

Communication

Radioactivity in Calabrian (Southern Italy) Wild Boar Meat

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Abstract: The production chain for game meat is specific and differs from the production chain of meat from domestic livestock. Wild boar meat is a foodstuff consumed in Italy. Wild boars are considered as a reservoir of environmental radionuclides, and the accumulation of radioisotopes can pose a radiological hazard. ^{40}K and ^{137}Cs activity concentrations were measured through HPGe gamma spectrometry in wild boar meat samples, coming from six hygiene points representative of the entire district of Reggio Calabria, South Italy. Experimental values were found to be in the range of $(91 \pm 11) \text{ Bq kg}^{-1}$ to $(117 \pm 14) \text{ Bq kg}^{-1}$ for ^{40}K and of $(0.09 \pm 0.03) \text{ Bq kg}^{-1}$ to $(1.61 \pm 0.24) \text{ Bq kg}^{-1}$ for ^{137}Cs , respectively. Any possible radiological risk for the population was also estimated. Obtained values are in the range of $2.66 \mu\text{Sv a}^{-1}$ to $4.00 \mu\text{Sv a}^{-1}$, much lower than the recommended level for the public (1 mSv a^{-1}).

Keywords: wild boar meat; environmental radionuclide; gamma spectrometry; activity concentration; annual effective dose; radiological risk

1. Introduction

The boar is widespread today. Although it prefers forest environments dominated by broad-leaved trees, it is able to colonize a wide range of environments: from densely inhabited plains to high mountain altitudes, with frequent summer observations of over 2000 m [1]. Although the wild boar feeds mainly on plant material, such as acorns, fruits, berries, tubers, roots and mushrooms, from time to time it consumes material of animal origin, such as insects and other invertebrates, eggs and sometimes even meat and fish, mainly coming from carcasses, which it identifies with its very fine sense of smell. Wild boars are also able to actively hunt, choosing small animals such as frogs and snakes, but also prey of a certain size, such as fawns and lambs. Locally it can cause great damage to crops. Similar to a domestic pig, but with dense bristles and evident fangs, it is today one of the most numerous and hunted ungulate species in Europe [2]. Wild boar meat belongs to “black-haired” meats and is part of the diet of the Italian population, being low in calories and rather lean. It is very tasty and is now easily available in large supermarkets. It is very renowned and appreciated as it combines the flavor of pork with that of game. Among the minerals contained, the following stand out: iron, fundamental for the transport of oxygen to the organs and tissues of the body and potassium, excellent for the proper functioning of muscles and heart and for the transmission of nerve impulses. Wild boar meat is also an excellent source of animal protein. To date, there are no known contraindications to the consumption of wild boar meat, except an allergy to this food [3]. Being quite fibrous, it is particularly suitable for cooking in a pan for stews or sauces. It also lends itself to being roasted on a spit, as long as it is larded to make it less dry. The analysis of the dangers deriving from the consumption of wild boar meat is significantly influenced by the lack of continuous monitoring of the health status of this wild animal [4].

Wild animals are bioindicators of environmental pollution, as game meat can be contaminated, mainly in areas heavily polluted by radioactive fallout, by the radiological hazards that circulate in the food chain between soil, plants and wild animals [5–7]. After the Chernobyl accident, wild boars with increased radioactivity levels were detected across Europe [8].

This article is devoted to the estimation of the anthropogenic and naturally occurring radionuclide content of wild boar meat from Southern Italy, in the district of Reggio Calabria in particular. This is not an area famous for contamination with radionuclides; in fact, there are no facilities related to nuclear power plants there. However, after the Chernobyl and Fukushima nuclear power plant accidents, the entire district was contaminated by fallout of radionuclides, especially at high altitudes, which are typical wild boar-inhabited areas. To what extent the study area is contaminated is then obtained from data reported in the present study, because wild boars are bioindicators of environmental pollution. Moreover, the authors evaluated if wild boars may constitute a radiological hazard as complementary foodstuff consumed by the local population [9].

2. Materials and Methods

Five samples of wild boar meat (muscle), 1 kg each, were collected for each one of the six hygiene points of the Reggio Calabria district, in the south of Italy. Each hygiene point is representative of a circular area of about 50 km radius.

The map of the sampling points is reported in Figure 1, and their GPS coordinates in Table 1.

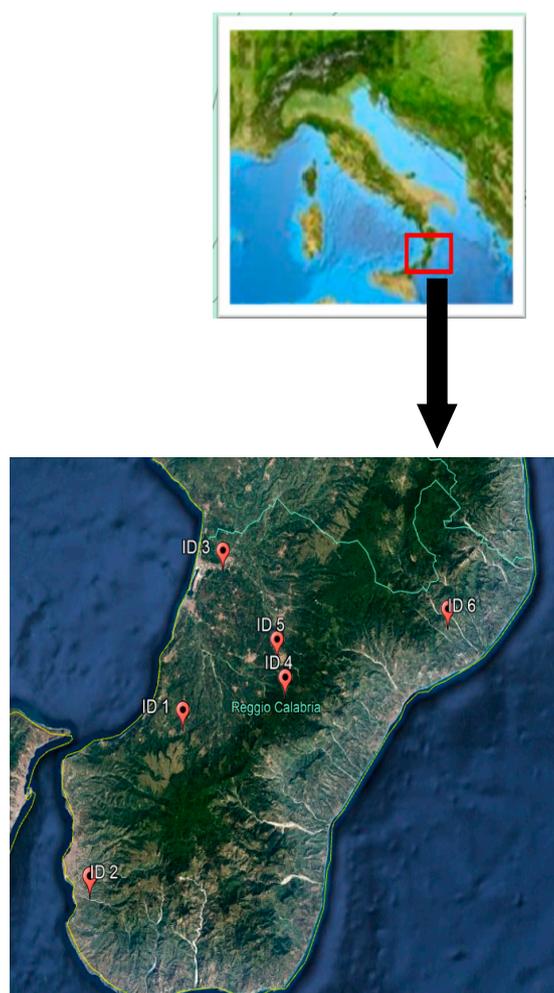


Figure 1. The map of the sampling points.

Table 1. The GPS coordinates of the sampling points.

| Sampling Point | GPS Coordinates |
|----------------|------------------------------|
| ID1 | 38° 15'49" N 15° 52'40" E |
| ID2 | 38° 02'59" N 15° 41'04" E |
| ID3 | 38° 29'03" N 15° 52'40" E |
| ID4 | 38° 18'01" N 16° 04'57" E |
| ID5 | 38° 21'01" N 16° 04'05" E |
| ID6 | 38° 22'51" N 16° 24'31" E |

At the laboratory, the inedible parts of all samples were removed before homogenization.

For the gamma spectrometry analysis, samples were enclosed in 1 L capacity plastic Marinelli containers and counted for a time equal to 70,000 s. The 661.66 keV ^{137}Cs and 1460.8 keV ^{40}K gamma ray lines were used to determine their specific activity.

The experimental setup consists of two Ortec HPGe detectors and integrated digital electronics. The first is a negative biased detector (GMX), cooled by the Ortec recycler condensing liquid nitrogen cooling Mobius system [10], characterized by a Full Width at Half Maximum (FWHM) of 1.94 keV, a peak to Compton ratio of 65:1 and a relative efficiency of 37.5% at 1.33 MeV (^{60}Co). The second is a positive biased detector (GEM), nitrogen liquid cooled, with a FWHM of 1.85 keV, a peak to Compton ratio of 64:1 and a relative efficiency of 40% at 1.33 MeV (^{60}Co).

The Eckert and Ziegler Nuclitec GmgH traceable multinuclide radioactive standard, number AK-5901, with an energy range of 59.54 to 1836 keV, reproducing the exact samples geometries in a water-equivalent epoxy resin matrix, was employed to perform efficiency and energy calibrations [11].

The Quality Analyses/Quality Controls (QA/QC) of the radiation measurements were performed according to the UNI 11665:2017 [12].

Gamma Vision (Ortec) software was used for data acquisition and analysis [13].

The activity concentration (Bq kg^{-1}) of the investigated radioisotopes was calculated using the following formula:

$$C = \frac{N_E}{\varepsilon_E t \gamma_d M} \quad (1)$$

where N_E indicates the net area of the peak at the energy E ; ε_E and γ_d are the efficiency and yield of the photopeak at the energy E , respectively; M is the mass of the sample after treatment (kg) and t is the live time (s).

In the measurement of error, at the 95% confidence level, the following components were taken into account: uncertainties of the counting estimation, calibration source, efficiency calibration, background subtraction and of the γ -branching ratio [14].

The possible radiological risk for human health is expressed by the total annual effective dose due to the ingestion of wild boar meat by adult members of the population, calculated with the following:

$$E \left(\text{Sv a}^{-1} \right) = Y C d_k \quad (2)$$

where Y is the annual intake of wild boar meat (kg per person), C the specific activity (Bq kg^{-1}) and d_k = dose coefficient (conversion factor), equal to $1.3 \times 10^{-8} \text{ Sv Bq}^{-1}$ and $6.2 \times 10^{-9} \text{ Sv Bq}^{-1}$ for ^{137}Cs and ^{40}K , respectively [15].

3. Results and Discussion

The activity concentration of ^{40}K and ^{137}Cs for the analyzed wild boar meat samples is reported in Table 2, together with their mean value. The average value uncertainty (for each ID) is the standard deviation.

Table 2. The activity concentration of ^{40}K and ^{137}Cs for the analyzed wild boar meat samples.

| Sampling Point | K-40 (Bq kg ⁻¹) | Cs-137 (Bq kg ⁻¹) | Sampling Point | K-40 (Bq kg ⁻¹) | Cs-137 (Bq kg ⁻¹) | Sampling Point | K-40 (Bq kg ⁻¹) | Cs-137 (Bq kg ⁻¹) |
|-------------------|-----------------------------|-------------------------------|-------------------|-----------------------------|-------------------------------|-------------------|-----------------------------|-------------------------------|
| ID1 | 110 ± 9 | 0.37 ± 0.10 | ID3 | 70 ± 6 | 0.62 ± 0.15 | ID5 | 80 ± 11 | 1.12 ± 0.19 |
| | 113 ± 9 | 0.51 ± 0.09 | | 63 ± 6 | 1.28 ± 0.18 | | 93 ± 12 | 0.30 ± 0.10 |
| | 97 ± 5 | 0.29 ± 0.08 | | 83 ± 11 | 0.06 ± 0.02 | | 80 ± 12 | 0.07 ± 0.02 |
| | 104 ± 6 | 0.61 ± 0.22 | | 107 ± 10 | 0.25 ± 0.06 | | 113 ± 15 | 0.08 ± 0.03 |
| | 95 ± 12 | 0.25 ± 0.07 | | 70 ± 5 | 0.11 ± 0.03 | | 92 ± 13 | 0.41 ± 0.09 |
| <i>Mean value</i> | 103 ± 8 | 0.40 ± 0.13 | <i>Mean value</i> | 79 ± 9 | 0.46 ± 0.09 | <i>Mean value</i> | 92 ± 13 | 0.39 ± 0.09 |
| ID2 | 153 ± 21 | 0.24 ± 0.08 | ID4 | 96 ± 7 | 1.87 ± 0.23 | ID6 | 102 ± 13 | 0.08 ± 0.03 |
| | 71 ± 10 | 0.45 ± 0.13 | | 118 ± 16 | 0.79 ± 0.18 | | 80 ± 11 | 0.09 ± 0.03 |
| | 75 ± 6 | 0.26 ± 0.06 | | 135 ± 18 | 2.14 ± 0.32 | | 95 ± 12 | 0.11 ± 0.04 |
| | 66 ± 6 | 0.13 ± 0.04 | | 119 ± 16 | 1.41 ± 0.25 | | 85 ± 11 | 0.07 ± 0.03 |
| | 93 ± 12 | 0.26 ± 0.08 | | 115 ± 15 | 1.83 ± 0.23 | | 91 ± 12 | 0.12 ± 0.04 |
| <i>Mean value</i> | 92 ± 11 | 0.27 ± 0.08 | <i>Mean value</i> | 117 ± 14 | 1.61 ± 0.24 | <i>Mean value</i> | 91 ± 11 | 0.09 ± 0.03 |

For the sampling point ID1, the average ^{40}K and ^{137}Cs specific activity is $(103 \pm 8) \text{ Bq kg}^{-1}$ and $(0.40 \pm 0.13) \text{ Bq kg}^{-1}$, respectively; for ID2, the mean activity concentration is $(92 \pm 11) \text{ Bq kg}^{-1}$ and $(0.27 \pm 0.08) \text{ Bq kg}^{-1}$ for ^{40}K and ^{137}Cs , respectively; for ID3, the average ^{40}K and ^{137}Cs specific activity is $(79 \pm 9) \text{ Bq kg}^{-1}$ and $(0.46 \pm 0.09) \text{ Bq kg}^{-1}$, respectively; for ID4, the mean activity concentration is $(117 \pm 14) \text{ Bq kg}^{-1}$ and $(1.61 \pm 0.24) \text{ Bq kg}^{-1}$ for ^{40}K and ^{137}Cs , respectively; for ID5, the mean ^{40}K and ^{137}Cs specific activity is $(92 \pm 13) \text{ Bq kg}^{-1}$ and $(0.39 \pm 0.09) \text{ Bq kg}^{-1}$, respectively and for ID6, the average activity concentration is $(91 \pm 11) \text{ Bq kg}^{-1}$ and $(0.09 \pm 0.03) \text{ Bq kg}^{-1}$ for ^{40}K and ^{137}Cs , respectively.

Several differences in the radiocaesium content can be noted. For example, the highest average ^{137}Cs content was found in samples from ID4, $(1.61 \pm 0.24) \text{ Bq kg}^{-1}$, while wild boar meats from the sampling site ID6 had the lower cesium activity, $(0.09 \pm 0.03) \text{ Bq kg}^{-1}$.

There are several factors influencing the ^{137}C content in the investigated samples [16]: the level of radioactive fallout, climate and bioavailability of the radionuclide. Among these, it is important to dwell above all else on the level of radioactive fallout, since the fallout of artificial radionuclides after the Chernobyl accident have been uneven in all affected areas.

Therefore, areas with different radioactive contamination can be found in a given country [17]. With respect to this, the authors plan to perform a study from the viewpoint of ecology in the future, taking into account the radiocaesium activity concentrations in soil. In the present article, the extent of the study area that is contaminated and the assessment of any possible radiological health hazards for the population are the focus of the entire study.

With respect to the radionuclide ^{40}K , the highest mean content was found in ID4, $(117 \pm 14) \text{ Bq kg}^{-1}$, while samples in ID3 had a lower average specific activity, $(79 \pm 9) \text{ Bq kg}^{-1}$. The range of variation of potassium is limited, because it is an essential nutrient and thus its value doesn't have a high variance for the same kind of sample.

All these experimental results, shown in Figure 2, are in good agreement with the food radioactivity database of the Italian Institute for the Environmental Protection and Research (ISPRA) [18].

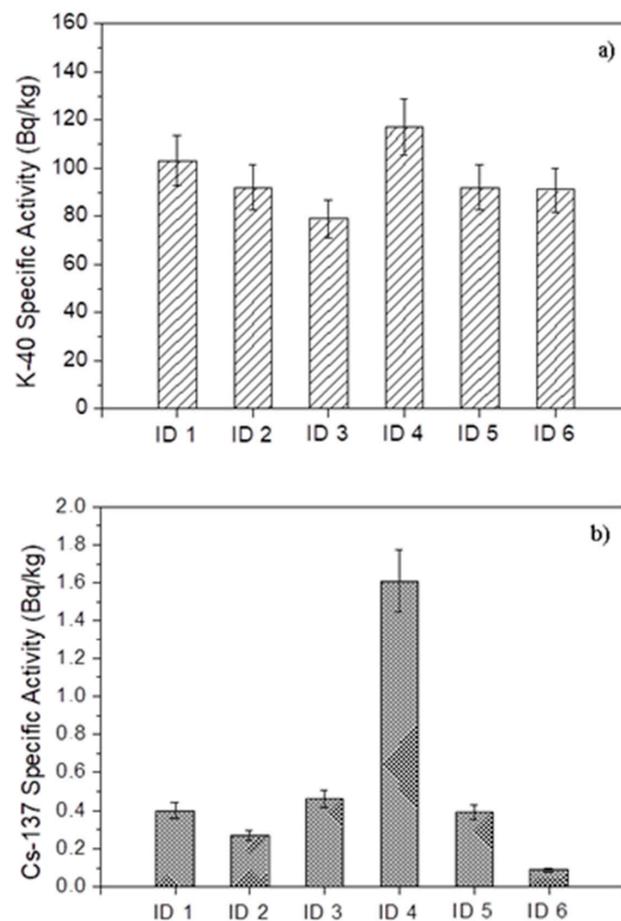


Figure 2. The activity concentration of ⁴⁰K (a) and ¹³⁷Cs (b) for the investigated samples in the selected sampling points.

The effective dose, due to sample ingestion by adult members of the population, was calculated with Equation (2), in a very precautionary scenario: it was taken into account that the average consumption per person, per year, is equal to that of wild boar hunters (5.36 kg annum⁻¹, maximum value), according to the literature [19]. The estimated value obtained, due to ⁴⁰K and ¹³⁷Cs radionuclides, is reported in Table 3, together with the total one, ranging from 2.66 μSv a⁻¹ (ID3) to 4.00 μSv a⁻¹ (ID4), much lower than the limit set for the population (1 mSv a⁻¹) [20], as reported in Figure 3.

The scenario used in the foregoing estimation of the dose by ingestion is also very conservative because the wild boar meat is not eaten raw. It is cooked and consumed immediately or preserved, thus reducing the ¹³⁷Cs content [21].

Table 3. The ⁴⁰K, ¹³⁷Cs and total effective dose due to sample ingestion by adult members of the population.

| Sampling Point | E _{K-40} (μSv a ⁻¹) | E _{Cs-137} (μSv a ⁻¹) | E _{tot} (μSv a ⁻¹) |
|----------------|---------------------------------------------|-----------------------------------------------|--------------------------------------------|
| ID1 | 3.42 | 0.03 | 3.45 |
| ID2 | 3.06 | 0.02 | 3.08 |
| ID3 | 2.63 | 0.03 | 2.66 |
| ID4 | 3.89 | 0.11 | 4.00 |
| ID5 | 3.06 | 0.03 | 3.09 |
| ID6 | 3.02 | 0.01 | 3.03 |

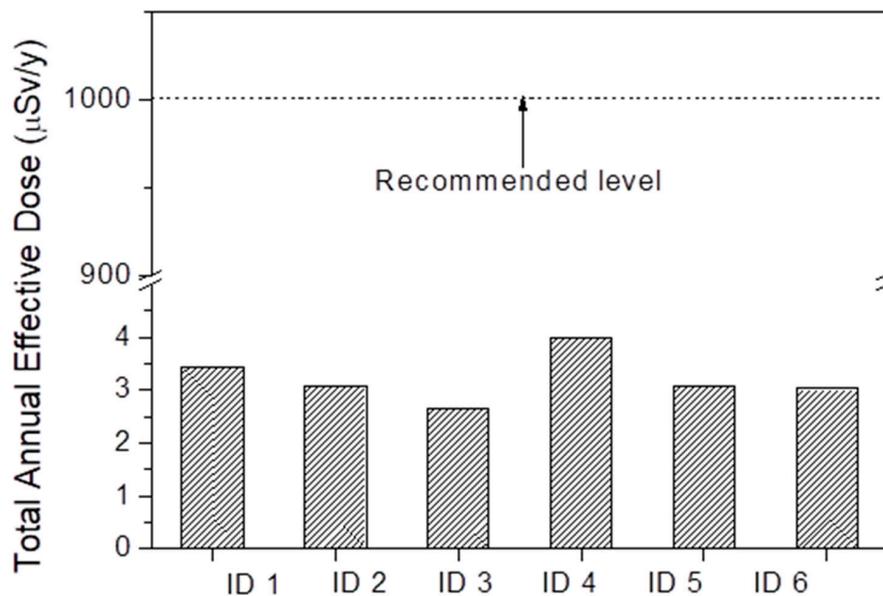


Figure 3. The total effective dose due to sample ingestion by adult members of the population.

4. Conclusions

Wild boars can accumulate radionuclides; therefore, they are considered as bioindicators of environmental pollution. Differences in the wild boar meat ^{137}Cs level, from the six different sampling sites, can be due to the different radioactive contamination, climate and bioavailability of the radionuclide.

The estimation of the extent that the investigated area is contaminated and the assessment of any possible risk of radioactivity for human health due to the ingestion of wild boar meat, were performed. From obtained results, we can exclude a significant fallout radiocaesium contamination and any possible radiological health hazards for the population.

Data reported in this article will be implemented in the future with an increase of the sampling points and the number of samples analyzed.

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Conflicts of Interest: The authors declare no conflict of interest.

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