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Radioactivity Content and Dosimetric Assessment in Bovine Meat from the Calabria Region, Southern Italy

Francesco Caridi [1,*], Valentina Venuti [1,*], Giuseppe Paladini [1], Maurizio D'Agostino [2], Alberto Belvedere [2], Santina Marguccio [2] and Domenico Majolino [1]

[1] Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università degli Studi di Messina, V.le F. Stagno D'Alcontres 31, 98166 Messina, Italy
[2] Agenzia Regionale per la Protezione dell'Ambiente della Calabria (ARPACal)—Dipartimento di Reggio Calabria, Via Troncovito SNC, 89135 Reggio Calabria, Italy
* Correspondence: fcaridi@unime.it (F.C.); vvenuti@unime.it (V.V.)

Abstract: In this article, the assessment of the radioactivity content in bovine meat from the Calabria region, Southern Italy, was performed. For this purpose, High Purity Germanium (HPGe) gamma spectrometry measurements were carried out in order to investigate any possible radioactive contamination by natural (^{40}K) and anthropogenic (^{137}Cs) radionuclides. Experimental mean values were found to be in the range from (78.9 ± 10.5) Bq kg^{-1} to (88.2 ± 12.5) Bq kg^{-1} for ^{40}K and lower than the minimum detectable activity (MDA) in all cases for ^{137}Cs, respectively. Moreover, any possible radiological health risk was also estimated, by calculating the total annual effective dose due to the ingestion of bovine meat by adult members of the population and by comparing it with the total natural radioactivity value (external + internal) for humans. Obtained values are in the range from 10.3 μSv y^{-1} to 11.5 μSv y^{-1}, several orders of magnitude lower than the value of the total exposure to natural radioactivity for human beings, i.e., 2.4 mSv y^{-1}. It is worth noting that the used approach could be used, in principle, for the evaluation of the radiological risk due to the presence of radionuclides in a large variety of food samples of particular interest, and thus it can constitute a guideline for investigations focused on the monitoring of food quality.

Keywords: bovine meat; radioactivity; contamination; high purity germanium gamma spectrometry; radiological risk

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1. Introduction

Humans are exposed to radiations from natural and artificial sources in their life environments [1–4]. Natural radioactivity is due to the presence of cosmogenic and primordial radionuclides in the Earth's crust [5–7], and it provides the greatest contribution to the dose received by the population [8,9]. Artificial fallout radionuclides, such as ^{137}Cs, are derived mainly from global nuclear tests conducted between the mid 1940s and the 1980s, as well as from nuclear accidents [10,11].

There are three ways of exposure to ionizing radiations for humans: external gamma rays, inhalation of radon as well as other radioactive nuclides and the ingestion of radioisotopes through food and water [12–15]. In the last case, in particular, concern about radioactivity levels in food samples is very important in order to safeguard human health [16,17]. In fact, food intake is usually the most important pathway, through which natural and anthropogenic radionuclides can enter the human body [18,19]. Accordingly, the estimation of radionuclide concentrations in different foods and diets appears to be crucial for estimating the human intake of these radionuclides [20].

The natural radioactivity in food mainly comes from ^{40}K, while uranium and thorium daughter products are usually present in traces [21]. When ingested radionuclides are distributed among body organs (according to the metabolism of the involved radioisotope and the specific type of organs), each of which is typically characterized by different radio sensitivities [22], they can induce potential harmful effects, including neoplasia and genetic mutations at somatic and germ cell levels, respectively [23,24].

As a matter of fact, natural and anthropogenic radioactivity has been already extensively quantified in foods and, in particular, in different types of meat from various places [25–28], but there are little data on meat samples from Italy. Meat is a very important food, as it supplies valuable nutrients for health [29]. It constitutes an essential *building block* of a well-balanced and healthy nutrition, as it holds high levels of protein, vitamins, minerals and micronutrients crucial for growth and development [30,31].

Moreover, 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 [32]. After the Chernobyl accident, bovines with increased radioactivity levels were detected across Europe and, since that time, the analysis of radioactivity content in bovine meat has been part of the environmental radioactivity monitoring network of the "National System for Environmental Protection in Italy" [33].

In the light of the aforementioned considerations, the present article is devoted to the estimation, for the first time, of the radioactivity content in bovine meat from the Reggio Calabria district, Calabria region, Southern Italy. Of note, there are no articles in literature referring to the radioactivity measurement in bovine meat of the investigated geographical area. High Purity Germanium (HPGe) gamma spectrometry measurements were carried out, with the aim to first provide information on the background specific activity of the ^{40}K natural radioisotope and contribute to the creation of databases on natural radioactivity. Moreover, the investigation of the ^{137}Cs content in bovine meat allowed for the evaluation of the residual impact of nuclear weapon tests and the Chernobyl and Fukushima accidents in Southern Italy. Finally, the calculation of the total annual effective dose due to the ingestion of bovine meat by adult members of the population, and a comparison with the total natural radioactivity value (external + internal) for humans, permitted the authors to properly evaluate whether the ingestion of bovine meat, as complementary foodstuff consumed by the local population, constitute a potential radiological hazard.

2. Materials and Methods

2.1. Samples' Collection

Fifteen samples of bovine meat (muscle), 1 kg each, were collected for each one of the three hygiene points (site IDs 1, 2 and 3) of the Reggio Calabria district, in the south of Italy (see Figure 1 and Table 1), according to that reported in [34]. Hygiene points are those places where the veterinary check is carried out from the hygienic–sanitary point of view. Each hygiene point is representative of the central, Ionian and Tyrrhenian area, respectively.

At the laboratory, each sample was first frozen at −20 °C. After, they were unfrozen just before the analysis and the inedible parts were removed before homogenization.

Table 1. The IDs and GPS coordinates of the sampling sites.

Site ID	GPS Coordinates	
	Latitude	Longitude
1	38.100833	15.646944
2	38.004444	15.857777
3	38.484166	16.082500

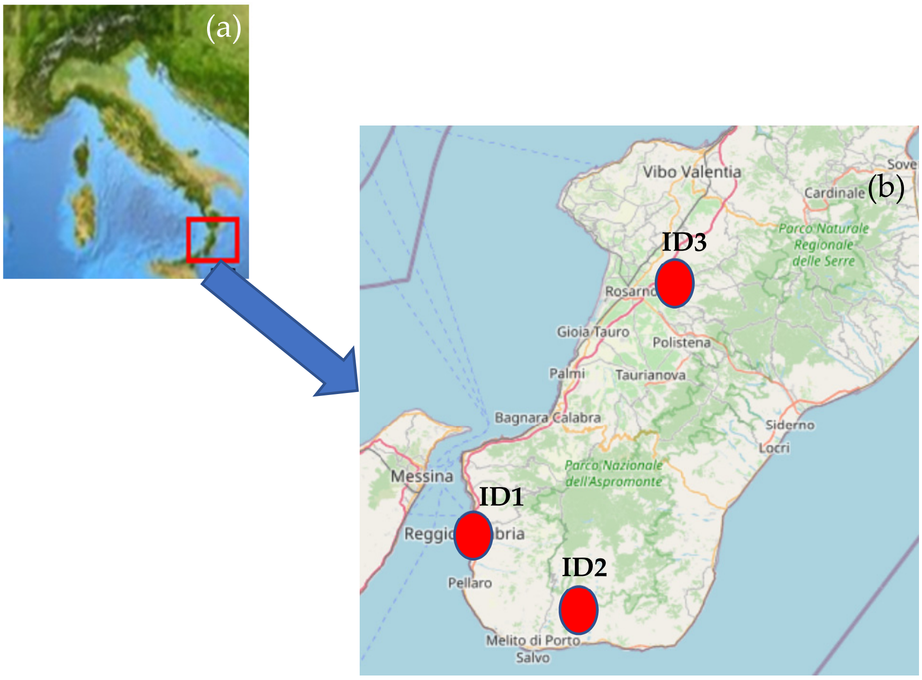

Figure 1. The map of the sampling area (**a**), with the site IDs (1–3) indicated (**b**).

2.2. HPGe Gamma Spectrometry Measurements

For the gamma spectrometry analysis, samples were enclosed in 1 L capacity plastic Marinelli containers and counted for 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 an Ortec HPGe detector and integrated digital electronics. In detail, it is a negative biased detector (GMX), cooled by the Ortec recycler condensing liquid nitrogen cooling Mobius system [35], 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 Eckert and Zigler 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 [36].

The Quality Controls (QC) of radiation measurements were conducted according to [37]. The Gamma Vision software (Ortec) was used to acquire and analyze the data [38].

The specific activity (Bq kg^{-1}) of the investigated radioisotopes was calculated using the following formula [39]:

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

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 measuring the error, at the 95% confidence level, the components taken into account were: uncertainties of count assessment, calibrating source, calibration efficiency, background subtraction, and γ-branching ratio [40].

The quality of the gamma spectrometry experimental results was certified by the Italian Accreditation Body (ACCREDIA) [41]. This implies continuous testing (annually) of whether the performance characteristics of the gamma spectrometry method are maintained [42].

2.3. Assessment of Radiological Hazard Effects

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

$$E\left(Sv\ y^{-1}\right) = ICd_c \quad (2)$$

where I is the annual intake of bovine meat (kg per person), C is the the specific activity (Bq kg^{-1}) and d_c is the conversion factor, equal to 1.3×10^{-8} Sv Bq^{-1} and 6.2×10^{-9} Sv Bq^{-1} for ^{137}Cs and ^{40}K, respectively [43].

The assessment of the dose levels due to bovine meat consumption is a critical point in order to evaluate whether it is safe from the radiological point of view and does not adversely affect human health.

3. Results and Discussion

3.1. Radioactivity Analysis

The ^{40}K and ^{137}Cs specific activity for the analyzed bovine meat samples is reported in Table 2 for each site ID, together with the mean value. Its uncertainty (for each ID) is the standard deviation.

Table 2. The specific activity of ^{40}K and ^{137}Cs for the analyzed bovine meat samples.

Sampling Point	^{40}K (Bq kg^{-1})	^{137}Cs (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	86.5 ± 6.8	<0.12	ID2	71.9 ± 5.9	<0.13	ID3	83.2 ± 11.5	<0.09
	73.4 ± 5.7	<0.08		83.1 ± 11.1	<0.09		84.5 ± 12.3	<0.10
	74.8 ± 5.9	<0.15		90.3 ± 12.5	<0.09		73.1 ± 12.5	<0.16
	90.1 ± 12.1	<0.10		67.3 ± 9.4	<0.08		85.4 ± 11.5	<0.08
	72.1 ± 10.1	<0.12		80.3 ± 11.4	<0.08		59.6 ± 8.1	<0.07
	83.6 ± 12.5	<0.09		97.2 ± 14.5	<0.18		52.5 ± 7.6	<0.07
	75.4 ± 4.9	<0.12		74.2 ± 10.6	<0.10		78.1 ± 11.5	<0.09
	65.2 ± 5.4	<0.08		76.5 ± 5.4	<0.11		91.6 ± 12.6	<0.07
	93.2 ± 12.5	<0.07		77.6 ± 12.5	<0.14		113.6 ± 15.1	<0.07
	79.2 ± 5.2	<0.11		87.1 ± 5.2	<0.12		142.5 ± 19.4	<0.08
	79.5 ± 5.3	<0.09		68.6 ± 5.3	<0.10		84.3 ± 12.4	<0.08
	81.8 ± 11.3	<0.08		86.1 ± 11.3	<0.08		80.4 ± 11.5	<0.12
	77.3 ± 5.1	<0.09		70.9 ± 5.1	<0.09		110.5 ± 15.4	<0.07
	88.5 ± 10.6	<0.11		81.1 ± 10.6	<0.13		77.5 ± 11.4	<0.10
	70.5 ± 8.5	<0.08		71.2 ± 8.5	<0.11		106.4 ± 15.1	<0.18
Mean value	79.4 ± 8.1	<0.10	Mean value	78.9 ± 10.5	<0.11	Mean value	88.2 ± 12.5	<0.09

As can be noted, the mean ^{40}K activity concentration is (79.4 ± 8.1) Bq kg^{-1}, (78.9 ± 10.5) Bq kg^{-1} and (88.2 ± 12.5) Bq kg^{-1} for the sites ID1, ID2 and ID3, respectively. As expected, the maximum variation range of potassium is limited (11.08%), since it is an essential nutrient, and so its value does not exhibit a high variance for the same specimen type.

Further, as far as any possible anthropogenic contamination of investigated bovine meat samples is a concern, the ^{137}Cs specific activity was also quantified. Generally, different possible factors affecting the level of ^{137}Cs in the analyzed samples can be distinguished: (i) the amount of the radioactive fallout, (ii) the climatic conditions and (iii) the radionuclide's bioavailability. From the results (see Table 2), the ^{137}Cs specific activity was found to be lower than the minimum detectable activity (MDA) in all cases, demonstrating the lack of residual contamination by antrophic radioactivity. It is worth noting, however, that different areas within the same country can be affected by different levels of radioactive pollution [44]. In this sense, an evaluation of the ^{137}Cs content in the soil appears to be crucial from the perspective of ecology, which will be the subject of a future investigation.

Of note, all the obtained experimental data are in a good agreement with those reported in the database of the "Italian Institute for the Environmental Protection and Research" (ISPRA) [45], since they are of the same order of magnitude and also very similar. It should be also observed that the ^{40}K activity concentration, measured for each sample, account for the amount of radioactivity and not the radiological health risk to human beings, for which additional factors need to be considered.

Finally, Table 3 reports a comparison of the values of ^{40}K activity concentration in bovine meat samples of various countries [46–49], including the results of the present study, revealing some differences. This may be explained by the physical properties of soil according to the geographical location, the characteristics of the growing grass, climatic condition during the growth of the grass, the race of grazing animals and their spending time on the pasture for grazing.

Table 3. Comparison of values of ^{40}K activity concentration (Bq kg^{-1}) in bovine meat samples of various countries.

Country	^{40}K Activity Concentration (Bq kg^{-1})	References
Southern Italy	78.9–88.2	Present study
Turkey	99.6	[46]
Egypt	44.0	[47]
Korea	90.1	[48]
Nigeria	265.9	[49]

3.2. Potential Health Hazards Resulting from Bovine Meat Consumption

The analysis of the bovine meat quality is of great relevance, given the growing global trend referring to the consumption of such foodstuffs [50]. In particular, with reference to national and supranational regulations related to bovine meat, the Council Regulation 2016/52 (Euratom) sets maximum permitted levels of radioactivity for food and feed following a nuclear accident or any other case of radiological emergency [51]. Specifically, it sets threshold levels only for anthropogenic radionuclides in various types of foodstuffs, in the particular scenario reported above. However, since the district investigated in the present study has never been affected by nuclear accidents, the assessment of any potential health risk for the population due to bovine meat consumption was carried out by calculating the effective dose for bovine meat ingestion by adult members of the population (Equation (2)), and by comparing it with the total natural radioactivity value (external + internal) for humans. More in detail, the effective dose was evaluated taking into account, as the average consumption per person, per year, 21 kg, according to the literature [50], and that the ^{137}Cs specific activity was found to be lower than the MDA in all investigated samples (see Table 2).

The obtained total effective dose value, due to the ^{40}K radionuclide, is reported in Table 4.

Table 4. The total effective dose due to sample ingestion by adult members of the population.

Sampling Point	$E_{k\text{-}40}$ (μSv y^{-1})
ID1	10.3
ID2	10.3
ID3	11.5

Worthy of note, the aforementioned doses are several orders of magnitude lower than the value of the total (external + internal) exposure to natural radioactivity for human beings, i.e., 2.4 mSv y^{-1} [52], thus, excluding any significant radiological health risk due to the ingestion of the investigated bovine meat.

4. Conclusions

The concentration levels of natural (^{40}K) and anthropogenic (^{137}Cs) radionuclides in bovine meat samples from the Calabria region, Southern Italy, were evaluated through the High Purity Germanium (HPGe) gamma spectrometry. In particular, regarding ^{40}K, the variation range of its specific activity was found to be limited, since it is an essential nutrient; thus, its value does not exhibit a high variance for the same specimen type. With reference to ^{137}Cs, otherwise, the obtained values were found to be lower than the minimum detectable activity (MDA) in all cases, demonstrating the lack of residual contamination by anthropogenic radioactivity. Moreover, the results of ^{40}K activity concentration reported in the present study were compared with ^{40}K specific activity in bovine meat samples of other countries, revealing some differences. This may be due to different reasons, such as the physical properties of soil according to the geographical location, the characteristics of the growing grass, climatic condition during the growth of the grass, the race of grazing animals and their spending time on the pasture for grazing.

Further, in order to assess any possible radiological risk for the population, the effective dose for bovine meat ingestion was evaluated. The calculated values were then compared with the total (external + internal) exposure to natural radioactivity for human beings, i.e., 2.4 mSv y^{-1} and they were found to be about three orders of magnitude lower. It can therefore be concluded that, in our case, radionuclide intoxication with consequent adverse impacts for humans is not a concern.

Data reported in this article thus confirm that the analyzed samples are safe for food purposes, in terms of natural (^{40}K) and anthropogenic (^{137}Cs) radionuclide content, and hence, no remedial actions are needed. Moreover, obtained results also represent a main reference for the investigated area and can be used as a baseline to extend this investigation to the whole region. Moreover, they will be implemented in the future with an increase in the sampling points and the number of samples analyzed, but, noteworthily, the approach reported in this paper could be applied, in principle, for the evaluation of any potential radiological health risk due to the presence of radioactive elements in a large variety of food samples, by constituting a guideline for investigations focused on the monitoring of food quality.

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