Earthworm consumption as a source of protein around the world: A review

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ABSTRACT
Population growth will increase global food demand compared to current demand. This factor leads to a shift in consumption to a more diverse diet, which includes a larger share of processed foods, meats, dairy, and fish, all of which add pressure to the supply system. The introduction of more sustainable food sources, such as earthworms, will improve the health of the planet and humans. The purpose of this article is to analyze and present a comprehensive literature review on earthworm consumption in the world. A literature survey was conducted from May to July 2023. The works related to the theme were searched through research on scientific platforms over a period of 27 years. A total of 10 articles related to the theme were found, most of which were in Europe, followed by Asia and America. All studies highlighted the importance of exploring earthworms as a viable sustainable protein alternative for the future, and more studies and awareness of the benefits of their consumption are needed.

Keywords: Sustainable protein, Food safety, Innovative food.

1 INTRODUCTION

It is estimated that by 2050, population growth will increase global food demand by up to 70% compared to current demand (NAWAZ; CHUNG, 2020). Steady population growth and diminishing contextual resources require a paradigm shift in food consumption, especially for the Western population. This factor leads to a shift in consumption to a more diverse diet, which includes a higher share of processed foods, meats, dairy, and fish, all of which add pressure to the supply system (BRUMMITT et al., 2020). The introduction of more sustainable food sources, such as invertebrates,

will improve the health of the planet and humans, as well as support socio-economic development (RUSSO et al., 2020; NAYLOR et al., 2021).

Among the animals that live in the soil, earthworms are one of the most important, as they are ecosystem engineers and perform various environmental services, including biological control, decomposition of organic matter, nutrient cycling, soil formation and aggregation, factors that generally positively affect plant growth (BROWN; DOMINGUEZ, 2010). In the literature, there are several works related to the manufacture and use of earthworm feed for feeding different animals. However, with regard to human consumption, little research has been conducted (TEDESCO et al., 2020). In China and Italy, where much of the research on earthworm-derived foods for human consumption is concentrated, the results reveal that this food provides our bodies with essential vitamins, helps in the stimulation and biochemical balance of vital functions, in the therapy of Parkinson's, in the treatment of hypothyroidism and in sleep therapy. In addition, protein has the property of strengthening muscles and bones, without fattening or accumulating cholesterol (TEDESCO et al., 2019).

Earthworms are rich in proteins, vitamins and minerals, and have been consumed around the world for thousands of years, as flour, in soups and in recipes for baked goods and sweets (CAYOT et al., 2009). According to Sun and Jiang (2017), earthworm meat is an excellent source of protein, having a high content in the range of 54.6% to 71% of dry matter, as well as micronutrients, minerals and vitamins that are biologically valuable in the human diet and rich in amino acids deficient in many plant meals commonly used in diets, such as lysine, threonine, arginine and valine. In addition, fatty acids of biological importance, such as octadecanoic acid, linoleic acid and linolenic acid, considered essential for humans, have been detected.

According to Paoletti et al. (2003), studies in countries such as Mexico, Bolivia, Chile, and Peru have resorted to the use of wormmeal as an alternative to the lack of animal protein to improve the nutritional quality of food and minimize the effects of hunger and child malnutrition. The same authors also argue that the results of the research were positive and the use of worm meal became popular in these countries as a food supplement.

The European Regulation (EU) 2015/2283 on novel foods provides that traditional foods consumed in third countries with a history of safe food use can be considered a valuable source of food nutrients in the food chain. In some parts of Africa, South America and Asia, earthworms have been introduced into the daily diet, being included in the Dictionary of Food Science and Technology (EU, 2015). In view of the above, the objective of this article is to analyze and present a comprehensive literature review on earthworm consumption in the world, exploring its cultural, nutritional, environmental and economic relevance.

2 MATERIALS AND METHODS

The present study is characterized as a bibliographic reference research whose objective is to search and systematically analyze the information available in various bibliographic sources, such as books and scientific articles, related to a certain theme or area of study. A literature survey was conducted from May to July 2023. The works related to the theme were searched through searches on the Google Scholar, CAPES Journal Portal, Scielo, Science Direct and Pubmed platforms.

The main terms used for the research were: "Worms as human food", "consumption of worms", "worm flour" and "Worm proteins". A total of 10 articles were selected, and the criteria for inclusion in the review were: date of publication in the last 30 years, English or Spanish language, and focus on the theme.

3 RESULTS AND DISCUSSION

As can be seen in Table 1, in the last 27 years, 10 relevant articles have been published on earthworm consumption, both in *natura* and powder. These studies have addressed the various ways in which earthworms can be incorporated into the human diet, either as an ingredient in gourmet dishes or as a raw material for the production of innovative processed foods.

Another highlight of these articles is related to the positive impacts on both the environment and human health. The presence of essential amino acids and high protein content make earthworms a promising food for improving nutrition in the human diet. In addition, earthworm farming is environmentally friendly, contributing to the treatment of organic waste, reducing greenhouse gas emissions and carbon footprint (TEDESCO et al., 2019; RUSSO et al., 2020).

The most recent publications indicate that worm meal is a promising sustainable source of protein, and can be used as a partial or total replacement for conventional protein. Studies indicate that by 2050, population growth will increase global food demand by up to 70% compared to current demand. In this context, worm meal presents itself as a viable alternative to meet this growing need for food in a more sustainable way (NAWAZ; CHUNG, 2020; RUSSO et al., 2020).

Table 1 – articles published during the review period

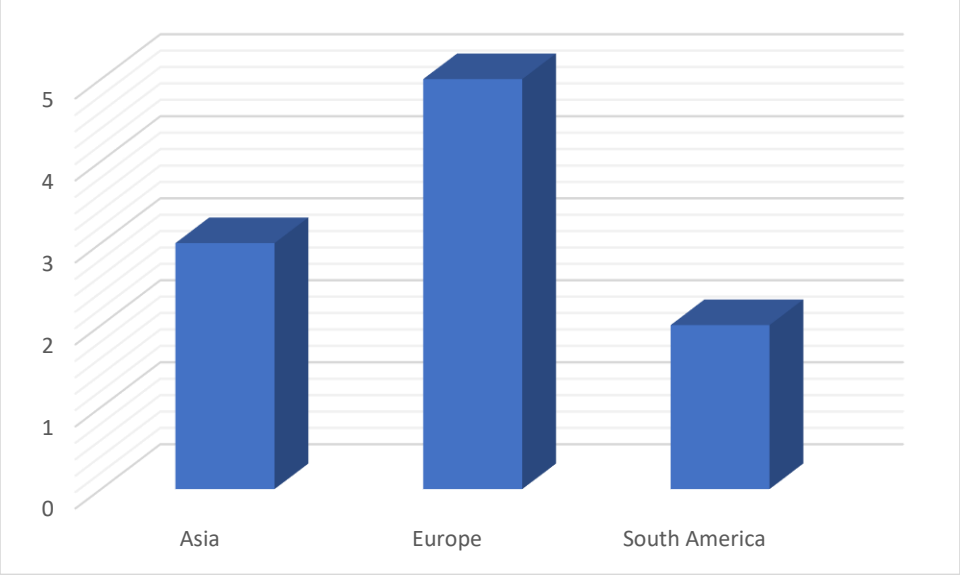
#Nº	Data	Title	Authors	Newspaper	Objective
01	1997	Earthworm as a potential protein resource	Sun Zhenjun, Liu Xianchun, Sun Lihui, Song Chunyang	Ecology of Food and Nutrition	To assess the potential of commonly cultured earthworms in China as a protein source for use in animal and human nutrition by comparing the nutrient composition of ground earthworm body, earthworm

					body fluids and earthworm casts with that of common animal feeds and food stuffs.
02	2000	The importance of leaf- and litter-feeding invertebrates as sources of animal protein for the Amazonian Amerindians.	Maurizio Guido Paoletti1, Darna L. Dufour , Hugo Cerda , Franz Torres, Laura Pizzo ferrato, David Pimentel	The Royal Society	Showing that the consumption of invertebrates that feed on leaves and leaf litter as a means of recovering protein, fats, and vitamins by forest peoples offers a new perspective for the development of animal-based food production within the paradigm of biodiversity conservation.
03	2003	Nutrient content of earthworms consumed by Ye'Kuana Amerindians of the Alto Orinoco of Venezuela	M. G. Paoletti, E. Buscardo, D. J. VanderJagt, A. Pastuszyn, L. Pizzoferrato, Y.-S. Huang, L.-T. Chuang, M. Millson, H. Cerda, F. Torres, R. H. Glew	The Royal Society	-
04	2009	Physico-chemical characterisation of a non-conventional food protein source from earthworms and sensory impact in arepas	Nathalie Cayot, Philippe Cayot, Elias Bou-Maroun, Hélène Laboure, Beatriz Abad-Romero, Karine Pernin, Nuria Seller-Alvarez, Ayary V. Hernandez, Elil Marquez, Ana L. Medina	International Journal of Food Science and Technology	Characterize an unconventional protein source: a powder made from earthworms, and evaluate its potential use in human food.
05	2017	Nutritive Evaluation of Earthworms as Human Food	Zhejun Sun, Hao Jiang	Intech	-
06	2017	Effect of the drying process of earthworm (eisenia andrei) on the amino acid profile of flour determined by chromatography (clae)	José Ovalles, Ana Medina, Elil Márquez, Leandra Rial	Basic Sciences and Technology	In this article, an additional study of the effect of the drying process of earthworm (E. andrei) biomass at moderate temperature (30-45ºC) on the amino acid profile of the resulting flour is presented
07	2019	Bioconversion of fruit and vegetable waste into earthworms as a new protein source: The environmental impact of earthworm meal production	Doriana Tedesco, Cecilia Conti, Daniela Lovarelli, Elisa Biazzi , Jacopo Bacenetti	Science of The Total Environment	Is to evaluate the environmental impact of the bioconversion of FVW into earthworm meal to be used as new food/feed source. This is carried out by adopting the Life Cycle Assessment (LCA)method with an attributional approach and solving the multifunctionality of the system with an economic allocation

					between earthworms and vermicompost.
08	2020	Novel Food-Based Product Communication: A Neurophysiological Study	Vincenzo Russo, Giulia Songa, Laura Emma Milani Marin, Claudia Maria Balzaretti , Doriana Eurosia Angela Tedesco.	Nutrients	Investigate possible communication strategies for novel foods through labels.
09	2020	From a Food Safety Prospective: The Role of Earthworms as Food and Feed in Assuring Food Security and in Valuing Food Waste	Doriana Eurosia Angela Tedesco, Marta Castrica, Aldo Tava, Sara Panseri, Claudia Maria Balzaretti	Insects	Describe all phases of a pilot earthworm rearing activity developed within the project "Bioconversion of fruit and vegetable waste to earthworm meal as novel food source" funded by FONDAZIONE CARIPLO—Integrated research on industrial biotechnologies 2015 (Project No. 2015-0501).
10	2023	Insects and worms as an alternative protein source in the halal food industry	Suganisha Suresh, Nurul Solehah Mohd Zaini, Muhamad Hafiz Abd Rahim, Nurul Hawa Ahmad	Innovation of Food Products in Halal Supply Chain World wide	-

As can be seen, most of the research is located on the European continent (Figure 1).

Figure 1: Consumption of earthworms on continents.



Although the topic of the consumption of earthworms as human food is not a recent subject, since in 1945 there were already studies discussing the high protein content of earthworm meat, only in recent years has there been an interest on the part of researchers. As can be seen in figure 1, the

research is more concentrated in Europe, with five (5) articles, followed by Asia. In the Americas, two papers were published in South America, one in 2009 and the other in 2017.

In China, more precisely in the provinces of Fujian and Guangdong, the inhabitants have the habit of adding earthworms to their diets (SUN; JIANG, 2017). The same authors say that in Fujian, a province known for its exotic cuisine, people usually cut worms into smaller pieces and mix them with another type of meat to make the food tastier. In Guangdong, many restaurants offer worm soup on their menus, considered a delicacy and one of the most expensive dishes in the establishments (SUN; JIANG, 2017). Another reference of the use of earthworms as human food is in Taiwan and Henan. In both provinces, local residents use earthworms as a staple ingredient in their diet (SUN; JIANG, 2017).

According to Sun and Jiang (2017), earthworm meat is an excellent source of protein, with a high content in the range of 54.6% to 71% of dry matter. In addition, it contains micronutrients, minerals and vitamins of great biological value in the human diet, being rich in amino acids that are deficient in many vegetable meals commonly used in diets, such as lysine, threonine, arginine and valine. Fatty acids of biological importance, such as octadecanoic acid, linoleic acid and linolenic acid, which are considered essential for humans, have also been detected.

Other nutrients, such as copper, iron, manganese, zinc, and phosphorus, have also been found in significant amounts (YILMAZ; WALHOUT, 2014).

The indigenous South American natives of the Yekuna tribe of the Upper Orinoco in Venezuela also have a habit of feeding on earthworms. The tribe uses the traditional recipe of whiting the earthworms and seasoning them with Aji, a traditional spice used for millennia by this tribe. Finally, they are eaten with cassava bread (PAOLETTI et al., 2003). Latin American countries, in order to minimize the effect of malnutrition and hunger, are resorting to the use of earthworms as an alternative to the lack of protein from animal sources. An example of this are Peruvian researchers from the Pedro Vilcapaza Institute of Public Higher Technological Education, in the city of Puno, Peru. They carried out research to combat childhood anemia with a wafer produced with worm flour. The result of the research was satisfactory and showed that, after 60 days, 90% of the 73 children who consumed the cookies showed remarkable improvements, making the earthworm the main ally in the fight against anemia in the child population of the puno region (KOECHLIN, 2015).

In Venezuela, a study conducted by Cayot et al. (2009) tested the use of worm meal for the fortification of a traditional corn-based food: arepas, which are pancakes produced with corn flour. According to the authors, from a sensory and nutritional point of view, they obtained satisfactory results, concluding that the use of earthworm biomass for human food is promising, and more studies and research are needed related to the use of earthworm as an unconventional source of protein.

Currently, the global demand for protein is increasing, with more and more people wanting to include animal protein in their diet. The need for new food products is anchored in two specific aspects:

the human population is increasing, with more than 821 million people still without regular access to adequate food, and, at the same time, there is a growing demand for new sources of animal protein, which are the most limiting and expensive in terms of resources (MYERS et al., 2017).

Traditionally, it is common to use earthworms as fishing lures and feed for various animals. However, in the last 30 years, the breeding of earthworms as a source of protein, replacing soybean and corn meal on a commercial scale, has gained ground worldwide and can be valued for human consumption.

Today, the food sector is considering the use of insects in human food, and in this context, terrestrial invertebrates, such as earthworms, used as an alternative source of protein, may represent a valid solution. The use of food waste as a substrate for the growth of earthworms, through the process of bioconversion, produces a protein-rich product that can be valued for human consumption (TEDESCO et al., 2019; TEDESCO et al., 2020). Earthworm farming is part of an ancestral culture and can be considered a dual-purpose activity: humus production and earthworm meal production as a protein-rich food (PÉREZ-CORRÍA et al., 2019).

According to Sun and Jiang (2017), earthworm meat is an excellent source of protein, having a high content in the range of 54.6% to 71% of dry matter, as well as micronutrients, minerals, and vitamins that are biologically valuable in the human diet. It is rich in amino acids deficient in many commonly used plant meals in diets, such as lysine, threonine, arginine, and valine. In addition, fatty acids of biological importance, such as octadecanoic acid, linoleic acid and linolenic acid, considered essential for humans, have been detected. Other nutrients, such as copper, iron, manganese, zinc, and phosphorus, have also been found in significant amounts (YILMAZ; WALHOUT, 2014).

Worm meal-based foods represent a high-quality protein source that can minimize malnutrition, as they are able to provide all the essential amino acids, those that the human body is not able to synthesize (OVALLES et al., 2017). According to Tedesco et al. (2020), earthworm-based foods have high nutritional properties. However, the product must be safe for both human and animal consumption, presenting sanitary compliance. Therefore, it is necessary to evaluate the microbiological profile and the chemical profile.

Interest in non-traditional foods has been growing more and more around the world. Many people still have taboos, fear, and prejudice towards these foods. Therefore, it is necessary to promote greater awareness, with the aim of changing thinking and values in relation to these new food options (RUSSO et al., 2020).

4 CONCLUSION

The inclusion of earthworm-based foods, or even earthworms in natura, for human consumption represents an innovative and sustainable source for the future. However, more research

and investment needs to be carried out in the techniques that involve the entire process, from breeding to processing earthworms as food. In addition, it is necessary to promote awareness and stimulate people about the benefits for both the environment and people's health.

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