PROCESSING AND PRODUCTS

Lipid profile and quality indices of ostrich meat and giblets

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ABSTRACT In this study, the lipid profile of 5 different edible tissues (leg, thigh, heart, gizzard, and liver) of ostrich was analyzed. Ostrich edible tissues presented a low fat content (<5 g/100 g wet basis). Gizzard and heart revealed the highest amounts of total cholesterol (1.77 and 1.47 mg/g wet basis, respectively), differing significantly from all other tissues (which averaged 0.95 mg/g wet basis). The main tocochromanol in all tissues was α-tocopherol (10.3 μg/g wet basis in heart and an average of 3.4 μg/g wet basis for all the remaining tissues). All the samples presented a fatty acid profile, dominated by polyunsaturated fatty acids (PUFA) (>38%), namely, linoleic and arachidonic acids. The leg presented simultaneously the highest PUFA/saturated fatty acids (SFA), the lowest n-6/n-3 ratios, and the most favorable lipid quality indices among all tissues in comparison.

Key words: ostrich, *Struthio camelus*, fatty acids, cholesterol, vitamin E

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INTRODUCTION

Ostrich was an alternative livestock species in South Africa in the 19th century. However, it was by the end of the 20th century that it became distributed worldwide, being produced in Australia, Asia, South and North America, as well as in most European countries. Nowadays, 3 ostrich subspecies are farmed. The most widespread subspecies is *Struthio camelus* var. *domesticus* (named as African Black), developed by the cross between *Struthio camelus australis* from South Africa and *Struthio camelus camelus* from North Africa (Swart et al., 1987). The African Black, was initially developed for the harvesting of feathers and afterwards for leather production (Horbañczuk et al., 1998). Once meat became the predominant goal in ostrich production, the domestication of wild subspecies occurred, namely *Struthio camelus massaicus* (named as Kenyan Red Necks) and *Struthio camelus australis* (named as Zimbabwean Blue ostriches or Blue Necks) (Hoffman et al., 2007; Horbańczuk et al., 2007). Such domestication happened because these wild subspecies enclose a higher mature live weight and faster growth rate (Hoffman et al., 2007).

Ostrich meat is considered simultaneously as gourmet, exotic, and a healthful alternative to red meat, since it encloses similar values of water, protein, amino acids, and mineral contents as those found in beef and chicken (Sales and Hayes, 1996). Additionally, it displays low intramuscular fat content and favorable fatty acid (**FA**) profile, with a higher percentage of polyunsaturated fatty acids (PUFA) (Sales, 1998). In Europe, ostrich meat is still a niche product, unknown by many people, despite that consumption of ostrich meat is rising, especially among consumers who pay greater attention to the nutritional composition of food.

Despite the potential previously specified, the total amount of meat recovered, around 26% of live weight (Hoffman et al., 2007) when considering whole muscles and trimmings, is relatively low when compared with traditional livestock species, poultry included. On the other hand, there is a considerable amount of edible viscera known as giblets—heart, liver, and gizzard (representing nearly 4.2 to 5.8% of live weight)—which are not valued by the market (Azahan and Noraziah, 2001; Balog and Almeida Paz, 2007). The FA composition of skeletal muscle meat of ostriches has been reported (Sales et al., 1996; Horbañczuk et al., 1998), but information about ostrich giblets is lacking.

This study was performed to compare the lipid composition of ostrich meat (leg and thigh) and giblets (heart, gizzard, and liver), taking into account the

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Table 1. Composition of concentrate feeding (% of dry matter) and premix used in ostrich growing and finishing stages.

Concentrate feeding (% of dry matter)*		Vitamin and mineral premix	
Crude protein	17.78	Vitamin A	12 000 000 U.I.
Lysine	0.97	Vitamin D_3	3000 000 U.I.
Methionine	0.43	Vitamin E (α-tocopherol)	44,000 U.I.
Methionine + Cysteine	0.69	Vitamin K_3	3000 mg
Tryptophan	0.24	Vitamin B_1	3.000 mg
Threonine	0.66	Vitamin B_2	8.000 mg
Starch	16.79	Vitamin B_3	60.000 mg
Sugar	1.36	Vitamin B_6	4.000 mg
Crude fiber	17.22	Vitamin B_7	130 mg
Acid detergent fiber	21.18	Vitamin B_9	2.000 mg
Neutral detergent fiber	29.03	Vitamin B_{12}	80 mg
Crude fat	4.71	Choline chloride	350.000 mg
Crude ash	9.77	Calcium pantothenate	14.000 mg
Calcium	2.11	Iron	30.000 mg
Phosphorous	0.57	Iodine	500 mg
Available phosphorous	0.16	Cobalt	100 mg
Sodium	0.24	Copper	15.000 mg
Potassium	0.43	Manganese	110.000 mg
chlorine	0.64	Zinc	80.000 mg
Magnesium	0.23	Selenium	300 mg
Premix	1.25		
Metabolizable energy (kcal/kg)	2600		

*Dry matter represented 89.98% of total concentrate.

increasing importance of ostrich production, the alleged healthful composition of its meat, the amount of giblets wasted, and the absence of scientific information about its nutritional value.

MATERIAL AND METHODS

Bird Management

The ostriches (*Struthio camelus* var. *domesticus*) used in this study were hatched and reared as a flock on a single commercial farm, located in Portugal and were all slaughtered at the 380 d old. The flock (12 male ostriches) was raised in semi-intensive conditions and kept on a farm with 2 hectares of green oat pasture; they were fed ad libitum with standard commercial concentrate feeding (Table 1) and received carrots and broccoli from the agroindustry surplus throughout the growing and finishing periods. Animals had access to a roofed paddock with free access to drinking water.

Sampling and Sample Preparation

The ostriches were slaughtered at an official abattoir, and their carcasses were stored in refrigeration (<5 °C.) for a 24-hour period. Sampling was performed in a cutting plant on the d after slaughter. One muscle from thigh (*iliotibialis lateralis*) and one muscle from leg (*gastrocnemius* pars *externa*) were excised, and a portion of each giblet (liver, gizzard, and heart) also was excised from each carcass. Samples were individually packed and identified according to the ostrich number and sample type. Afterwards, they were placed in a cooler at 4°C and transported to the laboratory. After arrival to the laboratory, samples were trimmed of all external fat and connective tissue, and then they were minced and homogenized in a food processor (Moulinex, France). Subsequently, each sample was individually vacuum-packed and stored frozen at -70°C until analysis.

Total Fat Content and Fatty Acid Composition

The total fat was determined in fresh samples by hydrolysis with hydrochloric acid (4 M), followed by Soxhlet extraction with petroleum ether (AOAC, 2000).

To assess FA composition of meat and giblets, samples were methylated by a direct method, previously described by O'Fallon et al. (2007). The *n*-hexane layer, containing the FA methyl esters, was placed into a GC vial, capped, and placed at -20°C until GC analysis.

FA methyl esters were analyzed by fast gas-liquid chromatography using a Shimadzu GC-2010 Plus (Shimadzu, Kyoto, Japan) equipped with a flame ionization detector and a SupraWax-280 capillary column (10 m, 0.10 mm i.d., 0.10 μm film thickness, (Teknokroma, Barcelona, Spain). The injector and detector temperatures were maintained at 250 and 280°C, respectively. The column oven parameters were as follow: initial temperature of 120°C was increased at 35°C/min to 175°C and held for 0.5 min, then it was increased at 70°C/min to 260°C and held for 6 min, with a total run time of 9.29 minutes. Helium was used as the carrier gas at a flow rate of 1 mL/min, and 1 μL of sample was injected. Identification of FAME was achieved by comparison of the FAME retention times with those of authentic standards (FAME mix 37 components from Supelco Inc., Bellefont, PA) and by electron impact mass spectrometry using a Shimadzu GC-MS QP2010 Plus (Shimadzu, Kyoto, Japan). Results for each FA were expressed as a

percentage of the sum of detected FA (g/100 g of total FA).

Total Cholesterol and Tocochromanol Contents

The simultaneous determination of total cholesterol and tocochromanols (tocopherols and tocotrienols) was estimated in duplicate for each sample based on the external standard technique from the standard curve of peak area vs. compound concentration, as previously described by Prates et al. (2006).

The chromatographic analysis was performed by HPLC, using an integrated Jasco System (Jasco, Tokyo, Japan) equipped with a PU-2089 PLUS quaternary gradient pump, an AS-2057 automated injector, a MD-2018 multi-wavelength diode array detector (**DAD**), and a FP-2020 fluorescence detector. The compounds separation was achieved using a normal-phase silica Zorbax RX-Sil column (4.6 mm ID x 250 mm, 5 μm particle size), with the corresponding 12.5 mm analytical guard column, from Agilent Technologies Inc. (Palo Alto, CA), operating at a controlled temperature of 24 °C (Jasco CO-2060 Plus, Jasco, Japan). A mixture of 1,4-dioxane and n-hexane (8:92) was used as eluent at a flow rate of 1.5 mL/minute. The injection volumes used varied between 20 and 100 μL in order to get values inside the linearity range of the standard curves. Chromatographic data were analyzed using a Borwin-PDA Controller Software (JMBS, Fontaine, France). Tocochromanols quantification was performed according to the external standard method using fluorescence signals (λ excitation = 290 nm, λ emission = 330 nm). For cholesterol, chromatograms were recorded at 202 nm. The compounds under study were identified by chromatographic comparison with authentic standards by co-elution and by their UV spectral characteristics (DAD).

Lipid Quality Indices

The peroxidability index (**PI**) was calculated according to the equation previously proposed (Arakawa and Sagai, 1986) as follows:

$$(\%\,\text{monoenoic} \times 0.025) + (\%\,\text{dienoic} \times 1) + (\%\,\text{trienoic} \times 2) + (\%\,\text{tetraenoic} \times 4) + (\%\,\text{pentaenoic} \times 6) + (\%\,\text{hexaenoic} \times 8)$$

The hypocholesterolaemic/hypercholesterolaemic ratio (**h/H**) was calculated using the equation previously proposed by (Santos-Silva et al., 2002), as follows:

$$[(\text{C18:1n}-9 + \text{C18:2n}-6 + \text{C18:3n}-3 + \text{C20:4n}-6 + \text{C20:5n}-3 + \text{C22:5n}-3 + \text{C22:6n}-3)/(\text{C14:0} + \text{C16:0})]$$

The indices of atherogenicity (**AI**) and thrombogenicity (**TI**), were estimated as proposed by (Ulbricht and Southgate, 1991):

$$\text{AI} = (\text{C12:0} + 4 \times \text{C14:0} + \text{C16:0})/ \times \left[\left(\sum \text{MUFA} + \sum(\text{n}-6) + \sum(\text{n}-3)\right)\right];$$

$$\text{TI} = (\text{C14:0} + \text{C16:0} + \text{C18:0})/[(0.5 \times \sum \text{MUFA} + 0.5 \times (\text{n}-6) + 3 \times (\text{n}-3) + (\text{n}-3)/(\text{n}-6)];$$

The nutritional ratios P/S were calculated as previously established (British Department of Health, 1994) and the n-6/n-3 considering all detected n-6 and n-3 PUFA:

$$\text{P/S} = [(18:2\,\text{n}-6) + (18:3\,\text{n}-3)/ \times (14:0 + 16:0 + 18:0)]; \text{n}-6/\text{n}-3 = \left[\left(\sum \text{n}-6\right)/\left(\sum \text{n}-3\right)\right]$$

Statistical Analysis

The statistical analysis was accomplished using the MIXED procedure of SAS (SAS Inst., Cary, NC), version 9.3. The model considered a single effect (sample type). Since measurements on different samples from the same animal are not independent observations, and portion type was treated as repeated measure within the same animal. Least square means were presented and compared using the LSMEANS/PDIFF option when interaction effect was significant ($P < 0.05$).

RESULTS AND DISCUSSION

Apart from carcass, edible by-products in both poultry (giblets) and mammals (offal) represent and important percentage of live body weight. These edible by-products offer different structures, different compositions, and different sensorial properties, and many are regarded as a source of high-quality protein (Ockerman and Hansen, 1999).

In ostrich, giblets (heart, gizzard, and liver) are accountable for 4.2 to 5.8% of total live weight and nearly 14.3 to 18.1% of total edible products obtained (Azahan and Noraziah, 2001; Balog and Almeida Paz, 2007), which is a substantial yield. However, ostrich giblets are not regarded as gourmet and are not regularly used for human consumption in Europe, and because of that, their value is substantially downgraded.

Lipid composition of ostrich skeletal muscle meat (leg and thigh) has been reported (Girolami et al., 2003), but to our best knowledge this is the first characterization of FA, cholesterol, and tocochromanols composition of ostrich giblets (heart, gizzard, and liver).

Table 2. Total lipid content (g/100 g wet basis), total cholesterol (mg/100 g wet basis), tocochromanols (μg/g wet basis), and the peroxidability index of ostrich meat (leg and thigh) and giblets (heart, gizzard, and liver).

	Meat		Giblets			Statistics	
Partial sums	Leg	Thigh	Heart	Gizzard	Liver	SEM	P
Total lipids	0.88^{b,c}	1.69^{b}	1.69^{b}	0.50^{c}	4.63^{a}	0.321	<0.001
Total cholesterol	92.0^{b}	87.6^{b}	147.3^{a}	176.8^{a}	105.2^{b}	22.88	<0.001
α-tocopherol	2.68^{b}	3.17^{b}	10.30^{a}	4.81^{b}	2.95^{b}	0.943	<0.001
β-tocopherol	0.72^{b}	0.72^{b}	0.76^{a}	0.72^{b}	0.70^{c}	0.005	<0.001
γ-tocopherol	0.80^{b,c}	0.84^{b}	1.26^{a}	0.81^{b,c}	0.64^{c}	0.067	<0.001
γ-tocotrienol	1.00	1.02	1.02	0.94	0.92	0.058	0.295
Total vitamin E	5.21^{b}	5.76^{b}	13.35^{a}	7.28^{b}	5.21^{b}	1.001	<0.001
Peroxidability index	95.4^{c}	73.3^{d}	116.0^{b}	126.6^{a}	82.9^{d}	3.48	<0.001

$^{a\text{-}d}$Different superscripts in the same row are associated with significantly different values.

Total Lipid and Total Cholesterol Content

Total lipid and cholesterol contents differed ($P < 0.001$) among tissues (Table 2). Liver was the fatter tissue, presenting 46 mg of total lipids per g of wet tissue. In contrast, gizzard and leg were quite leaner, containing a total lipid content of 5 and 9 mg/g wet basis, respectively. The thigh and heart both contained 17 mg of lipids per g of wet tissue.

The intramuscular fat content is one of the most important factors influencing consumers' choice with regard to meat type, and it is also the prime factor influencing meat sensorial characteristics. However, the health consequences associated with animal fat consumption advise the consumption of lean meat (FAO, 2008). Therefore, the low intramuscular fat content of ostrich meat is regarded as a natural advantage of this species (Polawska et al., 2011), although it is comparable to other species with very lean meat. The total lipid content in ostrich meat averaged 1.3 g/100 g wet basis, being in between the values previously presented for ostrich meat (Sales and Hayes, 1996; Sales et al., 1996; Poławska et al., 2011). Considering the low intramuscular lipid content observed in ostrich tissues, with exception of liver, it is expectable that membrane phospholipids comprise the majority of tissue lipids. Despite significant differences among tissues in comparison, all tissues revealed a TL content below 5%.

The content of total cholesterol of gizzard (1.8 mg/g wet basis) and heart (1.5 mg/g wet basis) was higher than all other tissues, which averaged 0.95 mg/g wet basis. Cholesterol is a structural molecule, present in cellular and subcellular membranes, where it plays an important role maintaining membrane fluidity in a narrow range (Alasnier et al., 1996). The total cholesterol content observed herein for meat (87.6 to 92.0 mg/100 g wet basis) is above the values published by others for leg muscles in ostrich (57 to 72 mg/100 g wet basis) (Sales et al., 1996; Horbañczuk et al., 1998; Sales, 1998; Girolami et al., 2003). However, values for total cholesterol near those presented herein (83 mg/100 g wet basis) have been published (Cooper, 1999). These differences in mean cholesterol content of ostrich meat are probably due to methodological issues as previously discussed (Nollet and Toldrá, 2011), including the incomplete recover of esterified cholesterol fraction in methods without a saponification step used in older reports (Sales et al., 1996; Horbañczuk et al., 1998; Girolami et al., 2003). Ostrich meat has been suggested to be a healthful alternative to beef, due to its low fat and low cholesterol contents (Sales et al., 1996; Paleari et al., 1998; Cooper, 1999; Balog and Almeida Paz, 2007). However, the total cholesterol content from ostrich leg and thigh ($\approx$ 90 mg/100 g wet basis) is quite above the contents observed in veal and beef (37 to 51 mg/100 g wet basis) using the same methodology (Prates et al., 2006; Quaresma et al., 2013). The higher total cholesterol content found in ostrich meat compared to bovine might be dependent on histological differences regarding muscular fiber type, as muscle fiber diameter and mitochondria content (Chizzolini et al., 1999). Ostrich is among the fastest runners on the planet and is also well adapted to endurance and thus its muscle fibers in leg might differ greatly from those present in bovine muscles.

The cholesterol content from ostrich heart and gizzard was higher than that found in meat and liver. The total cholesterol content of ostrich heart is within the range of values found in chicken heart (136 to 170 mg/100 g wet tissue) and turkey heart (147 mg/100 g wet basis) (Chizzolini et al., 1999; United States Department of Agriculture, 2015). The gizzard of chicken and turkey has been reported to contain a large concentration of total cholesterol (240 and 197 mg/100 g wet tissue, respectively) (United States Department of Agriculture, 2015). The gizzard of ostrich also contains large quantities of total cholesterol (177 mg/100 g wet tissue), close to turkey but clearly lower than chicken gizzard. The most striking difference between ostrich and common poultry was observed in liver total cholesterol content (105 mg/g wet tissue), which is much lower than was previously reported in chicken (345 to 380 mg/100 g wet basis), turkey (331 mg/100 g wet basis), and duck and goose (515 mg/100 g wet basis) (United States Department of Agriculture, 2015). Ostrich liver presents a much lower content of cholesterol when comparing with liver from conventional poultry species, but we have no

explanation for such differences. There is, however, one remarkable anatomic difference between traditional poultry species and ostrich; the former is deprived of a gallbladder, but we do not have information to discuss it further.

It has been established that the daily ingestion of cholesterol should not exceed 300 mg per d (Krauss et al., 2000). A daily intake of 100 g of ostrich meat and liver would supply 90 to 105 mg of cholesterol (i.e., 30 to 35% of the maximum recommend daily intake), whereas 100 g of heart and gizzard would supply about 50 and 60% of the maximum recommend daily intake.

Regarding ostrich meat total lipid content (0.9 to 1.7 g/100 g wet basis), total saturated fatty acids (**SFA**) content (2.7 to 5.1 mg/g wet basis), and total cholesterol content (88 to 92 mg/100 g wet basis), it can be classified as extra lean, according to the Food and Drug Administration (2013), which states that an extra lean food contains less than 5 g total fat, less than 2 g saturated fat, and less than 95 mg cholesterol per 100 g, whereas, giblets cannot be regarded as lean, since their total cholesterol content exceeds 95 mg cholesterol per 100 g.

Vitamin E Content

Vitamin E is a collective term for a total of at least 8 natural isoforms or tocochromanols (4 tocopherols and another 4 tocotrienols) exhibiting the antioxidant activity of R, R, R-α-tocopherol (Schneider, 2005). Four tocochromanols (α-tocopherol, β-tocopherol, γ-tocopherol, and γ-tocotrienol) were detected in the sampled tissues (Table 2) and all differed ($P < 0.001$) among tissues with the exception of γ-tocotrienol.

The α-tocopherol was the most abundant tocochromanol, comprising between 50 and 80% of total tocochromanols, whereas the others were present in roughly similar low concentrations. The predominance of α-tocopherol was previously identified in meat from other species, (Ponte et al., 2008; Quaresma et al., 2011, 2012a, b, 2013, 2016) and was explained by the much higher affinity of α-tocopherol transfer protein (α-TTP) towards α-tocopherol compared to all other tocochromanols, determining the relative abundance of α-tocopherol in very low density lipoprotein (**VLDL**) that supply animal tissues (Schneider, 2005).

Heart displayed a higher ($P < 0.05$) content of α-tocopherol (10.3 μg/g), β-tocopherol (0.76 μg/g), and γ-tocopherol (1.3 μg/g), and thus of the total vitamin E (13.4 μg/g), than all other tissues in comparison. No significant differences ($P > 0.05$) were observed for α-tocopherol, β-tocopherol, and γ-tocopherol among leg, thigh, and gizzard. On the other hand, liver displayed a significant lower content of β-tocopherol, not diverging significantly in the remaining tocochromanols. In meat from domestic ruminants (lamb, goat kid, veal, and beef), only the α- and γ-tocopherols have been found (Prates et al., 2006; Quaresma et al., 2013), whereas a richer tocochromanol profile was detected in broiler (Ponte et al., 2008), in wild mammals, as wild boar and red deer (Quaresma et al., 2011, 2012a), and also in pheasant (Quaresma et al., 2016). Meat from broilers (Ponte et al., 2008) and pheasant displayed the same 4 tocochromanols reported here for ostrich tissues, although in pheasant, the α-tocotrienol was also present (Quaresma et al., 2016).

After slaughter the enzymatic mechanisms that withstand oxidation reactions in vivo are progressively less effective, allowing for the meat oxidative process to proceed, resulting in deterioration of sensorial and nutritional qualities of meat (Descalzo and Sancho, 2008). Tocochromanols and β-carotene exert their antioxidant functions by non-enzymatic reactions and remain effective after slaughter for a longer period (Descalzo and Sancho, 2008; Insani et al., 2008), although their content in meat is variable and dependent on several factors, particularly their content in the diet (Yang et al., 2002a; b). The susceptibility of animal tissues to oxidative damage is highly dependent of its content in PUFA (Wood et al., 2008). Therefore, due to their high PUFA content, ostrich tissues can be considered highly susceptible to lipid peroxidation. We computed the PI of ostrich tissues, and the highest PI values were obtained in gizzard (126.6) and heart (116.0), because they are more prone to lipid oxidation than liver (82.9) and skeletal muscles (95.4 for leg muscle and 73.3 for thigh muscle). However, this seems to be rewarded by the total vitamin E content, since heart and gizzard displayed the highest values of total vitamin E among all tissues in comparison.

Fatty Acid Profile

It has been shown that in comparison with other species commonly used for meat production, as chicken and beef, ostrich meat shows a beneficial FA profile (Polawska et al., 2011), which was achieved by a high content in PUFA and low content of SFA (Sales, 1998). Ostrich meat presents a very high proportion in PUFA (38 to 41% total FA, averaging 39.5% of total FA), which is considerably above the total PUFA proportion found in traditional red meats, as beef (5 to 14% of total FA), lamb (3 to 11% of total FA), goat (7 to 13% of total FA), and horse meat (21 to 25% of total FA) (Enser et al., 1998; Banskalieva et al., 2000; Tateo et al., 2007). The comparison of ostrich meat PUFA proportion (39.5% of total FA) with traditional poultry species reveals a slight superiority over broiler meat (37.2% of total FA), similar values as turkey meat (39.5% of total FA), and a lower content when compared with quail (47.5% of total FA) (Karakök et al., 2010). Nevertheless, ostrich low fat content confers it as a modest PUFA concentration ranging from 3 mg/100 g wet tissue in gizzard to 20 mg/100 g of wet tissue in liver and averaging 5.8 mg/100 g of wet tissue in meat.

Table 3. Fatty acid composition of ostrich meat (leg and thigh) and giblets (heart, gizzard, and liver) expressed as g/100 g total fatty acids.

	Meat		Giblets			Statistics	
Fatty acids	Leg	Thigh	Heart	Gizzard	Liver	SEM	*P*
14:0	0.32	0.40	0.42	0.40	0.43	0.06	0.289
anteiso-15:0	0.13^{b}	0.09^{c}	0.15^{a}	0.15^{a}	0.02^{d}	0.07	<0.001
15:0	0.09^{c}	0.11^{c}	0.10^{c}	0.15^{b}	0.24^{a}	0.010	<0.001
16:0	11.36^{c}	16.16^{b}	10.94^{c}	13.07^{c}	22.16^{a}	0.971	<0.001
17:0	0.22^{c}	0.27^{b,c}	0.27^{b,c}	0.28^{b}	0.46^{a}	0.022	<0.001
anteiso-17:0	0.27^{b}	0.26^{b}	0.33^{a}	0.33^{a}	0.19^{c}	0.016	<0.001
18:0	10.62^{b,c}	9.58^{c}	11.36^{b}	14.94^{a}	13.64^{a}	0.577	<0.001
20:0	0.20	0.25	0.29	0.20	0.31	0.153	0.916
14:1 *cis*-9	0.06^{c}	0.07^{b,c}	0.14^{a}	0.13^{a,b}	0.02^{c}	0.019	<0.001
16:1 *cis*-9	3.34^{a,b}	3.94^{a}	1.75^{c}	1.73^{c}	2.83^{b,c}	0.328	<0.001
17:1 *cis*-9	0.22^{a}	0.22^{a}	0.29^{a}	0.29^{a}	0.13^{b}	0.027	<0.001
18:1 *cis*-9	19.82^{b}	22.70^{a}	16.23^{c}	12.26^{d}	18.13^{b,c}	0.676	<0.001
18:2n-6	23.48^{b}	26.52^{a}	20.78^{c}	18.83^{c}	26.27^{a}	0.874	<0.001
18:3n-3	0.99^{c}	1.24^{b}	0.90^{c}	0.34^{d}	2.18^{a}	0.080	<0.001
20:2n-6	0.47^{b}	0.40^{c}	0.61^{a}	0.61^{a}	0.40^{c}	0.023	<0.001
20:3n-6	0.45^{b}	0.38^{b}	0.26^{c}	0.65^{a}	0.20^{c}	0.026	<0.001
20:4n-6	11.51^{b}	7.55^{c}	20.52^{a}	20.59^{a}	10.46^{b}	0.565	<0.001
20:5n-3	0.23	0.23	0.12	0.04	0.83	0.479	0.501
22:4n-6	1.31^{a}	0.66^{b}	0.45^{c}	1.46^{a}	0.37^{c}	0.072	<0.001
22:5n-6	0.28^{b}	0.13^{c,d}	0.11^{d}	0.34^{a}	0.18^{c}	0.021	<0.001
22:5n-3	1.15^{b}	0.46^{c,d}	0.29^{d}	1.70^{a}	0.67^{c}	0.074	<0.001
22:6n-3	0.85^{a}	0.58^{b}	0.61^{b}	0.52^{b}	0.26^{c}	0.035	<0.001
DMAs							
DMA-16:0	10.49^{a}	6.49^{c}	10.48^{a}	7.54^{b}	0.25^{d}	0.356	<0.001
DMA-18:0	1.63^{c}	0.98^{d}	2.08^{b}	2.55^{a}	0.35^{e}	0.094	<0.001
DMA-18:1	0.50^{b}	0.32^{c}	0.54^{b}	0.90^{a}	0.004^{d}	0.034	<0.001

[a-e]Different superscripts in the same row are associated with significantly different values.

The FA profile of ostrich tissues expressed as g/100 g total FA, is depicted in Table 3, while the FA partial sums, the nutritional FA ratios, and lipid quality indices are presented in Table 4. Differences among tissues ($P < 0.001$) were detected for all FA and its sums, except for C14:0, C20:0, and C20:5n-3.

The FA profile of ostrich tissues was dominated by PUFA, representing from 4.7 to 7.0 mg/g wet basis (38 to 41% of total FA) in meat and 3.1 to 22.0 mg/g wet basis (39.5 to 45.1% of total FA) in giblets. Total PUFA was higher in gizzard and heart (45% of total FA) than in thigh (38% of total FA) and liver (40% of total FA), while leg displayed an intermediary total PUFA content (41% of total FA), not differing ($P > 0.05$) from other tissues in comparison.

The linoleic (C18:2n-6) and arachidonic (C20:4n-6) acids comprise the majority of PUFA and are predominant FA in all tissues. The C18:2n-6 was the predominant FA in leg, thigh, heart, and liver (20.8 to 26.5% of total FA), while the C20:4n-6 was the predominant FA in gizzard (20.6% of total FA). Four n-3 PUFA were detected: alpha-linolenic (C18:3n-3), eicosapentaenoic (C20:5n-3), docosapentaenoic (C22:5n-3), and docosahexaenoic (C22:6n-3) acids. The C18:3n-3 was the main n-3 PUFA in thigh, heart, and liver (comprising 46.9 to 55.3% of the n-3 PUFA), while the C22:5n-3 was the main n-3 PUFA in leg and gizzard (comprising 35.7 to 65.4% of the n-3 PUFA).

Saturated FA was the second-most predominant FA group in ostrich giblets and thigh, but not in leg, where monounsaturated fatty acids (**MUFA**) were slightly more abundant than SFA (0.2%). Liver displayed a significantly higher content of SFA (37.2% of total FA) than the remaining tissues. Together, palmitic (C16:0) and stearic (C18:0) acids comprised 93.5 to 96.3% of total SFA in all tissues.

The highest proportion of MUFA was observed in thigh (27%), followed by leg and liver (≈ 22%), whereas heart (18%) and particularly gizzard (14%) presented lower proportions. Together, oleic (C18:1cis-9) and palmitoleic (C16:1cis-9) acids comprised 84 to 88% of total MUFA.

The FA composition of ostrich meat present herein revealed an higher PUFA and thus a lower SFA and MUFA proportions (23.3 to 26.1% of total FA) than was reported by others and recently reviewed by Poławska et al. (2011), and this might be related to muscle lipid content or dietary factors.

Three dimethylacetals (**DMA**) were detected (DMA-C16:0, DMA-C18:0, and DMA-C18:1cis-9). The DMA-C16:0 comprised 69 to 83% of DMA in all tissues except liver, which contained only residual concentrations of all DMA.

Nutritional ratios and lipid quality indices are depicted in Table 4. Meat from leg presented simultaneously the highest PUFA/SFA ratio, the lowest n-6/n-3 ratio, and the most beneficial lipid quality indices. Among tissues in comparison, heart revealed several similarities with leg in PUFA/SFA ratio and in all 3 quality indices presented, because they are the most

Table 4. Fatty acid partial sums (expressed as g/100 g total fatty acids and as mg/g wet basis), and nutritional ratios in ostrich meat (leg and thigh) and giblets (heart, gizzard, and liver).

	Meat		Giblets			Statistics	
	Leg	Thigh	Heart	Gizzard	Liver	SEM	*P*
Partial sums (expressed as g/100 g of total FA)							
Σ SFA	23.2^{d}	27.1^{c}	23.8^{d}	29.5^{b}	37.2^{a}	0.17	<0.001
Σ MUFA	23.4^{b}	26.9^{a}	18.4^{c}	14.4^{d}	21.1^{b}	0.90	<0.001
Σ PUFA	40.7^{a,b}	38.2^{b}	44.8^{a}	45.1^{a}	39.5^{b}	1.80	<0.001
Σ n-6PUFA	37.5^{b}	35.6^{b}	42.7^{a}	42.5^{a}	37.9^{b}	1.28	<0.001
Σ n-3PUFA	3.22^{a}	2.52^{b}	1.93^{c}	2.60^{b}	3.18^{a}	0.134	<0.001
Σ DMA	12.63^{a}	7.79^{c}	13.10^{a}	10.99^{b}	0.61^{d}	0.443	<0.001
Partial sums (expressed as mg/g of fresh meat)							
Σ SFA	2.66^{b}	5.05^{b}	5.54^{b}	2.05^{b}	22.07^{a}	2.255	<0.001
Σ MUFA	2.71^{b}	5.03^{b}	1.31^{b}	1.00^{b}	12.84^{a}	1.512	<0.001
Σ PUFA	4.65^{c,d}	7.02^{c}	10.33^{b}	3.14^{d}	21.97^{a}	0.952	<0.001
Σ n-6PUFA	4.29^{c,d}	6.56^{c}	9.89^{b}	2.96^{d}	20.19^{a}	0.832	<0.001
Σ n-3PUFA	0.36^{b}	0.47^{b}	0.45^{b}	0.18^{b}	1.78^{a}	0.132	<0.001
DMA	1.43^{b}	1.43^{b}	3.01^{a}	0.76^{c}	0.33^{d}	0.110	<0.001
Ratios							
P/S	1.10^{a}	1.07^{a}	0.94^{a,b}	0.67^{c}	0.88^{b}	0.065	<0.001
n-6/n-3	11.86^{d}	14.32^{c}	22.84^{a}	16.62^{b}	12.23^{d}	0.663	<0.001
hH	5.16^{a}	3.75^{b}	5.49^{a}	4.11^{b}	2.78^{c}	0.209	<0.001
AI	0.20^{c}	0.27^{b}	0.20^{c}	0.25^{b,c}	0.39^{a}	0.024	<0.001
TI	0.43^{c,d}	0.49^{b,c}	0.39^{d}	0.54^{b}	0.72^{a}	0.025	<0.001

[a-d]Different superscripts in the same row are associated with significantly different values.

similar tissues in comparison. The worst PUFA/SFA ratio and n-6/n-3 ratios were observed in gizzard and heart, respectively. On the other hand, liver lipid quality indices were the least favorable of all tissues in comparison.

The nutritional evaluation of the intramuscular lipid composition can be estimated by nutritional quality indices, but also by the absolute content of some health beneficial FA, as the n-3PUFA (Simopoulos, 2002; Givens and Gibbs, 2008). The n-3PUFA (eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and docosahexaenoic (DHA)) averaged 1.75% of total FA in ostrich meat and 1.68% of total FA in ostrich giblets (ranging from 1.0% in heart to 2.3% in gizzard). Therefore, a 100 g portion of ostrich meat encloses an average of 24.4 mg of these FA, contributing just 9.7% of the recommended adult daily intake, while 100 g of giblets enclose 15.7 to 79.5 mg of these FA, contributing 6.3 to 31.8% of the recommended adult daily intake (250 mg) (FAO, 2008), depending on the viscera.

Among giblets, liver proved to be the best nutritional option concerning the health beneficial n-3 PUFA, since 100 g of liver supplies 3.3 times the amount supplied by meat, 3.9 times the amount supplied by heart, and 9.9 times the amount supplied by gizzard.

Concerning nutritional ratios and lipid quality indices, they are used to estimate the potential health contribution of the fatty acid profile present in food. In this regard, they represent a useful tool to compare the FA profile from ostrich meat and giblets.

The P/S ratio provides information on the proportion of major PUFA (C18:2n-6 and C18:3n-3) and major SFA (C14:0, C16:0, and C18:0), which does not provide accurate information regarding all PUFA and SFA, since some important FA are not included in this ratio. The PUFA/SFA ratio revealed quite a superiority of PUFA over SFA in both meat and giblets, reaching its highest and lowest values in heart (1.9) and liver (1.0), respectively, while gizzard displayed a value (1.5) in between leg (1.8) and thigh (1.4). The comparison of PUFA/SFA ratios from meat and giblets revealed that ostrich meat, heart, and gizzard are rich in PUFA, while liver has a less satisfactory PUFA/SFA ratio, but as seen previously, liver is the richest source of health beneficial n-3 PUFA.

On the other hand, the n-6/n-3 ratio showed that gizzard and heart displayed a significantly higher n-6/n-3 value than was observed in meat and liver, while liver displayed a n-6/n-3 value in between leg and thigh.

Lipid quality indices, i.e., AI, TI, and the (h/H) index also were calculated and compared for ostrich meat and giblets. The highest and most favorable h/H index was observed in gizzard and meat from leg, while liver revealed the lowest and most favorable AI and TI indices.

CONCLUSION

Given the increasing importance of ostrich production, the nutritional valorization of all edible products is necessary for the sustainability of chain production. The study confirmed that ostrich meat is very lean and displays a favorable FA profile, rich in PUFA, although its total cholesterol content is higher than previously presented for ostrich meat. Ostrich heart and gizzard share with meat the high proportion of PUFA, but were

richer in total cholesterol. The liver, due its high lipid content and relatively low cholesterol content, seems to be a good dietary source of PUFA.

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