

significant difference in SF were observed in relation to diet or production system. Mean SF values were 3.67 kgf in pigs fed diets without olive cake. Animals reared under extensive conditions showed a mean SF of 3.87 kgf, while those raised indoors averaged 3.49 kgf. Higher SF values have been reported for Pietrain, Duroc and Polish landrace breeds [26]. Under semi-extensive conditions [27] reported even higher SF values with mean of 6.12 kgf for the Lampiño breed, 6.10 kgf for the Retinto breed, and 6.09 kgf for the Iberian x Duroc crossbreed.

Regarding meat color parameters, neither diet nor production system significantly influenced the CIELAB parameters of Bísaro pork loin. Lightness (L^*) ranged from 52 to 53 regardless of olive-cake inclusion or production system. Similarly, no significant differences were observed in redness (a^*) or yellowness (b^*) with a^* values between 11 and 12, and b^* values between 10 and 11. Comparable L^* values have been reported for several breeds as Apulo-Calabrese [28], Iberian [29], Pulawska [30], Mangalica [31], Bísaro [8] and Prestice Black-Pied [32]. In contrast, lower L^* values have been observed in pigs raised under semi-extensive or extensive systems, such as Lampiño, Entrepelado and Retinto breeds [27]; Celta breed [33]; and Alentejana and Bísaro breeds [34]. Similar a^* and yellowness b^* values were reported for animals reared under semi-extensive production system and fed diets containing 10 % olive cake [8] as well as for Entrepelado and Lampiño pigs raised semi-extensively without dietary by-products [27].

Table 2. Effect of rearing system (Extensive and Indoor) and olive cake supplementation on the physical composition of Bísaro pork LTL.

							Sig		
	WOC	OC	SEM	Extensive	Indoor	SEM	Farming	Diet	Farming*Diet
BW	124.536	127.278	1.146	127.838	123.967	1.468	0.063	0.182	0.981
CW	96.810	99.181	1.388	99.644	96.347	1.215	0.056	0.165	0.996
pH (1h)	6.18	6.19	0.190	6.181	6.194	0.061	0.624	0.524	0.895
pH (24h)	5.76	5.83	0.084	5.76	5.82	0.074	0.535	0.483	0.916
WHC (%)	11.959	10.220	0.921	10.674	11.504	0.834	0.133	0.469	0.874
SF (Kgf)	3.671	3.689	0.229	3.873	3.487	0.207	0.949	0.179	0.858
Color parameters									
L^*	53.424	52.035	0.928	52.314	53.145	0.813	0.464	0.224	0.710
a^*	12.327	11.627	0.571	11.891	12.063	0.500	0.805	0.317	0.891
b^*	11.290	10.484	0.505	10.732	11.042	0.442	0.614	0.194	0.940
H^*	42.479	42.061	0.522	42.067	42.473	0.457	0.525	0.512	0.876
C^*	16.722	15.666	0.749	16.022	16.366	0.656	0.706	0.251	0.964

WOC – Without olive cake; OC – Olive cake; BW – live weight; CW - carcass weight; CSW - left side carcass weight. WHC – water holding capacity (%); SF – Shear Force (Kgf).

3.2. Chemical Composition

As shown in Table 3, the inclusion of olive cake in the diet of Bísaro pigs had a significant effect on the ash content of the *Longissimus thoracis et lumborum* (LTL) muscle. This result suggests that the incorporation of this by-product may influence the mineral fraction of the meat, either through its intrinsic mineral composition or by modifying nutrient availability during digestion. In contrast, no significant differences were observed for the total fat, moisture or protein content. These findings indicate that partial replacement of conventional feed with olive cake does not compromise the main nutritional characteristics of meat. Similarly, the production system (extensive vs. indoor), did not significantly influence the chemical composition of the LTL muscle, suggesting that, under the conditions evaluated, management system does not exert a decisive effect on the intrinsic nutritional properties of the meat.

For total fat content ranged from 6% to 7% with no influence detected from either dietary treatment or production system. Lower total fat values have been reported in crossbred Thai pigs, whose diets were partially replaced with different inclusion levels of ground perilla cake [35]. Similar values were observed in Bísaro pigs [8] reared under a semi-extensive production system and fed diets including 10 % olive cake. Liotta et al., in a trial with Pietrain pigs fed with different proportions of olive cake, recorded a lower intramuscular fat percentage than those observed in the present study. Likewise, lower intramuscular fat values have been reported for Celta pigs as well as for crossbreeds involving Duroc and Landrace indicating the important role of genetic background in determining IMF deposition [33]. Several studies suggest that extensive production systems – characterized by greater freedom of movement, increased physical activity, and more natural feeding– can enhance increased intramuscular fat deposition in some breeds [36–38].

Ash content ranged from 1.31% to 1.34% for the control diet (without olive cake) and the diet including olive cake, respectively, with no significant difference of diet ($p>0.05$). In contrast, significant differences were observed between production systems, with higher ash content recorded in pigs raised indoors. This increase may result from several factors. Indoor-reared pigs generally receive a controlled, mineral-supplemented diet, which may enhance mineral deposition in muscle tissue. Their lower physical activity could also reduce mineral mobilization for metabolic and structural functions, contributing to higher retention in muscle. Conversely, pigs raised in extensive systems typically exhibit greater physical activity and face more environmental conditions, which may increase mineral turnover and slightly reduce ash levels in the muscle [39,40].

Table 3. Chemical composition of LTL muscle in pigs fed diets with or without olive cake and raised under extensive or indoor production systems.

	LTL						Significance		
	WOC	OC	SEM	Extensiv e	Indoo r	SEM	Farmin g	Diet	Farming*Die t
Total Fat	6.752	7.563	0.83 8	7.224	7.091	7.33 0	0.899	0.43 7	0.456
Ash	1.339	1.313	0.06 2	1.216	1.436	0.05 7	0.007	0.74 3	0.789
Moistur e	68.41 2	68.67 5	0.63 5	68.303	68.784	0.57 5	0.542	0.73 9	0.708
Protein	23.00 4	22.76 2	0.25 6	22.857	22.909	0.23 2	0.871	0.44 8	0.745

WOC – Without olive cake; OC – Olive cake;.

For the moisture parameter, the values obtained in the LTL muscle were approximately 68%, with no detectable influence of either diet type or the production system in the Bísaro pigs. Comparable moisture values have been reported in the same breed when partially fed with olive cake [8]. Slightly higher values (72-73%) were observed in animals receiving a low-lysine diet supplemented with perilla cake, suggesting that such dietary formulation may affect water retention in the LTL muscle [35]. Other authors have reported moisture values of around 75% when comparing conventional, traditional, and organic rearing systems, also finding no significant effect of the rearing system on this parameter [38]. As expected, the protein content of the LTL muscle ranged between 22 and 23% which falls within the typical values reported for this type of muscle. Protein content may be influenced by factors such as diet (higher protein or amino acid levels that promote protein deposition) or genetic background (which affects the muscle to fat ratio and consequently the overall protein content). However, in the present study, no significant differences ($p >0.05$) were observed with either the inclusion of olive cake in the diet or the production systems. In contrat, other authors

have reported significant differences in protein content among production systems with conventional systems yielding the highest protein content (22%), compared to traditional and organic systems [38]. Furthermore, have demonstrated that protein content of the LTL muscle can vary significantly depending on breed (Preto Alentejano vs. commercial Large White x Landrace crossbred) [41]

3.3. Fatty Acid Profile

The fatty acid profile of the LTL muscle (Table 4) showed no significant differences among treatments for the total fractions of saturated (SFAs), monounsaturated (MUFAs), and polyunsaturated (PUFAs) fatty acids, either between dietary treatments (with or without olive cake inclusion) or between production systems (extensive vs indoor). The stability of these major fatty acid classes suggests that neither dietary supplementation with olive cake nor differences in rearing conditions were sufficient to modify the overall intramuscular lipid composition. The predominant SFAs were palmitic acid (C16:0) and stearic acid (C18:0). Palmitic acid ranged from 26.07% to 25.54% in diets without and with olive cake, respectively. Regarding the production system, the extensive system presented a mean value of 25.69%, while the indoor system reached 25.92%. In all cases, these differences were not statistically significant ($p > 0.05$). The narrow variation observed across both dietary treatments and production systems suggests that palmitic acid deposition in the LTL muscle is relatively stable and not readily modified by the inclusion of olive cake or by rearing conditions. Among all fatty acids identified in longissimus thoracis et lumborum, oleic acid (C18:1n-9), palmitic acid (C16:0), stearic acid (18:0), linoleic acid (C18:2n-6), and palmitoleic acid (C16:1n-7) represent more than 95% of total acids. Although several factors – such as diet, breed, and production system – can influence the fatty acid composition of pork, the profile described and discussed above is consistent with the typical fatty acid pattern generally reported for pork meat.

As expected for this type of matrix, MUFAs were the most abundant fatty acid group in the LTL muscle of animals reared under both extensive and indoor production systems, as well as those diets supplemented with olive cake or standard feed typical of an autochthonous breed. The mean MUFA content was 53%, with no statistically significant differences observed among groups. SFAs, accounted for an average of 38%, which falls within the range typically reported for pork fat. Conversely, PUFAs accounted for an average of 7%, reflecting their characteristically lower abundance in pork intramuscular fat. These values align with the general distribution of fatty acid classes commonly observed in pork meat. Lower MUFA and higher SFA values have been reported by other Portuguese autochthonous breeds, such as the Alentejano pig [42], the Chinese pig breed [43], and Zlotnicka Spotted pigs [44]. Studies investigating the effect of adding olive cake to the diet of Pietrain pigs [45] observed an increase in MUFA percentage at the highest inclusion level tested; however, MUFA values reported in that study remained lower than those obtained in our work. On the other hand, comparable MUFA values have been reported for the Iberian pig [46], Sicilian Black pig [47], Celta pig [33] and Croatian pig [48]. PUFA content is shaped by multiple physiological and nutritional factors, including not only the amount and structural characteristics of dietary lipids, but also the rate of *the novo* fatty acid synthesis, the efficiency with which specific fatty acids are converted into other metabolites, and the balance between oxidative pathways and overall energy demand. When olive cake is incorporated into the diet, the high availability of MUFAs can alter the incorporation of PUFAs into tissues. As a result, several studies have reported reductions in PUFA levels, particularly in red blood cell membranes, suggesting that elevated MUFA levels may limit the incorporation of PUFAs into cellular lipid fractions [45]. The SFA, MUFA, and PUFA proportions observed in the present study are consistent with values previously reported for the same muscle in pigs reared under semi-extensive production conditions and fed diets supplemented with 10% olive cake [8]. These similarities further support the consistency of the fatty acid profile reported here with findings from comparable production and feeding systems. The mean PUFA values obtained in the present study were lower than those reported for the Iberian breed under standard unsupplemented diets [46]. In addition, higher PUFA levels have been described in Pietrain pigs [45] when olive cake was incorporated into the diet. Together, these comparisons suggest that the PUFA content observed

in our experimental conditions is comparatively reduced, even when compared with breeds and dietary strategies generally associated with moderate to elevated PUFA deposition.

Within the fatty acid profile obtained, two individual fatty acids exhibited variation associated with either the diet type or the production system. Pentadenoic acid (C15:0) averaged 0.169% in animals raised under the extensive system, whereas a significantly higher value (0.216%) was observed in the indoor system. No significant differences were detected with respect to diet type. Although previous studies on pork lipid composition rarely highlight this fatty acid due to its residual level, interest in odd-chain fatty acid has been increasing. In the present study, a significant difference associated with the production system was observed; however, its precise physiological or nutritional origin could not be determined. Several studies indicate that pentadecanoic acid (C15:0), an odd-chain saturated fatty acid, plays an essential role in maintaining health, and may exert beneficial cardiometabolic, immune, and hepatic effects [49].

Table 4. Fatty acid composition of LTL muscle in pigs fed diets with or without olive cake and raised under extensive or indoor production systems.

Fatty Acid	LTL						Significance		
	WOC	OC	SEM	Extensive	Indoor	SEM	Farming	Diet	Farming*Diet
C12:0	0.043	0.041	0.003	0.041	0.042	0.003	0.685	0.663	0.235
C14:0	1.078	1.097	0.032	1.116	1.059	0.029	0.157	0.624	0.442
C14:1	0.026	0.022	0.003	0.022	0.026	0.003	0.402	0.385	0.335
C15:0	0.193	0.191	0.018	0.169	0.216	0.016	0.038	0.929	0.088
C16:0	26.068	25.543	0.189	25.693	25.918	0.237	0.491	0.112	0.915
C16:1n-7	3.014	2.776	0.083	2.898	2.892	0.075	0.951	0.024	0.545
C17:0	0.108	0.097	0.01	0.098	0.101	0.009	0.416	0.369	0.319
C17:1n-7	0.176	0.184	0.024	0.195	0.165	0.022	0.320	0.773	0.643
C18:0	11.126	11.162	0.204	11.030	11.257	0.185	0.374	0.886	0.298
9t-C18:1	0.161	0.171	0.006	0.175	0.157	0.008	0.095	0.377	0.379
C18:1n-9	49.883	50.300	0.413	50.362	49.821	0.374	0.293	0.417	0.237
9t,12t-C18:2	0.002	0.003	0.001	0.003	0.003	0.001	0.721	0.702	0.810
C18:2n-6	6.059	6.302	0.185	6.130	6.231	0.168	0.661	0.294	0.096
Fatty Acid	LTL						Significance		
	WOC	OC	SEM	Extensive	Indoor	SEM	Farming	Diet	Farming*Diet
C20:0	0.149	0.163	0.008	0.152	0.160	0.008	0.426	0.169	0.964
C18:3n-3	0.684	0.724	0.018	0.698	0.710	0.016	0.587	0.084	0.736
C20:1n-9	0.205	0.228	0.016	0.212	0.220	0.014	0.672	0.237	0.319
C21:0	0.024	0.019	0.005	0.019	0.024	0.004	0.364	0.392	0.321
C20:2n-6	0.194	0.216	0.016	0.203	0.208	0.014	0.815	0.265	0.492
C22:0	0.026	0.025	0.003	0.025	0.025	0.003	0.976	0.868	0.342
C20:3n-6	0.036	0.037	0.009	0.032	0.041	0.008	0.398	0.865	0.463
C22:1n-9	0.013	0.021	0.004	0.012	0.021	0.004	0.095	0.125	0.904
C20:3n-3	0.525	0.519	0.038	0.521	0.523	0.035	0.973	0.900	0.686
C24:1n-9	0.101	0.088	0.01	0.093	0.096	0.009	0.756	0.296	0.221
C22:6n-3	0.050	0.040	0.006	0.044	0.046	0.005	0.840	0.155	0.639

Fatty Acid	LTL						Significance		
	WOC	OC	SEM	Extensive	Indoor	SEM	Farming	Diet	Farming*Diet
SFA	38.841	38.361	0.428	38.368	38.834	0.388	0.381	0.369	0.692
MUFA	53.599	53.791	0.427	53.992	53.399	0.387	0.267	0.717	0.226
PUFA	7.560	7.847	0.226	7.641	7.767	0.205	0.654	0.310	0.124
n-6/n-3	12.548	13.905	0.995	13.294	13.159	0.902	0.913	0.245	0.472
IA	0.498	0.487	0.009	0.491	0.494	0.008	0.725	0.332	0.741
IT	1.193	1.174	0.024	1.173	1.194	0.022	0.493	0.534	0.680
h/H	2.082	2.152	0.039	2.132	2.103	0.035	0.545	0.155	0.904

WOC – Without olive cake; OC – Olive cake; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; IA, index of atherogenicity; IT, index of thrombogenicity; h/H, hypocholesterolemic/ hypercholesterolemic index; Only fatty acids which represented more than 0.1% are presented in the table, although all detected fatty acids were used for calculating the summatories and the indices.

The fatty acid profile is a key determinant of the metabolic effects associated with dietary lipids, as different classes of fatty acids influence plasma lipid fractions in distinct ways. Well-established evidence indicates that high dietary intake of saturated fatty acids increases low-density lipoproteins (LDL) concentrations, whereas a greater proportion of polyunsaturated fatty acids has the opposite effect, lowering LDL levels. In addition, polyunsaturated fatty acids are known to enhance high-density lipoprotein (HDL) concentrations, a lipoprotein fraction associated with cardioprotective mechanisms [50]. The relevance of the dietary n-6/n-3 ratio in the prevention of chronic diseases is largely attributed to the anti-inflammatory properties of α -linolenic acid (ALA, 18:3n3) and of the long-chain n-3 PUFA [51]. The n-6/n-3 PUFA ratio was not significantly influenced by dietary treatment or the production system, with mean values ranging from 12 to 13%. According to the recommendations of the British Department of Health [52], the n-6/n-3 ratio should not exceed 4. However, the literature consistently indicates that achieving this threshold in pork is particularly challenging. This challenge is mainly attributed to the high content of C18:2n-6 in conventional pig diets, which strongly affects the meat's lipid profile and results in n-6/n-3 ratios that commonly exceed recommended values. Similar PUFA values have been reported by other authors for the Prestice Black-Pied breed [32]. Higher values were observed in the Alentejano breed [42] and Bísaro pigs [8], whose diets also included olive cake, potentially explaining their increased PUFA levels. The atherogenicity index (AI) and the thrombogenicity index (TI) are indicators that reflect the tendency of fatty acids to contribute to atherogenic or thrombogenic processes [18]. Lower AI and TI values denote a more favorable nutritional lipid profile, potentially associated with a reduced likelihood of developing coronary heart disease. Despite their relevance, reference guidelines defining optimal or recommended AI and TI values have not yet been issued by regulatory or health institutions. The h/H ratio expresses the balance of fatty acids according to their impact on cholesterol metabolism. Higher values indicate a more desirable nutritional contribution [53]. In the present study, the lipid quality indices AI, IT and h/H remained consistent across both production systems and dietary treatments. This outcome aligns with expectations based on the profiles of individual fatty acids and their respective fractions, suggesting that the type of feeding or rearing system employed did not substantially alter the nutritional quality of the fat.

4. Conclusions

Overall, the present results clearly demonstrate that olive cake can be incorporated into Bísaro pig diets as a sustainable feeding strategy without compromising the chemical quality of the meat. The absence of significant differences between indoor and extensive systems further confirms that

the production system is not a key determinant for the parameters assessed. The consistent outcomes across both systems highlight the potential value of olive cake as an effective circular-economy ingredient capable of reducing agro-industrial waste while supporting environmentally responsible livestock production and demonstrates that nutritional innovation can be integrated into traditional systems without compromising product quality. Collectively, these findings provide robust evidence that olive cake is a feasible, sustainable and quality-preserving option for Bisaro pork production, maintaining the meat's quality attributes.

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