Does hunted wild boar meat meet modern consumer nutritional expectations?

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Abstract

The present study aimed to evaluate the nutritional characteristics of hunted wild boar (WB) meat and compare them with those of meat from analogous domestic animals (pigs) reared in two different rearing systems: indoor-intensive (PI) and outdoor-extensive (PO). WB meat showed a lower amount of lipid content compared to pork and a higher antioxidant activity compared to PI and PO. The comparison of the fatty acid composition of WB and domestic pig reveals significant differences in saturated fatty acids (SFA) and polyunsaturated fatty acids (PUFA), with WB having the highest PUFA level and the lowest SFA level. The omega 6/omega 3 (n-6/n-3) PUFA ratio, PUFA/SFA, atherogenic and thrombogenic indices (AI and TI), as well as the hypocholesterolemic/hypercholesterolemic index (h/H), were calculated. The n-6/n-3 PUFA ratio was higher in pork independently of the rearing system. The PUFA/SFA ratio of WB meat was above the minimum ratio of 0.40 recommended to contribute to a reduction in the risk of coronary diseases in pork from both rearing systems. AI and TI were lower in WB meat compared to commercially reared pigs, while h/H was higher in WB in comparison with pork meat. WB meat shows good nutritional quality; therefore, the use of game meat as a food source could be appropriate and could benefit contemporary consumers looking for "green" and high-nutritional products.

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Introduction

In recent years, ungulate populations, particularly wild boars (WB), have grown significantly in Europe and other industrialized countries, both in their absolute numbers and their range of distribution. This growth is frequently perceived as posing a threat due to increased contact with urban environments, which could result in damage to crop production, collisions with vehicles, and the potential spread of zoonoses (Ramanzin *et al.*, 2010; Ranucci *et al.*, 2021). Hunting activity plays an important role in regulating wildlife populations, and sustainability is ingrained in many current hunting practices. Currently, approximately 7 million hunters are registered in Europe (Needham *et al.,* 2023) and are pivotal in the primary production sector of game meat. European countries with the highest absolute numbers of registered hunters include France (approximately 1.3 million), Spain, the United Kingdom, and Italy (Needham *et al.,* 2023).

The expansion of wild game species poses several issues in European countries as they increasingly come into contact with urban areas, causing crop damage, vehicle collisions, and the potential spread of zoonotic diseases (Ranucci *et al*., 2021). On the other hand, enhancing the availability of WB meat and products thereof could have a positive effect on local economies (Ranucci *et al.,* 2021; Roila *et al.,* 2021). Consumers are becoming more positive towards game meat consumption, primarily because of its perceived health benefits, ethical production practices, and the experience of tasting exotic meats (Czarniecka-Skubina *et al.,* 2022). The health benefits of game meat are associated with a very good chemical composition, low fat content, an ideal ratio of

unsaturated to saturated fatty acids (SFA), and high protein content and protein composition, according to the available scientific evidence (Viganò *et al.,* 2019; Ciobanu *et al*., 2022; Marescotti *et al*., 2021). Indeed, nowadays there is public consciousness of the role of diet in contributing to health status; therefore, game meat could serve as a substitute for meat from domestic animals to meet the needs of consumers both now and in the future (Demartini *et al*., 2021). Despite the growing interest, game meat consumption contributes marginally to total meat consumption compared to domesticated livestock species (Corradini *et al.,* 2022).

The objective of this study was to evaluate the nutritional quality of hunted WB meat, determining the physico-chemical characteristics, antioxidant status, and fatty acid composition, as well as the nutritional indices of *Longissimus lumborum* (LL) muscle in the sampled animals.

Specifically, the study aims to compare the characteristics of WB meat to those of pigs reared in indoor (PI) and outdoor (PO) systems, thus widening the knowledge of existing differences between wild and domestic animals.

Materials and Methods

The study was conducted on 20 WB collected during hunting season following a selection plan for population control (from October 2022 to April 2023) set by the Umbria region (Central Italy) (Umbria Region, 2017). WB were hunted using the "*aspetto*" system (or still hunting) without dogs, just waiting for WB to pass in front of specific hidden shooting points in the area between Gubbio and Gualdo Tadino (province of Perugia, Italy).

The feeding areas of WB are mainly characterized by forest, and they are mainly featured by *Quercus pubescens*, *Quercus cerris*, *Ostrya carpinifolia*, and *Quercus robur* (Pedrazzoli *et al.,* 2017). As reported in the literature (Pedrazzoli *et al.,* 2017; Ranucci *et al.,* 2021), the plant species present in the area according to season can influence WB meat quality. The *LL* muscle of the hunted WB was sampled at the local game-handling establishment, where skinning was promptly performed [as set by Regulation 853/2004 (European Parliament and Council of the European Union, 2004)]. The meat of 20 hunted adult (>12 months) male WB (live weight 68±6 kg) was compared with that of 20 PI male hybrid pigs and 20 PO male hybrid pigs from farms located in the Umbria region (central Italy). For pork, LL sampling was carried out by collecting the meat cut from the carcass (average weight 103±7 and 92±10 kg for PI and PO, respectively) in the sectioning laboratory of a local butcher. *LL* muscles of WB and pork after sampling were transported under refrigerated conditions to the laboratory, where they were frozen at -20°C until analysis.

Physicochemical analysis of meat

A sample of each LL muscle (20 WB, 20 PI, and 20 PO) was analyzed for chemical composition according to the Association of Analytical Chemists methods (AOAC, 2000). The moisture content was obtained by oven-drying meat samples (125°C for 2 hours) (method 950.46). The fat content was gravimetrically determined using ether solvent extraction (method 960.30). The nitrogen content was determined using the Kjeldahl method (method 992.15). The protein content was obtained by multiplying the total Kjeldahl nitrogen with a coefficient factor of 6.25. The ash content was obtained using a muffle furnace at 600°C (method 923.03).

Antioxidant capacity of *Longissimus lumborum* muscle

The antioxidant capacity was evaluated using the oxygen radical absorbance capacity ($ORAC_{FL}$) method. One gram of muscle was mixed with a buffer containing KH_2PO_4 13.19 g/L and K_2HPO_4 10.26 g/L (v/v) solution at pH 7.2, homogenized with Ultra-Turrax homogenizer (Ultra Turrax T25 Basic, IKA Labortechnik Janke & Kunkel GmbH, Staufen, Germany) for 1 minute, and then vortexed for 2 minutes. The homogenates were centrifuged at 6000 rpm at 4°C for 20 minutes, and the supernatant was used for the determination of the antioxidant capacity using the $ORAC_{FL}$ method based on the fluorescence decay rate of a probe in the presence of a radical oxygen species compared with that of a reference standard, Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, Sigma-Aldrich, Steinheim, Germany). The $ORAC_{FL}$ assays were carried out on a FLUO-star OPTIMA microplate fluorescence reader (BMGLABTECH, Offenburg, Germany) at an excitation wavelength of 485 nm and an emission wavelength of 520 nm, as reported in Branciari *et al*. (2015). The results were expressed as µg of Trolox equivalents per 100 g sample.

Fatty acids profile of *Longissimus lumborum* muscle

LL muscle fatty acids were extracted according to Branciari *et al.* (2017), and the lipids were then esterified following the method described by Branciari *et al.* (2020). Fatty acid methyl esters were separated and quantified using a Perkin-Elmer AutoSystem-XL gas chromatograph equipped with a flame ionization detector and a split-splitless injector. Analyses were conducted with a CP-Select CB for FAME fused silica capillary column (100 m × 0.25 mm i.d., film thickness 0.39 µm, J&W, Agilent Technologies, Palo Alto, CA, USA). The injection volume was 1 µL. The carrier gas was high-purity helium with a flow rate of 1 mL/min. The injector and detector temperatures were kept at 290°C. The column oven temperature was programmed at 120°C increasing by 3.2°C/minute up to 170°C and then increasing by 2.1°C/minute from 170 to 225°C. Fatty acids were identified by comparison with standards as described by Branciari *et al.* (2017).

Nutritional indices

The nutritional value of fatty acids in LL muscle was calculated as reported in Table 1 (Fernández *et al.*, 2007; McAfee *et al*., 2010; Pires *et al.*, 2020; Ciobanu *et al.*, 2022; Reitznerová *et al*., 2023).

Statistical analysis

The data were analyzed using the generalized linear model procedure of SAS (2010). An analysis of variance model was considered with WB, PI, and PO as fixed variables. The age and weight of the animals were not considered in the model because they were not found to be significant ($p>0.05$). Data are reported as least squares mean ± standard deviation. A p value lower than 0.05 was considered to be statistically significant.

Results and Discussion

The results of the chemical composition and antioxidant activity of the *LL* muscle of PI and PO pigs and hunted WB are reported in Table 2. No significant differences in the protein content were found among the three groups, while WB showed a lower amount of lipid

content compared to pork. PO had a higher lipid content percentage than their indoor counterparts. It is generally accepted that rustic breeds reared outdoors produce a higher intramuscular fat content (Franco *et al.,* 2014). This is probably due to their higher capacity for accumulating fat (Renaudeau and Mourot, 2007), although it could also be influenced by the feed and the growing system (Edwards, 2005). The results of the lipid content of WB are similar to those of the literature confirming the low fat content of hunted game meat (Viganò *et al*., 2019), which is influenced mainly by the season and food availability (Ciobanu *et al.,* 2022).

The results for the antioxidant activity of *LL* muscle indicated by $ORAC_{FL}$ values are reported in Figure 1. Higher antioxidant activity was found in WB in comparison with PI and PO. Furthermore, the PO LL muscle showed higher antioxidant activity than the PI one. The production system influences the muscle antioxidant contents of pork meat, as reported in the literature (Tejerina *et al*., 2012). Indeed, Rey *et al.* (2006) state that the PO system could be a natural way to increase the content of antioxidant substances in pigs. In fact, in nature, WB, having an opportunist and omnivorous feeding behavior, eats a great variety of vegetable material, including herbs, grains, seeds, roots, soft and hard mast, but also insects, earthworms, slugs, small mammals, eggs, and nestlings of ground-nesting birds (Pedrazzoli *et al*., 2017), which influences the incorporation of natural antioxidant substances in the diet. The results of the determination of fatty acids composition and nutritional indices are presented in Tables 3 and 4.

A total of 30 major fatty acids, including eight SFA, nine monounsaturated fatty acids (MUFA), and ten polyunsaturated fatty acids (PUFA), were identified and quantified. Significant differences were detected among the three groups. Total SFA ranged from 34.08% in WB to 43.49% in PI, and the most prominent (C16:0 and C18:0) were identified, accounting for over 60% and about 30% of total SFA, respectively, in all three animals' groups. MUFA ranged from 45.24% in WB to 49.76% in PO and was the most prevalent lipid component in pork and WB meat. C18:1 n-9 was the major MUFA group, accounting for over 80% of all MUFA. PUFA ranged from 8.76 in PO to 20.68 in WB, and C18:2 omega 6 (n-6) was the most prevalent in terms of amount (accounting for up to 78% of all PUFA in WB). The fatty acid composition of the samples, both pork meat and WB meat, was in accordance with the results of other studies (Pedrazzoli *et al*., 2017; Ciobanu *et al.,* 2022), where C18:1 n-9 (oleic) was the most abundant fatty acid, followed by C16:0, C18:0, and C18:2 n-6. The same decreasing order of concentration was found in pork as well as WB meat submitted to different feeding regimes (natural feed, supplementary feed, complete diet), age, or gender (Högberg *et al.,* 2002; Pedrazzoli *et al.,* 2017; Ciobanu *et al.,* 2022; Reitznerová *et al.,* 2023).

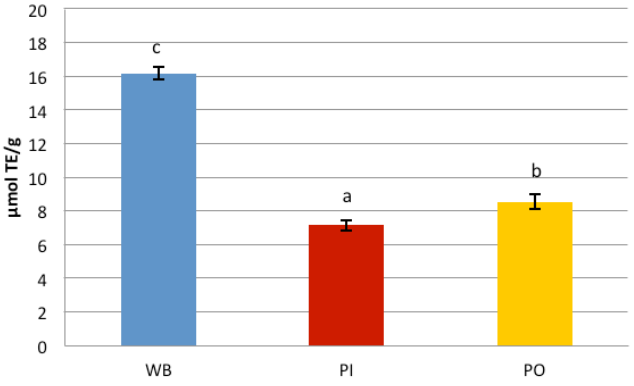

Figure 1. Oxygen radical absorbance capacity value (µmol Trolox equivalent g^{-1}) of *Longissimus lumborum* muscle of hunted wild boars and pigs reared indoors and outdoors (mean ± SD). The means with different superscripts differ for $p<0.05$. WB, wild boar; PI, pigs reared indoors; PO, pigs reared outdoors.

Table 1. Fatty acid-related nutritional indices considered.

Indices	Name	Formula	References
n-6/n-3	Omega 6/omega 3 ratio	Σn-6/Σn-3	Ciobanu *et al.* (2022)
PUFA/SFA	Polyunsaturated fatty acid/saturated fatty acid ratio	ΣPUFA/ΣSFA	Pires *et al.* (2020)
IA	Atherogenicity index	[C12:0+(4 x C14:0)+C16:0]/ΣUFA	McAfee *et al.* (2010)
IT	Thrombogenicity index	(C14:0 + C16:0 + C18:0)/[(0.5xΣMUFA)+(0.5xΣn-6 PUFA)+(3xΣn-3 PUFA)+(n-3/n-6)]	Reitznerová *et al.* (2023)
h/H	Hypocholesterolemic/hypercholesterolemic ratio	(cis-C18:1+ΣPUFA)/(C12:0+C14:0+C16:0)	Fernández *et al.* (2007)

n-6/n-3, omega 6/omega 3; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; IA, index of atherogenicity; UFA, unsaturated fatty acids; MUFA, monoinsaturated fatty acids; IT, index of thrombogenicity; h/H, hypocholesterolemic/hypercholesterolemic index.

Table 2. Proximate composition (% wet weight) and oxygen radical absorbance capacity value (µmol Trolox equivalent g^{-1}) of *Longissimus lumborum* muscle of pig reared indoor and outdoor and hunted wild boar (mean ± standard deviation).

	Moisture	Ether extract	Protein	Ash
Pig reared indoor	72.29±1.04	3.69±0.34^{b}	22.99±0.73	1.10±0.02^{c}
Pig reared outdoor	71.12±0.32	4.65±0.28^{c}	23.17±0.12	1.06±0.01^{b}
Hunted wild boar	73.60±1.46	2.23±0.46^{a}	23.16±0.98	1.02±0.03^{a}

Means within the columns with different superscripts differ for $p<0.05$. Means within the columns without superscripts are not statistically different.

Table 3. Fatty acid composition g/100 g of total fatty acid methyl esters of *Longissimus lumborum* muscle of pig reared indoors and outdoors and hunted wild boar (mean ± standard deviation).

Fatty acids	Pig reared indoor	Pig reared outdoor	Hunted wild boar
C10:0	0.15±0.02^{b}	0.13±0.02^{ab}	0.01±0.01^{a}
C12:0	0.11±0.09^{b}	0.10±0.09^{ab}	0.08±0.07^{a}
C14:0	1.52±1.43^{b}	1.41±1.33^{ab}	1.17±1.15^{a}
C15:0	0.06±0.02^{b}	0.06±0.01^{b}	0.14±0.04^{a}
C16:0	26.79±2.03^{c}	24.93±0.75^{b}	21.35±0.59^{a}
C17:0	0.19±0.04^{a}	0.20±0.05^{a}	0.45±0.03^{b}
C18:0	14.26±1.24^{b}	11.71±0.65^{a}	10.31±1.12^{a}
C20:0	0.23±0.02	0.20±0.05	0.22±0.04
C22:0	0.05±0.02	0.04±0.01	0.05±0.03
C23:0	0.05±0.01^{a}	0.01±0.01^{a}	0.19±0.05^{b}
C24:0	0.01±0.01	0.01±0.01	0.02±0.02
Total SFA	43.49±2.85^{c}	38.80±1.30^{b}	34.08±1.36^{a}
C14:1	0.04±0.01	0.05±0.01	0.03±0.03
C16:1	2.69±0.45	3.04±0.53	2.14±0.37
C18:1n9trans	0.17±0.02	0.19±0.02	0.26±0.20
C18:1n7trans	0.06±0.04	0.00±0.00	0.00±0.00
C18:1n9cis	40.70±1.80	42.02±3.77	39.14±1.64
C18:1n7cis	3.22±0.30	3.63±0.78	2.74±0.47
C20:1n9	0.85±0.12	0.75±0.08	0.79±0.02
C22:1n9	0.01±0.01	0.01±0.01	0.00±0.00
C24:1	0.00±0.00	0.05±0.11	0.12±0.25
Total MUFA	47.76±1.93	49.76±4.54	45.24±0.39
C18:2n6*trans*	0.02±0.0.02	0.03±0.02	0.00±0.00
C18:2n6*cis*	7.10±1.34^{a}	9.33±3.78^{a}	16.12±1.55^{b}
C18:2 c9 11t	0.13±0.04	0.08±0.02	0.11±0.05
C18:3n6	0.06±0.02	0.07±0.01	0.03±0.04
C18:3n3	0.27±0.05^{a}	0.38±0.18^{a}	1.43±0.15^{b}
C20:2	0.34±0.07^{a}	0.35±0.13^{a}	0.58±0.03^{b}
C20:3n6	0.11±0.02^{a}	0.14±0.02^{a}	0.21±0.04^{b}
C20:4n6	0.57±0.13^{a}	0.86±0.32^{a}	1.62±0.39^{b}
C20:5n3 (EPA)	0.04±0.01^{a}	0.04±0.01^{a}	0.16±0.09^{b}
C22:5n3	0.08±0.02^{a}	0.12±0.03^{a}	0.33±0.15^{b}
C22:6n3 (DHA)	0.04±0.02^{a}	0.04±0.02^{a}	0.11±0.03^{b}
Total PUFA	8.76±1.45^{a}	11.44±3.24^{a}	20.68±1.70^{b}
n-3 PUFA	0.44±0.08^{a}	0.58±0.15^{b}	2.02±0.06^{c}
n-6 PUFA	7.85±1.35^{a}	10.42±2.98^{b}	18.03±1.72^{c}

SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; n-3, omega3; n-6, omega 6. Means within the raw with different superscripts differ for p<0·05. Means within the raw without superscripts are not statistically different.

Table 4. Nutritional indices of *Longissimus lumborum* muscle of pig reared indoors and outdoors and hunted wild boar.

	n-6/n-3	PUFA/SFA	IA	IT	h/H
Pig reared indoor	18.32±2.05^{b}	0.24±0.05^{a}	0.60±0.08^{c}	1.47±0.19^{c}	1.86±0.24^{a}
Pig reared outdoor	17.77±0.53^{b}	0.29±0.09^{a}	0.50±0.03^{b}	1.19±0.07^{b}	2.16±0.10^{b}
Hunted wild boar	8.93±1.04^{a}	0.61±0.09^{b}	0.39±0.02^{a}	0.86±0.06^{a}	2.77±0.10^{c}

n-6/n-3, omega 6/omega 3 ratio; PUFA/SFA, polyunsaturated fatty acids/saturated fatty acids ratio; MUFA, monounsaturated fatty acids; IA, index of atherogenicity; IT, index of thrombogenicity; h/H, hypocholesterolemic/hypercholesterolemic ratio. Means within the column with different superscripts differ for p<0·05. Means within the column without superscripts are not statistically different.

Grazing or the consumption of various feedstuffs by PO pigs influences the fatty acid composition of LL in comparison to indoor-reared pigs. For instance, the levels of omega 3 (n-3) PUFA and n-6 PUFA are higher in PO than in PI, and the concentrations of n-3 PUFA and n-6 PUFA in WB were higher than in domestic pigs from both rearing systems, according to published data (Hoffman and Wiklund, 2006; Reitznerová *et al.*, 2023). A comparison of fatty acid composition between WB and domestic pigs shows high differences in SFA and PUFA content. This is the consequence of the fact that, in nature, WB has a highly variable diet as previously reported, in comparison to formulated diets provided to domestic animals, even PO pigs (Schley and Roper, 2003; Sales and Kotrba, 2013).

The ratio for n-6/n-3 PUFA is an index to estimate a potential risk factor for cancer and coronary heart disease, particularly the development of blood clots that result in heart attacks. Gerster (1998) recommended that the dietary n-6/n-3 ratio should not exceed 6. In the present study, the n-6/n-3 ratio was very high in pork (three times the recommended value) independently from the rearing system. The n-6/n-3 PUFA ratio in WB meat ranges from 7.02 to 9.50 in the samples examined, less than the ratio registered in pork, and the value was similar to those reported by Viganò *et al.* (2019) and much lower than those reported by other authors (Pedrazzoli *et al.,* 2017; Reitznerová *et al*., 2023). As a result, the n-6/n-3 ratio of WB samples was closer to the guide values, indicating that these species may be less detrimental to human health than pork. The high value of pork, as well as in meat animals, was due to the high content of 18:2 in the cereal-based diets consumed by animals, and this produced an undesirably high n-6/n-3 ratio. The ruminant meats had a more favorable n-6/n-3 ratio, due both to the lower content of 18:2 fatty acids compared to pork and the relatively high levels of n-3 PUFA, especially 18:3; this favorable ratio was also found in WB in comparison with pork of both rearing systems (Chen and Liu, 2020). The ratios of PUFA to SFA in meat from hunted WB were above the minimum ratio of 0.40 recommended to contribute to a reduction in the risk of coronary diseases. In pork from both rearing systems, the ratio was below the value recommended (Fernandes *et al.,* 2014; Pires *et al.*, 2020). Due to the content of C18: 2 n-6, the P/S ratio (0.61) in WB meat was slightly higher than that obtained by Razmaite *et al.* (2012) (0.27-0.53) in meat from WB hunted in Lithuania, but similar to the values obtained by Quaresma *et al.* (2011) (0.52-0.60).

The hypocholesterolemic/hypercholesterolemic (h/H) ratio is an index used to characterize the relationship between hypocholesterolemic fatty acids (cis-C18:1 and PUFA) and hypercholesterolemic fatty acids. h/H ratio is an important additional index to determine the effect of individual fatty acids on cholesterol metabolism. In terms of nutritional value, a greater h/H ratio is directly proportional to a high PUFA content, which is considered more beneficial for human health. The index may accurately reflect the effect of the fatty acids' composition on cardiovascular disease (Fernández *et al.,* 2007; Chen and Liu, 2020). For PO, the h/H value was higher than PI (1.86), and in WB, the value was almost double the one for PI. The reduction in the proportion of SFA leads to a higher value in comparison to the meat of domestic animals.

Atherogenic and thrombogenic indices (AI and TI) as measurements of lipid quality, which could serve as predictors of cardiovascular risks and are less than 1.0 in the diet, respectively, are advised for human health. AI and TI were lower in meat from WB compared to commercially reared pigs, in agreement with the literature (Marsico *et al*., 2007; Reitznerová et al., 2023). AI and TI in WB were always lower than the values reported by Ulbricht and Southgate (1991) in pork, beef, and lamb (1.66, 1.39, 1.58, respectively). Low AI and TI and a higher h/H index are characteristics of an animal product that is of good quality (Wołoszyn *et al.,* 2020). All three indices were fulfilled by the WB meat samples in our experiment.

Conclusions

The results of this study demonstrated the high nutritional quality of WB meat. Hunted WB compared to livestock meat such as pork shows: a lower fat content and therefore a lower energy content; similar protein content; a positive fatty-acid profile, showing a higher proportion of PUFA, especially n-3, and consequently a more favorable PUFA/SFA ratio. Finally, hunted WB meat is a source of fatty acids with functional properties for human health and should be included in a balanced diet.

Studies present in the literature on consumers' perceptions and attitudes toward hunted WB meat show increasing interest in the product and its positive characteristics that meet consumers' needs for ethical, healthy, and environmentally friendly food. The findings of this study may aid in promoting the concept that game meat is healthier; moreover, they may assist stakeholders in developing targeted marketing strategies and market expansion plans using a certified game meat chain approach.

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