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Probabilistic Assessment of the Intake of Trace Elements by Consumption of Red Deer (*Cervus elaphus*) and Wild Boar (*Sus scrofa*) Meat

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Abstract: The aim of this work was to study the nutritional value of game meat through the fulfillments of Dietary Reference Intakes (DRI) for trace elements (Co, Cr, Cu, Fe, Ni, Se, and Zn). A probabilistic model (@Risk) was developed based on the consumption data of hunter-consumers obtained from a previously published survey. Two game species widely consumed in Europe were selected: red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*). Red deer muscle had the highest content of Cr (0.25 mg/kg) and Zn (44.3 mg/kg) and wild boar muscle recorded the highest Cu (2.23 mg/kg), Ni (0.60 mg/kg), and Se (0.19 mg/kg), showing statistically significant differences between the two species for these elements. No statistically significant differences were found for Fe between both game species (red deer: 52.9 mg/kg and wild boar: 53.3 mg/kg). Co content in this kind of meat was negligible for both species. The results obtained from the simulation of the probabilistic model with red deer indicated that a consumption once per week of this meat fulfills Cr, Fe, and Zn DRIs for the 95th percentile in hunter-consumers. Regarding wild boar, the values obtained also fulfill the Fe DRI and were between 61 and 75% for the rest of the trace elements analyzed.

Keywords: trace elements; hunters; game meat; dietary intake

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1. Introduction

The United Nations estimates that the size of the world population could reach 11 billion by the end of this century [1]. The rising global population and improved living standards are driving a growing demand for high-protein products, such as meat. However, there are resource constraints on the mass production of traditional farmed-meat animals [2]. Thus, in recent years there has been a growing interest in alternative protein sources such as meat derived from nonconventional animal species [3]. One alternative meat source considered as “non-traditional” is game meat [2].

Game meat is a product derived from hunting, obtained from wild animals that are classified as hunting species. These animals belong to specific groups of mammals and some bird species. In the last years, game meat production has witnessed a significant increase, rising from 1.1 million tons in 1977 to 2.1 million tons in 2017 worldwide [2]. However, meat from wild animals accounts for only about 0.5% of the total meat production [4]. In Europe, game animals are categorized into large wild game (e.g., elk, deer, fallow deer, wild boar, roe deer) and small wild game (e.g., hare, game birds: pheasant, partridge) [5]. European ungulate populations have been on the rise, with approximately 6.3 million large game animals, primarily deer species and wild boar, harvested annually [6]. The game meat sourced from these wild European species contributes to an increased meat supply and provides market diversification as an alternative to other red meats [7].

The consumption of game meat varies significantly among populations and can be influenced by a multitude of factors [8]. In the majority of European countries, the consumption of game meat remains relatively low, with only 2–4% of the population regularly including this type of meat in their diet [9]. Traditionally, game meat is cherished and predominantly consumed by hunters and their relatives [8,10]. In Europe, approximately 5.5 million hunters have been identified as frequent consumers of game meat, partaking in its consumption at least once a week [6]. Furthermore, there exists a segment of the population, distinct from the hunting community, that also includes wild game meat in their diet [6].

In recent decades, there has been a surge of interest in game meat, and its demand has experienced a noteworthy increase [5,11] as consumer perceptions of game meat are evolving. Game meat is seen as "natural meat" where animals roam freely, primarily graze on pastures, and are devoid of hormones, antibiotics, and other additives [11]. It is often regarded as more organic compared to other meat varieties [12]. Furthermore, game meat is prized for its exceptional nutritional quality and sensory attributes [7], as well as its potential health benefits [5]. Additionally, red deer meat obtained through hunting has a lower environmental impact when compared to conventional beef [13].

In general, game meat stands out for its low fat, high protein, and low energy content. The nutritional profile of large wild ungulates, such as wild venison and wild boar species, showcases exceptional nutritional qualities in terms of protein and fats [14], largely attributed to its low fat content and its fatty acid composition [10,15]. Moreover, wild ruminant meat exhibits a favorable n-6/n-3 ratio (typically lower or near 4) and boasts a high content of compounds, such as fatty acids, amino acids, vitamins, and essential trace elements, that hold significance in human nutrition [7,16].

Spain holds a prominent position among European nations in the production, processing, and trade of large game meat and related food products sourced through hunting [17]. Notably, it ranks as the world's second-largest producer of wild red deer, after New Zealand (the world's leading producer of farmed venison), which are mainly harvested through traditional driven hunts taking place during the autumn–winter season [18]. Over recent years, the production of game meat in Spain has seen a substantial upswing, with a recorded output of approximately 53 thousand tons in 2019 [19]. Game meat consumption in Spain surpasses that of many other European countries, and a significant portion of the game meat production is reserved for self-consumption by hunters themselves, bypassing the commercial food chain [8].

The growing enthusiasm for game meat in Europe, particularly the elevated consumption of deer and wild boar meat in Spain, combined with the limited research on trace element contents in these species, underscores the necessity of this study. The primary objective was to assess the nutritional value of game meat from red deer and wild boar by evaluating its compliance with Dietary Reference Intakes (DRI) for trace elements, including cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), selenium (Se), and zinc (Zn).

2. Material and Methods

2.1. Biological Samples

Muscle samples were collected from 40 red deer and 60 wild boars, which were hunted in Cordoba province, Andalusia, located in southern Spain. These samples were harvested in driven hunts during the autumn–winter season in compliance with current regulations. Animals were shot down using rifle firearms equipped with lead ammunition. Given the nature of driven hunts, wild animals move freely within the hunting ground, making encounters unpredictable. Animals may receive multiple shots from hunters until the decisive, fatal shot is delivered. Following this critical moment, the animal succumbs in the field and remains lifeless for a variable duration until it is ultimately retrieved, typically towards the conclusion of the hunt, often in the afternoon.

Muscle samples (250 g) were extracted from the cervical region, encompassing brachycephalic and external cephalic muscles of the red deer, and from the leg, including the gracilis, semimembranosus, and femoral muscles of wild boar using a ceramic knife to avoid potential possible contamination with a metal device. Samples were procured in situ during the carcass inspection of the hunted animals. Additionally, muscle samples derived from the sirloin, specifically the psoas muscle, were obtained from individuals of both species within the designated game-handling establishment.

The samples were initially frozen in separate labeled plastic bags, and then placed inside a portable cooler and stored in a −20 °C laboratory freezer, until their preparation for analysis. In the laboratory, muscle samples were lyophilized (for 48 h) (Scanvac Cool Safe freeze dryer, model 55–44, Rugby, UK) and homogenized so that the harvesting for processing was completed in the most objective way possible.

2.2. Analytical Method Chemicals Used and Preparation of Samples

All reagents used were of analytical grade such as hyperpure HNO_3 (69%) (Panreac, Barcelona, Spain) and H_2O_2 (33%) (Merck, Sigma-Aldrich, St. Louis, MO, USA). All plastic and glass materials were decontaminated from traces of metallic elements by immersing them in a 50% HNO_3 bath for 24 h. These materials were then transferred to a 20% HCl bath and left in it for a further 24 h. Finally, the plastic and glass materials were rinsed three times with deionized water and allowed to dry. Finally, all the experiments were developed with deionized water (resistivity 18 µS/cm) obtained using a Milli Q Reference Water Purification system (Millipore, Madrid, Spain).

The samples were digested in a microwave system (Multiwave GO, Anton Paar, Ostfildern, Germany) using modified PTFE containers. Thus, 0.5 g of lyophilized sample was mixed with 6.25 mL of HNO_3 and 0.75 mL of H_2O_2. Finally, the digested sample was brought to a final volume of 15 mL with deionized water.

2.3. Trace Element Determination

The analysis of trace elements was carried out by atomic absorption spectroscopy. For Fe (λ = 248.3 nm) and Zn (λ = 213.9 nm), flame absorption atomic spectroscopy was used (FAAS) (Varian Spectra AA-50B model, Palo Alto, CA, USA), equipped with a standard air–acetylene flame and single-element hollow cathode lamps. For the following elements studied (Co, Cr, Cu, and Ni), we used electrothermal atomic absorption spectroscopy (ET-AAS) (Agilent Technologies model 240Z, Santa Clara, CA, USA). The instrumental conditions for the analysis of these elements are shown in Table 1.

Table 1. Instrumental conditions for Co, Cr, Cu, and Ni analysis by ET—AAS.

	Co (λ = 240.7 nm)		**Cr (λ = 357.9 nm)**		**Cu (λ = 324.8 nm)**		**Ni (λ = 232.0 nm)**		
Step	**T (°C)**	**t (s)**	**T (°C)**	**t (s)**	**T (°C)**	**t (s)**	**T (°C)**	**t (s)**	**Argon Flow (L/min)**
Drying	85	5	85	5	85	5	85	5	0.3
	95	40	95	40	95	40	95	40	0.3
	120	8	120	20	120	10	120	10	0.3
Pyrolysis	750	5	1000	5	800	5	800	5	0.3
	750	3	1000	3	800	3	800	3	0
Atomization	2300	2.8	2600	2.8	2300	2.8	2400	2.8	0
Cleaning	2300	2	2600	2	2300	2	2400	2	0.3

Finally, Se content in samples was determined by atomic fluorescence spectroscopy (AFS) (λ = 196.0 nm) (Millennium Excalibur Instrument, PSA Analytical, Kent, Orpington, UK). The formation of the Se hydride was carried out by pumping 0.7% w/v $NaBH_4$ (in 0.1 M NaOH) and 4.5 M HCl with a flow rate set at 10 mL/min. A gas–liquid separator and Argon gas (300 mL/min) were used to transport the selenium hydride.

Standard solutions for quantifying Co, Cr, Cu, Fe, Ni, Se, and Zn were prepared prior to usage. These solutions were created by diluting with deionized water 1000 mg/L standard solutions obtained from Certipur, Merck (Darmstadt, Germany). Samples were analyzed in duplicate.

2.4. Quality Control and Assurance

The accuracy and precision employed in determining the concentrations of Co, Cr, Cu, Fe, Ni, Se, and Zn were confirmed through recovery experiments. Certified Reference Materials (Mussel tissue ERM®-CE278k) from IRMM in Geel, Belgium were utilized for this validation process. Certified Reference Materials were treated and analyzed in the same way as the samples. Recovery percentages for Co, Cr, Cu, Fe, Ni, Se, and Zn were near to 100%. The limits of detection (LOD) and quantification (LOQ) were established following standard procedures that are used in the determination of chemical elements and species in food products [20]. The samples of all the elements analyzed were above the LOQ, except for Co (13% > LOQ) (Table 2).

Table 2. Performance characteristics of the analytical method used to measure the content of Co, Cr, Cu, Fe, Ni, Se, and Zn.

Element	LOD (mg/kg)	LOQ (mg/kg)	Mussel Tissue ERM—CE278k		
			Certified	Found	Recovery (%)
Co	0.010	0.032	0.21 *	0.18 ± 0.01	86
Cr	0.006	0.022	0.73 ± 0.22	0.77 ± 0.12	105
Cu	0.078	0.260	5.98 ± 0.27	6.38 ± 0.66	107
Fe	1.092	3.624	161 ± 8	174 ± 7	108
Ni	0.023	0.077	0.69 ± 0.15	5.00 ± 0.21	102
Se	0.0001	0.001	1.62 ± 0.12	1.55 ± 0.23	97
Zn	1.203	4.841	71 ± 4	74 ± 4	104

* Indicative value.

2.5. Statistical Analyses and Risk Assessment

Statistical analysis was carried out using SPSS v.15. Normality and homogeneity of variances of the data were checked through the Kolmogorov–Smirnov test and Levene's tests, respectively. The effect of the species on the analyzed traits was determined using the non-parametric Mann–Whitney test. Statistically significant differences were set at $p < 0.05$. Data were presented in terms of mean, median, standard deviations, as well as the minimum and maximum values, and they were expressed in milligrams per kilogram of wet weight (mg/kg ww).

A probabilistic model (@Risk) was developed to estimate the intake levels for Co, Cr, Cu, Fe, Ni, Se, and Zn derived from the consumption of red deer and wild boar meat according to previous studies [21]. The developed model followed a probabilistic approach, where variables were described using probability distributions that were adjusted to the concentration data obtained in our study for each element and to the consumption data of red deer and wild boar meat in hunter-consumers. Data regarding the consumption of deer and wild boar meat, collected from hunters in southern Spain, were obtained from a previously published survey [8] and were expressed in kilograms per person per year (kg/person year), as detailed in Table 3.

Table 3. Consumption data of red deer and wild boar meat in hunter-consumers (kg/person per year).

Statistic	Red Deer	Wild Boar
mean	4.70	4.32
standard deviation	6.15	5.88
median	2.00	1.75
95 percentile	18.7	17.7
minimum	0.13	0.13
maximum	30.0	30.0

The exposure model did not incorporate a distinction between the variability and uncertainty of input variables, following a first-order model approach. The goodness-of-fit was evaluated using statistical tests, including the Kolmogorov–Smirnov and Chi-square tests, which offer insights into how effectively the fitted distribution characterizes the observed data. Visual analysis was also considered to evaluate the adequacy of the probability distributions with respect to the concentration data. The model was simulated using @Risk version 7.5 by Palisade© software in Ithaca, NY, USA and executed with 10,000 iterations for each element using consistent seed values for the Random Number Generator, ensuring that the results are directly comparable.

Game meat is mostly frozen and consumed throughout the year [8]. Then, the intake data obtained through this probabilistic model were divided by 52 weeks of the year, which accounts for one weekly meal. Intake data were compared to the Spanish DRI for adult population (>20 years of age) [22,23] (see Table 4). In the case of Cr and Ni, tolerable intakes indicated by the European Food Safety Agency were considered.

Table 4. Dietary Reference Intake (DRI) of Co, Cr, Cu, Fe, Se, and Zn (mg/day) for adult men and woman according to EFSA [22] and AESAN [23].

Element	Consumers	EFSA [22] Adequate Intake	AESAN [23] Dietary Reference Intake
Co	men women	0.065	
Cr	men women		0.035 0.025
Cu	men women	1.6 1.3	1.3 1.1
Fe	men women	11 16	9.1 18
Se	men women	0.07	0.070 0.055
Zn	men women	12.7	11 9

3. Results and Discussion

The concentrations of Co, Cr, Cu, Fe, Ni, Se, and Zn for red deer and wild boar meat are shown in Table 5. The probabilistic model intakes are indicated for the consumption of deer and wild boar meat for each trace element in Figures 1–3, while the intakes of trace elements from the consumption of one weekly meal of deer and wild boar meat are summarized in Table 6.

Table 5. Trace element concentrations in red deer and wild boar meat (mg/kg ww).

	Red Deer (40)				Wild Boar (60)				
Element	**Mean**	**SD**	**Median**	**Min-Max**	**Mean**	**SD**	**Median**	**Min-Max**	***p***
Co	<LOQ	<LOQ	<LOQ	<LOQ–0.08	<LOQ	<LOQ	<LOQ	<LOQ–0.07	>0.05
Cr	0.25	0.20	0.20	0.08–0.96	0.16	0.16	0.13	0.03–1.30	<0.001
Cu	1.87	0.76	1.75	0.68–4.73	2.23	0.77	2.05	1.03–5.94	<0.001
Fe	52.9	46.8	38.4	12.7–267	53.3	36.8	40.8	14.6–180	>0.05
Se	0.05	0.07	0.03	0.02–0.41	0.19	0.09	0.20	0.02–0.56	<0.001
Ni	0.40	0.15	0.40	0.12–0.67	0.60	0.21	0.50	0.27–1.18	<0.001
Zn	44.3	17.2	45.8	4.60–75.8	29.0	10.6	27.4	10.8–62.0	<0.001

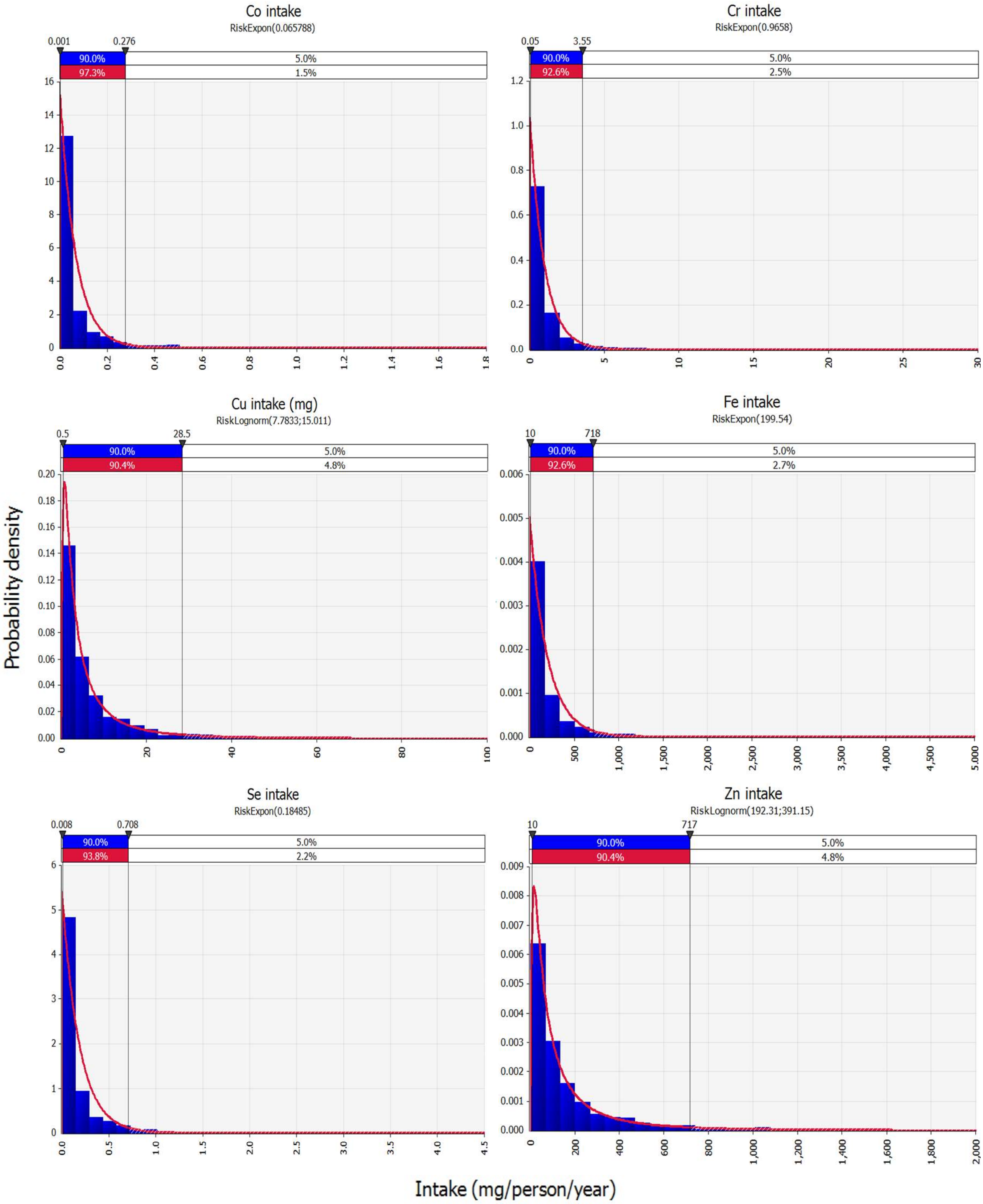

Figure 1. Simulation data and the fitted probability density distribution for the intake of Co, Cr, Cu, Fe, Se, and Zn resulting from the consumption of red deer meat in hunter-consumers.

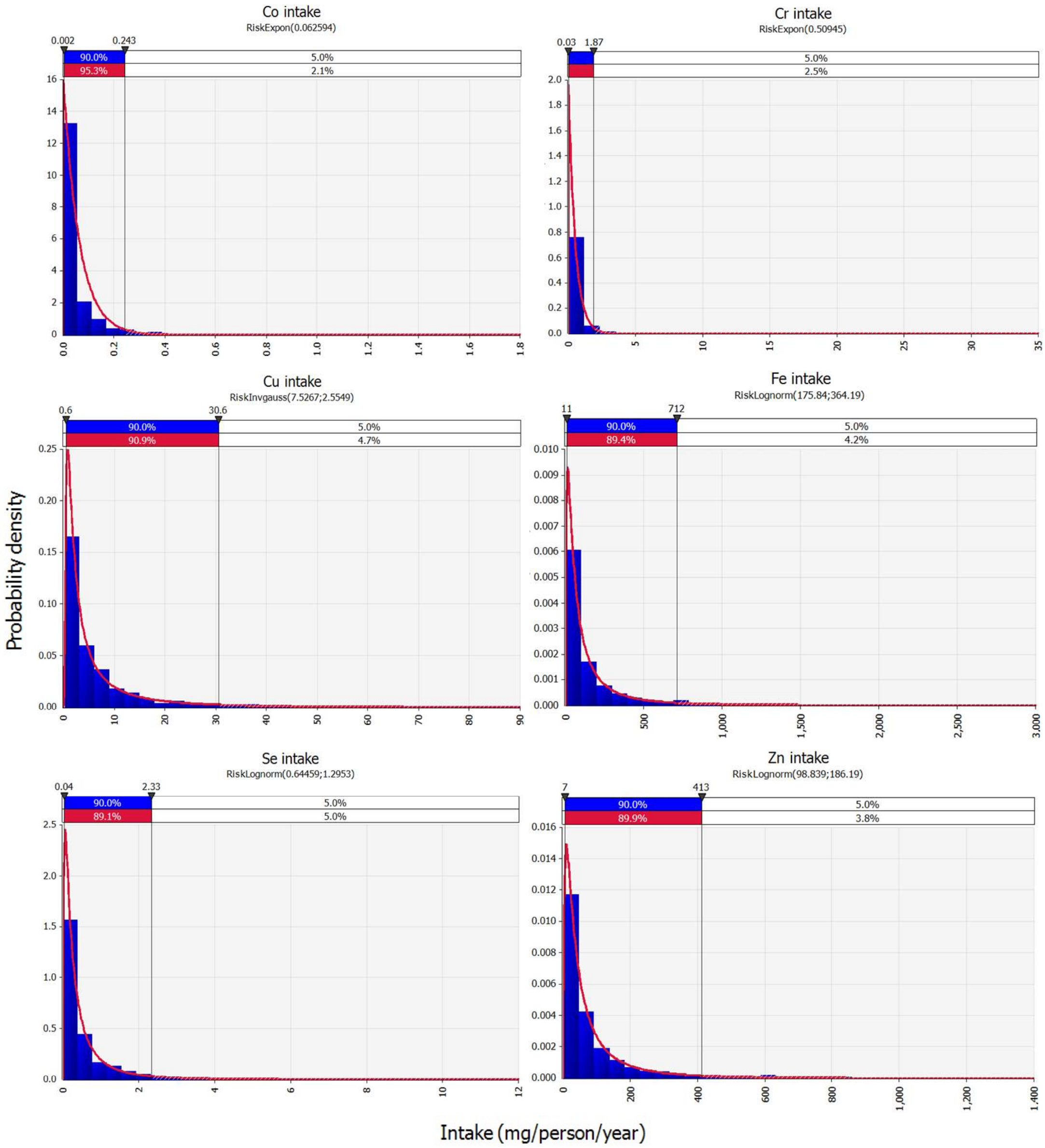

Figure 2. Simulation data and the fitted probability density distribution for the intake of Co, Cr, Cu, Fe, Se, and Zn resulting from the consumption of wild boar meat in hunter-consumers.

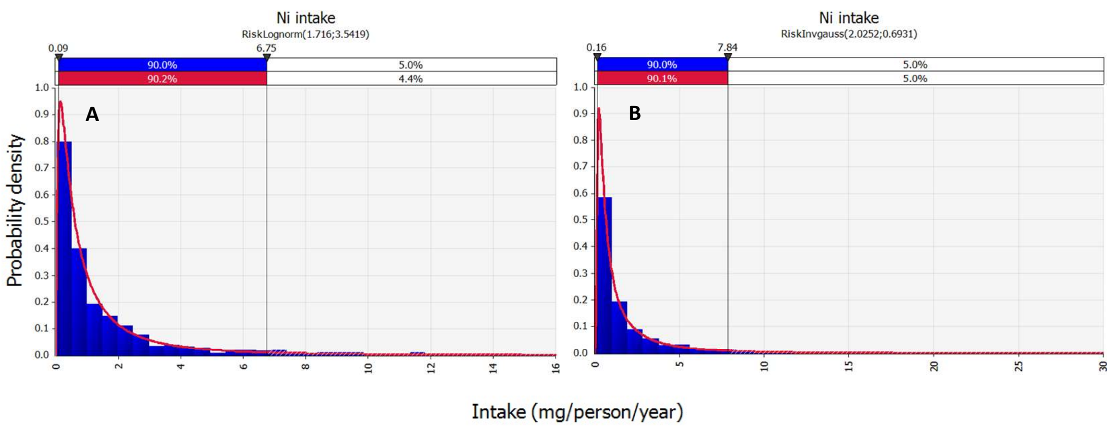

Figure 3. Simulation data and the fitted probability density distribution for the intake of Ni resulting from the consumption of deer (**A**) and wild boar (**B**) meat in hunter-consumers.

Table 6. Estimated intake of Co, Cr, Cu, Fe, Ni, Se, and Zn by probabilistic assessment due to consumption of red deer and wild boar in hunter-consumers (mg/person/year).

Element	Statistic	Intake of Red Deer Meat	Intake of Wild Boar Meat
Co	5th	0.003	0.003
	50th	0.046	0.043
	95th	0.197	0.188
Cr	5th	0.010	0.026
	50th	0.669	0.353
	95th	2.893	1.526
Cu	5th	0.198	0.581
	50th	3.583	3.162
	95th	27.80	29.33
Fe	5th	10.24	9.150
	50th	138.3	76.45
	95th	597.8	638.8
Ni	5th	0.090	0.157
	50th	0.748	0.855
	95th	6.229	7.878
Se	5th	0.009	0.035
	50th	0.128	0.287
	95th	0.554	2.326
Zn	5th	10.35	6.120
	50th	84.85	46.34
	95th	695.8	350.9

Statistical analysis revealed significant differences in Cr, Cu, Ni, Se, and Zn content between both studied species ($p < 0.001$). Specifically, red deer exhibited the highest levels of Cr and Zn, while wild boar had elevated Cu, Ni, and Se content. In contrast, for Fe and Co, there were no statistically significant differences between the two species under investigation. These interspecific differences can be attributed to differences in dietary composition and eating habits as well as the distinct anatomical and physiological characteristics unique to each species [24].

As previously detailed in the Materials and Methods section, the probabilistic model employed was constructed using consumption data gathered from a survey of the hunting population [8], in conjunction with the analysis of trace element concentrations in red deer and wild boar. It is remarkable that although game meat harvest is limited to the hunting season, game meat consumption occurs consistently throughout the year [8]. Therefore, the intake data have been obtained for one year, and determining the intake per serving is straightforward by dividing the annual intake by 52, given that this type of meat is typically consumed about once a week [6].

3.1. Cobalt

Co content in both red deer and wild boar meat proved to be negligible for both species. In the majority of the samples examined, the Co concentration in game meat closely approached the limit of quantification (LOQ). These Co levels align with findings reported by other researchers who studied these same species, such as Ertl et al. [25] (0.002 mg/kg) and Kalinina et al. [26] (0.02 mg/kg). In contrast, Pilarczyk et al. [27] and Gašparík et al. [28] found higher Co contents in wild boar meat, measuring at 0.17 mg/kg and 0.44 mg/kg, respectively. Cawthorn et al. [29], studying the chemical composition of wild fallow deer in different types of muscle, found very low Co levels that varied from 0.002 to 0.003 mg/kg.

Cobalt is part of the core of vitamin B12, and its main source comes from meat-based foods. The Adequate Intake (AI) recommended by the EFSA [22] is 65 µg per person per day. The estimated intake of cobalt through the consumption of deer and wild boar meat for 50% of hunter-consumers represents 1.4% and 1.3% of the AI, respectively.

3.2. Chromium

The average Cr contents were measured at 0.25 mg/kg for red deer and 0.16 mg/kg for wild boar. It is worth mentioning that limited data regarding Cr content in red deer meat were available, with only Ertl et al. [25] reporting a lower concentration of 0.005 mg/kg, and Cawthorn et al. [29] found that Cr levels in fallow deer ranged between 0.058 and 0.071 mg/kg. On the other hand, Cr content found in wild boar meat was similar to those reported in previous studies (0.12–0.14 mg/kg) [30–33]. Notably, the Cr concentrations in game meat were significantly higher than those observed in other meats sourced from slaughtered animals, such as beef (0.004 mg/kg) and pork (0.004–0.017 mg/kg) [34].

Hence, the results obtained from the probabilistic model simulations with red deer and wild boar indicated values for Cr of 0.0129 and 0.0068 mg per week, respectively, for the 50th percentile. This shows that the intake of Cr of at least half of the population consuming this game meat will not be lower than these values. In the case of the red deer, that intake complies with 37% of men and 51% of women of the DRI for Cr. This DRI would be fulfilled from the 85th percentile for men and 75th percentile for women (data not shown).

In addition, considering the 95th percentile Cr intake as the worst-case scenario, the Cr exposure levels amounted to 0.11 and 0.06 μg/kg body weight (bw) per day for the consumption of red deer and wild boar meat, respectively. Remarkably, these exposure levels are 11 to 20 times lower than those outlined by the EFSA under the same scenario, which is in comparison to the lower 95th percentile dietary exposure range (1.2 μg/kg bw per day) observed in European adults [35]. These Cr intakes from the consumption of game meat represent only 0.04% and 0.02%, respectively, of the Tolerable Daily Intake (TDI) established by the EFSA for this element (0.3 mg/kg bw) [35]. It is noteworthy that the primary toxicological form of Cr is hexavalent, which is virtually absent in food [36,37]. The outcomes of this analysis indicate that the Cr (III) content in the examined game meat falls below accepted safety limits, posing no discernible risk to human health.

3.3. Copper

The medium concentrations of Cu for red deer and wild boar measured 1.9 and 2.2 mg/kg, respectively. The Cu content in red deer agrees with findings in previous studies where levels were reported as 1.5 mg/kg [38] and 2.0 mg/kg [16]. In another deer species, fallow deer, Cawthorn et al. [29] found Cu levels that ranged between 1.94 and 2.01 mg/kg. In contrast, recent investigations examining Cu content in wild boar meat have reported lower values (<2 mg/kg) [26,32,33,39] compared to those observed in this study.

Cu contents in game meat are slightly higher than those reported for meat from animal husbandry such as pork (0.68–0.80; 0.43–0.67 mg/kg) [34,40] or beef (0.56–1.1 mg/kg) [34]. This is relevant because, from a meat quality point of view, a higher Cu content has been related to a higher protein content, with a greater essential/non-essential amino acids ratio and lower cholesterol content and incidence of DFD meats [41]. However, Cu also plays a relevant role in human nutrition such as in antioxidant defense (superoxide dismutase), Fe homeostasis, mitochondrial respiration, and the development of connective tissue, among others [42].

In this sense, the probabilistic model reveals an annual Cu intake at the 50th percentile: 3.58 mg from the consumption of deer meat and 3.16 mg from the consumption of wild boar meat. When distributed across 52 meals per year, this intake barely fulfills the Cu DRI by 5%, showing that game meat is a poor dietary source of this element.

Finally, the 95th percentile Cu intake accounts for 0.5 and 0.6 mg/day for red deer and wild boar, respectively. These values represent approximately one-tenth of the tolerable upper intake level (5 mg/day) established by the international food safety authorities [43].

3.4. Iron

Fe concentrations in game meat ranged between 13 and 267 mg/kg and 15 and 180 mg/kg for red deer and wild boar respectively, with medium values of 53 mg/kg for both species. In red deer, similar values were shown by Soriano et al. [11] at 53.6 mg/kg while other authors recently showed Fe concentrations around 30 mg/kg [18,20]. Recently, in fallow deer other authors found Fe level averages that ranged between 43.2 and 38.3 mg/kg [29]. On the other hand, wild boar displayed varying Fe content levels, with some higher and lower values compared to those obtained in this study. Pilarczyk et al. [27] and Tekeli et al. [32] reported concentrations of 36.4 and 41.9 mg/kg, respectively, while Babicz and Kasprzyk [44] and Kalinina et al. [26] indicated Fe concentrations exceeding 80 mg/kg.

In developed countries, red meat is the main source of Fe in the diet, with pork and beef being the most consumed species of this type of meat [45]. Previous studies have shown Fe contents in pork meat of 8.1 mg/kg [46] or 23.6 mg/kg [44]. In relation to beef, Fe contents ranged between 42 and 65 mg/kg [40], or 14 and 29 mg/kg [45,47] have also been reported. According to these data, Fe contents in the game meat analyzed in this study are similar to or even higher than those reported in previous works for red meat from animal husbandry. The high content of iron, in contrast to that of domestic animals, could be attributed to the irrigation of the muscle tissue with the blood from the wound itself or internal bleeding caused by the impact or impacts of bullets on the animal. Some health agencies in the United States consider that wounds caused by bullets would inflict enough damage to the animal, ensuring sufficient bleeding [48].

This highlights game meat as an excellent dietary source of Fe. Furthermore, between 40 and 90% of Fe present in red meat is in the form of heme Fe [49,50], a chemical form of this trace element with high bioavailability [51].

The results obtained from the simulation of the probabilistic model with red deer and wild boar indicated intake values for Fe of 11.5 and 12.3 mg, respectively, for the 95th percentile for hunter-consumers. This intake (corresponding to a serving size) fulfills Fe DRI for men and complies with 64–68% Fe DRI for women. Even at a less favorable percentile (50th percentile), these intake values of 2.7 mg for red deer and 1.5 mg for wild boar represent more than one-tenth of the Fe DRI and surpass the levels reported in a previous study for pork and meat products (1.2 mg) [40].

3.5. Selenium

Se contents displayed a range of 15–407 µg/kg for red deer and 24–564 µg/kg for wild boar. However, despite the similar ranges for both species, Se medium contents were higher for wild boar (193 µg/kg) than red deer (53 µg/kg). Comparable Se content values in wild boar were reported by other authors, ranging from 130 to 150 µg/kg [25,52], while recent studies have indicated Se values in deer ranging from 40 to 80 µg/kg [11,53]. Moreover, the Se content in wild boar meat aligns with that reported for pork (123–176 µg/kg) [40].

Meat and meat products are one of the main dietary sources of Se in the human diet [54]. A recent study [55] has shown higher serum Se concentrations in omnivores (62.85 µg/L) and flexitarians (61.37 µg/L) than vegetarians (55.12 µg/L) and vegans (52.84 µg/L), with statistically significant differences between both groups. According to this, wild boar meat could be a reliable dietary source of Se. The probabilistic model showed Se intakes of 5.5 µg (9% Se DRI) for the 50th percentile and even 44.7 µg (75% Se DRI) for the 95th percentile from wild boar meat consumption (one service size) in the hunter-consumers. Se intakes from red deer meat consumption were lower. Moreover, the EFSA Panel on Dietetic Products, Nutrition and Allergies [56] estimated a Se intake in adults from EU countries between 31 and 66 µg/day. In this study, Se intakes resulting from the consumption of wild boar are found to fall within this range, notably remaining well below the established tolerable upper intake level for Se in adults (255 µg/day) [57]. Furthermore, most of the Se present in meat is found in an organic form (selenocysteine and selenomethionine) and therefore has greater bioavailability.

3.6. Zinc

The average Zn contents for both species were 44.3 mg/kg for red deer and 29.1 mg/kg for wild boar. The Zn content in deer closely matched the findings of other authors, with Lazarus et al. [58] reporting 43.4 mg/kg and Pérez-Serrano et al. [18] reporting 39.2 mg/kg. Additionally, the average Zn content in deer was consistent with the Zn level found in farmed deer muscle (46 mg/kg) [59]. A recent study has suggested that Zn levels in deer meat can fluctuate seasonally, with higher levels in stags hunted during autumn, potentially attributed to seasonal changes in plant composition and availability [11]. Moreover, Jarzynska and Falandysz [60] indicated that the consumption of deer muscle could represent an important contribution to Zn intake. Another study indicated that the Zn content in deer can vary depending on the muscle type of the animal [29]. On the other hand, Zn content in wild boar was similar to the contents shown by other authors as such Ertl et al. (27 mg/kg) [25]; Pilarczyk et al. (28.7 mg/kg) [27]; Długaszek and Kopczyński, (31.5 mg/kg) [31]; and Tekeli et al. (32.3 mg/kg) [32].

As occurs for the rest of the trace elements studied, these Zn contents are higher than those found in similar meats from slaughtered animals such as beef (27–45 mg/kg) and pork (20–27 mg/kg) [34]; (13.1–27.2 mg/kg) [40]. Just like Fe, one of the main dietary sources of Zn is meat and meat products. Several studies have shown lower serum/plasma Zn concentrations in vegetarians or vegans than omnivores [61–63].

In this study, we found that an intake corresponding to a red deer serving covers 15–20% of the Zn DRI from the 50th percentile (male and female) and fulfills the Zn DRI from the 90th percentile. In the case of wild boar, the intake for consuming this meat would be 6.8 mg for the 95th percentile, covering up to 61–75% of the DRI. The bioavailability of this Zn present in game meat would also be increased by the presence of animal proteins which, when hydrolyzed by digestive enzymes, form low molecular mass peptides. These peptides join to Zn, forming soluble compounds with this element until Zn is absorbed by the enterocytes [64].

Finally, the 95th percentile Zn intake accounts for 13.4 and 6.8 mg/day for red deer and wild boar, respectively. These values are approximately two and four times lower than the tolerable upper intake level (25 mg/day) established by the European Food Safety Authority [43].

3.7. Nickel

Finally, Ni is an element with an unclear role in human nutrition. For plants, Ni acts as a cofactor regulating the enzymatic activity of urease, superoxide dismutase, and hydrogenase [65]. In vivo research, using animal models, has shown that Ni deficiency can affect vision and Fe and Na metabolism. [66]. However, Ni may also have an important toxicological role in humans. In 2015, the European Food Safety Authority (EFSA) received a request to conduct a scientific investigation regarding the potential risk to human health stemming from the presence of a specific element in food and drinking water [67]. Nevertheless, this toxicological limit has recently been increased from 2.8 to 13 µg/kg body weight (bw) per day [68].

Ni medium contents in game meat were 0.40 and 0.60 mg/kg for red deer and wild boar, respectively. These data are above the average Ni content data in meat and meat products of 0.105–0.144 mg/kg indicated by EFSA [68]. Hence, for individuals consuming one weekly meal of red deer and wild boar, the Ni intakes at the 95th percentile were 120 µg and 152 µg, respectively. Based on these values and assuming a mean bw of 70 kg per person, the resulting exposure levels to Ni amounted to 1.71 µg/kg bw per day and 2.17 µg/kg bw per day, respectively. These exposure levels are notably lower, ranging from three to five times less, than the 95th percentile exposure range observed in European adults [68]. Considering Ni as a heavy metal and taking the 95th percentile intakes as the most unfavorable scenario, the Tolerable Intake percentages were calculated at 13.3% and 16.7% for red deer and wild boar, respectively. Unlike the toxicological risk due to the presence of other heavy metals such as lead [69–71], these results indicate that the Ni content in the game meat analyzed is below the accepted safety limits and does not pose any risk to human health.

4. Conclusions

Deer and wild boar meat, from the perspective of contributions to the Dietary Reference Intakes (DRI) of trace elements, is an excellent dietary source of Fe and Zn. For the rest of the elements studied, deer is also a good dietary source of Cr and wild boar of Se. Furthermore, from the perspective of the toxicology of Cr and Ni, it is a safe meat, not exceeding, in the worst case, the toxicological threshold allowed for these elements, and they are not a limiting factor for the consumption of this type of meat.

Currently, this meat represents an alternative for the consumption of animal protein in hunter-consumers, the main consumers of this type of meat. Furthermore, its consumption should be encouraged and extended to other population groups, always respecting the recommendations for red meat consumption established by various national and supranational health organizations.

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