

Impact of volcanic eruptions on heavy metal contamination in the food chain

Samuele Pulze,¹ Noemi Presti,² Aniello Anastasio³

¹1st Section of the Veterinary Service of the Carabinieri General Headquarters, Department of Health and Veterinary Organization, Rome; ²Provincial Health Office of the Police Headquarters, Naples; ³Department of Veterinary Medicine and Animal Production, University of Naples Federico II, Italy

Abstract

This work aims to assess the risk of heavy metal contamination of volcanic origin in the agri-food chain, describing the potential danger to human health. Volcanic phenomena lead to the environmental presence of contaminants, including heavy metals, which influence our ecosystems, food, and health. Opinions have been expressed regarding the presence of heavy metals in our diet and the potential risk of food contamination following volcanic eruptions. Regulation (EU) 915/2023 does not reference the sanctions that would be applied if food products with analytical values exceeding the established tolerance limits for heavy metals were marketed. Legislative Decree No. 18 of February 23, 2023, while providing a sanctions framework, is not specific to the exceedance of maximum limits for heavy metals in water intended for human consumption; it is plausible to apply the Penal Code (Articles 444 and 452) and Law No. 283 of April 30, 1962. The effect of volcanic eruptions seems to play a residual role in heavy metal contamination in food supply chains, considering that their presence is quantified in trace

amounts. Given that a limited number of active volcanoes have been monitored for heavy metal emissions and that data regarding the contribution of volcanic activity is lacking, there are still too many missing pieces to conduct a realistic risk assessment of the impact volcanic activity has on the food chain. In conclusion, the 2022 Environmental Data Yearbook from the Higher Institute for Environmental Protection and Research indicates that Italy has achieved the goals set internationally by the Aarhus Convention.

Introduction

This work considers the main regulatory references concerning food safety, particularly relating to contaminants and pollutants, especially of volcanic origin, and describes their potential danger to human health when present in food (Codex Alimentarius Commission, 2020). Currently, there are 789 volcanoes on Earth that have erupted in the last 10,000 years and are therefore considered active (www.mapsism.com); in addition to visible surface activity, there are also lava emissions from the ocean floor. The eruptive column and its collapse are vehicles and causes for the environmental presence of derived contaminants, such as atmospheric particulate matter, fine dust, sulfur dioxide, carbon monoxide, nitrogen oxides, polycyclic aromatic hydrocarbons, heavy metals, dioxins, and dioxin-like substances.

Geochemical studies conducted in recent decades on the gas emissions of major active volcanoes indicate that Mount Etna emits about 16% of global volcanic heavy metals and 19% of alkaline metals during eruptions, and 5% of these elements during periods of quiescence (Andronico and De Giammarco, 2021). Regarding potential health risks, several studies conducted over the last 20 years have correlated the number of paroxysmal eruptions and the large amount of ash produced by the volcano with a slight but significant increase in certain neurodegenerative and tumor pathologies in the area, with statistically higher incidences compared to the rest of Sicily and other Italian regions (Boumediene *et al.*, 2019). It has been scientifically demonstrated that oxidative stress caused by the bodily absorption of metals, such as nickel (Ni), cadmium (Cd), vanadium (V), *etc.*, can play a significant role in the pathogenesis of certain neurodegenerative diseases. Recent studies (2019) have shown a higher incidence of ALS among people living on the southeastern flank of Mount Etna, the most exposed to volcanic metals; a higher incidence of lung and hematological cancers in the same area could, however, be linked not only to deposited metals but also to the high concentrations of volcanic fine dust that settle there (Andronico and De Giammarco, 2021).

The contaminating effect of heavy metals present in volcanic ash has also been demonstrated by some documents preserved in the Historical Archive for the Neapolitan Provinces, referring to the eruptive phenomenon that affected Vesuvius in the summer of 1794 (Guerra, 2018).

Correspondence: Noemi Presti, Provincial Health Office of the Police Headquarters, Naples, Italy.
E-mail: mvppresti@gmail.com

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“Metals and other elements” in food products

Assessing the “National Multiannual Control Plan 2020/2022” data from 40,927 food and beverage samples subjected to 123,580 analytical determinations in Italy, specifically for the year 2020, shows 23,609 determinations for organic contaminants (dioxins and polychlorinated biphenyls), with 3 non-compliant results; 21,085 determinations for chemical elements (including heavy metals), with 29 non-compliant results.

It can be further observed that, in 2020, out of 3783 notifications, 133 were related to heavy metals (3.5%), of which 68 concerned fish products, 12 for bivalve mollusks and cephalopods, and 7 for fruits and vegetables; 52 notifications concerned mercury (Hg), 40 Cd, 17 lead (Pb), 8 arsenic (As), and 3 Ni; for Italy, out of 300 notifications, those regarding heavy metals were 38 (12.6%) (Ministry of Health, 2020).

In 2021, out of 4588 notifications, 155 were related to heavy metals (3.4%), of which 61 were for fish products, bivalve mollusks, and cephalopods, and 9 for fruits and vegetables; 49 notifications concerned Hg, 10 Cd, 1 Pb, and 1 As; for Italy, out of 387 notifications, those regarding heavy metals were 55 (14.2%) (Ministry of Health, 2021). In 2022, out of 4339 notifications, 163 were related to heavy metals (3.8%), of which 48 were for fish products, 35 for fruits and vegetables, and 9 for cephalopods; for cephalopods, all notifications (9) concerned Cd; for Italy, out of 318 notifications, those regarding heavy metals were 38 (12.1%) (Ministry of Health, 2022).

The factors that most significantly affect the toxic potential of heavy metals are exposure, which includes dose, as well as the mode, duration, and frequency of exposure; the host, with reference to age, gender, and biotransformation capacity; and intrinsic characteristics, lifestyle factors such as alcohol consumption, smoking, and diet composition.

From a regulatory perspective, within the European Union, the cornerstone principles regarding “contaminants in food products” are established by Regulation (EC) 315/1993, which introduces the definition of contaminant: “a substance not intentionally added to food products but present as a residue from production, manufacturing, transformation, preparation, treatment, conditioning, packaging, transport, or storage of these products, or as a result of environmental contamination” (Article 1, paragraph 1) (Council of the European Communities, 1993).

This Regulation prohibits the marketing of food containing “contaminants in unacceptable quantities from the public health perspective and particularly from a toxicological standpoint” (Article 2, paragraph 1) and mandates the adoption of maximum tolerance values for specific contaminants, in relation to the food products concerned, to protect public health (Article 2, paragraph 3).

The aforementioned tolerance levels have been established by the European Commission in community lists found in the Annex of Regulation (EC) 1881/2006 and its amendments (European Commission, 2006), among which, Part 3 is dedicated to metals: Pb, Cd, Hg, inorganic Tin, and As. In addition to this Regulation, numerous EU Commission Recommendations have been drafted, particularly Recommendation No. 2022/1342 on “monitoring mercury in fish, crustaceans, and mollusks” (European Commission, 2022), which originates from both the Scientific Opinion on mercury and methylmercury adopted by EFSA (dated November 22, 2012) and the establishment of maximum levels of Hg in fish muscle, crustaceans, bivalve mollusks, and food supplements set by the same standard.

The substantial amendments to Regulation (EC) 1881/2006 led to the publication of new Regulation (EU) 2023/915 (European Commission, 2023).

Directive (EU) 2020/2184 of December 16, 2020, “concerning the quality of water intended for human consumption” (Implementation Legislative Decree No. 18 of February 23, 2023), provides (Article 4, co. 1) that such waters must meet the minimum requirements set out in Annex I, parts A, B, D; part B, in particular, lists the chemical parameters used to assess the quality of water intended for human consumption and the respective maximum allowable values for each parameter, among which, in addition to the heavy metals already identified by Regulation (EU) 915/2023 (As, Cd, Hg, and Pb), Ni and Uranium (U) are also considered, to which Legislative Decree 18/2023 (Annex I, Part B) further adds V (2020; Italian Republic, 2023).

The EFSA Scientific Expert Group on contaminants in the food chain (CONTAM) has identified dietary sources as the main source of inorganic As exposure for the European population, particularly in processed cereal products, milk and dairy products, and drinking water (EFSA, 2009).

EFSA (2012) identified dietary sources as the primary exposure to Cd for the European population, particularly in cereals and derived products, vegetables, tubers, crustaceans, and mollusks. The CONTAM expert group identified (EFSA, 2010) that the main source of Pb exposure for humans and animals is the ingestion of contaminated food (cereals and vegetables) and water, improperly disposed batteries, paint chips, and Pb shot, although exposure can also occur *via* inhalation and contact (WHO, 2015).

The main source of Hg exposure for the population is the ingestion of contaminated fish and seafood, where levels can reach up to 5 mg/kg (Bagnato, 2020; FDA, 2014).

EFSA first conducted a specific study (2015) on the risk assessment associated with the chronic effects of sensitization from Ni due to its ingestion through food and drinking water (WHO, 2005); subsequently, it carried out an update of this risk assessment in compliance with Recommendation (EU) 2016/1111 (European Commission, 2016; EFSA, 2020), concluding that there is no evidence of a correlation between oral exposure to Ni and a carcinogenic effect in humans. The highest risk of dietary exposure for the EU population is associated with “legumes, hazelnuts, and oilseeds” and “products for special nutritional use” (Ministry of Health, 2016a).

Food is the main source of exposure to c for the general population: significant levels are found in cereals, radishes, mushrooms, and fish products, while technological processes can increase its concentration. The presence of the metal in drinking water is closely related to the geographical area considered (Barceloux, 1999; Ministry of Health, 2016b). The IARC classification places V in Group 2B, “possibly carcinogenic to humans”.

When food is “harmful”

Both the repealed Regulation (EC) 1881/2006 and the current Regulation (EU) 915/2023 do not provide any references to the sanctions applicable in cases where food products are marketed with analytical values exceeding the tolerance limits established for the relevant heavy metals.

The lack of specificity in the category of harmful foods, which likely encompasses all products exceeding the maximum thresholds for the contaminants considered in Annex 1 of Regulation (EU) 2023/915, would lead to the application of criminal protec-

tion: under Articles 444 and 452 of the Penal Code (Crimes against public health) for intent and negligence, respectively; under Article 5, paragraph 1, letter d) of Law No. 283 of April 30, 1962 (Italian Republic, 1962), also noting the possibility of seeking clemency for the criminal offense through the payment of a specific administrative pecuniary sanction, in the cases and manner provided for by Article 70 of Legislative Decree 150/2022 (Italian Republic, 2022), known as the Cartabia Reform.

These legal provisions appear consistent with those arising from exceeding the microbiological limits established for specific food categories by Regulation (EC) No. 2073/2005 and its amendments, with the only difference being that, regarding criminal protection under the aforementioned Law 283/1962, the specific offense violated.

The comparison with anthropogenic effects

The impact of human activities is the primary cause of environmental contamination, with both direct and indirect mechanisms and actions. A predominance of the heavy metals category is observed compared to the other components of the group of environmental pollutants and contaminants that affect the food chain (EFSA, 2009).

Conclusions

Regarding the above, the effect of volcanic eruptions and related phenomena appears to play a marginal role in heavy metal contamination in food chains, given that their presence, particularly in relation to volcanic ash, is quantified in trace amounts. Nevertheless, a currently underestimated phenomenon is the presence of heavy metals contained in volcanic gases. It is estimated that Mount Etna emits approximately 5 tons of Hg annually during its quiescent degassing phases, but this figure is significantly underestimated, as it does not account for potential increases during the volcano's eruptive phases (Andronico and De Giammarco, 2021). In summary, considering that only a small number of active volcanoes have been investigated and monitored in terms of Hg emissions, that the reported measurements almost exclusively relate to the quiescent phase of the investigated volcanoes, and that

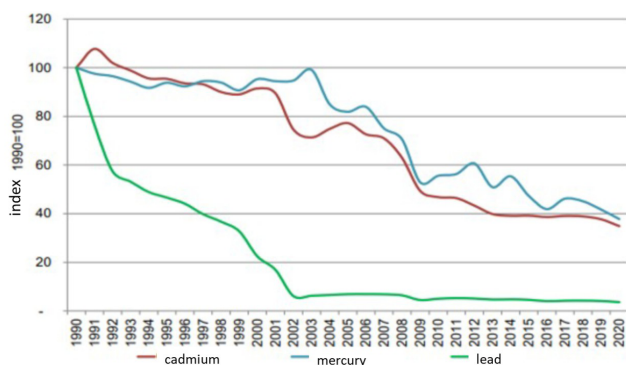


Figure 1. Trend of national emissions of heavy metals (cadmium, mercury, lead) indexed to 1990. Modified from: ISPRA, 2023.

there is a significant lack of data regarding Hg contributions from volcanic and submarine hydrothermal activity, many pieces are still missing to conduct a fully realistic risk assessment regarding the actual impact volcanic activity may have on environmental contamination and the food chain (Codex Alimentarius Commission, 2020).

The oversight actions by the competent authorities regarding the effects of pollutants and contaminants on food products and drinking water have also been established for the 2023-2027 period, with the adoption, pursuant to Article 109 of Regulation (EU) 625/2017 (European Parliament and Council of the European Union, 2017), of the National Multiannual Control Plan (State-Regions Agreement No. 55/CSR of March 22, 2023) (State-Regions Conference, 2023). The Sicilian Region (2023) has developed its “Regional Official Control Plan for Environmental Contaminants and Natural Plant Toxins in Food - Years 2023/2027” (Sicilian Region, Decree No. 329 of March 31, 2023), which specifically provides for controls on compliance with the maximum levels established for Pb, Cd, Hg, and As in the area of environmental and industrial contaminants.

In conclusion, from the pages of the 2022 Environmental Data Yearbook (“Environment in Italy: An Overview”), published by the Higher Institute for Environmental Protection and Research, an encouraging fact emerges regarding the emissions of heavy metals at the national level: (coverage period 1990-2020) Italy has met and achieved the internationally set goals under the aforementioned Aarhus Convention (Figure 1) (ISPRA, 2023).

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