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Review

Assessment of Several Approaches to Biofortified Products: A Literature Review

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Abstract: The aim of this study is to provide a literature review on biofortified products and their role in the scientific sphere. Despite the large number of studies conducted on biofortified products in the last 20 years, many defining issues are still debated in the literature and several research questions should be clarified. It is therefore relevant to investigate more on this topic, which is considered increasingly important to human health, world hunger reduction strategy, and also for the international marketing strategy of production holdings. The papers were analyzed according to a chronological/conceptual approach, with greater emphasis on research that has added significant value to the literature. The research was carried out using a scientific database from which 1189 scientific papers were extracted. A careful analysis of the abstracts and the text led to the identification of the five dimensions of our greatest interest (Reducing world hunger; Human health; GMOs; Agronomy, herbaceous crops; Economy and the market). The suggestions for future research reported by various authors are organized and structured in order to create an incentive for new studies and insights into biofortification.

Keywords: biofortification; marketing; economic approaches; health; innovation; nutrition

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1. Introduction

The main objective of agricultural innovations, whether technological, agronomic or genetic, has been to increase the final yields. Until the 1990s, limited attention was given to improving nutritional qualities.

In recent years, increasing attention has been paid to "hidden hunger," two research terms used to indicate people around the world who suffer from vitamin and micronutrient deficiencies.

Unfortunately, malnutrition is still a global health problem with many related diseases [1]. This phenomenon has a significant socio-economic impact and has contributed, together with difficult social and environmental conditions to the current situation in low- and middle-income countries [2,3].

In 2015, the Millennium Development Goals (MDGs) [4] aimed to eradicate health and poverty problems, world hunger, reduce child and maternal mortality, and overcome malnutrition resulting from a scarcity of food resources [5].

Biofortification is widely regarded as a very valuable technique that increases the availability of micronutrients (vitamin A, selenium, zinc, iron and other micronutrients) absorbed by plants and transferred from them to consumers. This process, therefore, can be useful in combating malnutrition, which is a major challenge, particularly in developing countries [6,7].

In this context, plant biotechnology applied to biofortification of staple crops has offered a powerful tool to counteract these deficiencies by providing nutritionally enhanced crops.

The availability of foods enriched with beneficial substances such as antioxidants, vegetable fibers, vitamins, and minerals has increased, as consumers [8] are attracted to labels such as "low fat," "low sugar," "no hydrogenated fats," "low sodium," in parallel with the promotion of a healthy lifestyle. All these different products have in common the fact that they provide health benefits and as such have been classified as functional food [9,10]. In recent years, the subject has become highly topical, in accordance with the new requirements expressed by an increasingly globalized market. Although there has been increasing discussion of biofortified products for some years now, there is some confusion, especially regarding the definition, which generates a lot of uncertainty for consumers and operators in the sector [11,12].

The lack of an unambiguous interpretation of the term often leads to confusion between the concept of biofortified products and other products, such as GMOs (genetically modified organisms), which they are increasingly referred to. Over the years, the various strands of research have addressed this issue, each with their own expertise, highlighting the specificities and peculiarities of these products, paving the way for further developments [13,14].

In view of the growing interest in this highly relevant research topic, it was felt necessary to carry out a literature review to shed light on what has been theorized over the last 18 years from 2003 to 2020 on biofortified products, thus assessing the state-of-the-art in the literature with the aim of understanding in which direction the various lines of re-search are moving [13]. The purpose of this document is, therefore, to draw a map of the current state of the meaning of biofortification research from the researchers' point of view.

The method for the literature is described, followed by a discussion of the complexity in defining biofortified products, thus assessing the state-of-the-art in the literature with the aim of understanding in which direction the various lines of research are moving. Overall, the study of biofortified products in relation to the different disciplines of analysis currently presents many opportunities for further research. Based on the empirical evidence, a review of the literature on biofortification was conducted to understand the level of investigation [15]. The research questions are:

RQ1. *How many research types were found in relation to biofortification?*

RQ2. *Which dimensions of biofortified products could been investigated?*

The analysis carried out in this paper aims to:

- Examine the trend of the literature (i.e., the number of articles and distribution over time) and the value of the published articles (considering citation indices);
- Classify the articles consulted, according to specific criteria that will be described later in the methodological part;
- Mapping of research themes and directions, through the analysis of the "keywords" with which articles were labelled.

Therefore, this paper is structured as follows: the next section is the materials and methods which report on the research methodology and criteria used to complete the literature review on biofortification. It then presents the results of the literature analysis, in terms of areas of interest in this specific research field, but also the dimensions proposed so far. The final section presents conclusions and future activities.

2. Materials and Methods

The purpose of a review should be to summarize the literature in a given time period and scientific area and to extrapolate the main topics where further research would be useful [16,17]. A literature review is an important tool to deepen the knowledge on the topic of interest. It can be of various types (argumentative, integrative, historical, methodological, systematic, or theoretical, etc.,) depending on the type of analysis to be carried out [18,19].

In this work, the literature review aimed to answer some research questions by reviewing previous research, assessing its strengths and weaknesses and highlighting open questions [16,17]. However, in order for the literature review to be a source for the development of future knowledge to generate new ideas and new theories especially in a specific field, it must be carried out following certain steps that guarantee the accuracy, precision, and reliability of the review itself [20].

The method used in this work is a combination of a quantitative survey of the articles consulted (e.g., counting publications, citations, keywords, etc.,) and a qualitative assessment of the contents, with the aim of better identifying the relevance, research themes, and orientation of each study investigated [20].

In summary, the work consists of several steps including:

- The description of the topic;
- The purpose of the review through the formulation of research questions;
- The method used to carry out the literature review, with the description of the search strategy, the databases and keywords used, the limiters and criteria for selecting the studies;
- Summary of findings and response to initial questions, describing the information obtained from the review.

The aim of this review is to find the most relevant literature in the biofortified products field in order to better answer the research questions outlined in priority section.

An extensive bibliographic research was conducted in line with other authors [13]. An analysis of the main references was made by looking at the number of hits only, see Table 1.

The problem of a clear definition of biofortified foods [21], forced a downsizing of the investigation by focusing exclusively on the first two search term.

Table 1. Number of papers published by year.

Search term	Hits
Biofortification	2,817
Biofortified	914
Fortification	13,894
Functional food	70,033
Micronutrient	32,461

Note: Our elaboration.

Inclusion and Exclusion Criteria

Writing takes the form of a literature review, a chronological/conceptual review of international literature [20].

As shown in Table 2, a documentary study was conducted in September 2020 where several publications in the scientific literature on biofortified products are reported (see the Supplementary Material).

The first step of the work concerned the search and selection of the studies under investigation. The search used Boolean strategy where the combination of the following keywords was used "Biofortification" OR "Biofortified" OR "Biofortfi*", AND/NOT Micronutrient, Functional food.

A database with 3106 papers was created and divided by national and international journals. This construction was based on the Scopus-Elsevier database, one of the most comprehensive databases containing high-quality, peer-reviewed publications [22].

Subsequently, the database was limited by extrapolating only "Final Articles," published in Journal, in English and disseminated between 2003 and 2020.

As already mentioned in relation to the authors′ areas of interest and research the study was limited to five subject areas: Agricultural and Biological Sciences, Economics, Econometrics and Finance, Social Sciences, Multidisciplinary and Business.

Scientific books and articles not published in full or otherwise not available online were not taken into account.

Table 2 presents a sample from the search results for biofortified products, during the literature review. We chose to extrapolate from the sample only those countries with a number greater than or equal to 30 papers for their relevancy. The final database includes 1189 papers.

Table 2. Inclusion and exclusion criteria used in the review.

		Document Search
Title-Abs-Key		Biofortification Biofortified
Total papers		**3106**
Refine Results		**Limit to**
Pubyear		2003–2020
Subjarea	"AGRI" "ECON"	"SOCI" "BUSI" "MULT"
Doctype Pubstage Countrys/Territory Source Type Language		Article Final >30 papers Journal English
Total papers		**1189**

Note: Our elaboration on Scopus Database.

3. Results

The synthesis and dissemination of the results of this literature review will be presented in two parts. The first one will highlight an analysis of the extracted data, through tables and graphs emphasizing key variables, such as the year of publication and the countries covered by the selected papers. The second part will provide an overview of the main emerging themes in relation to the different aspects of biofortified products and the five dimensions identified for them. Finally, an attempt will be made to justify the proposed research questions.

3.1. Primary Findings

Figure 1 shows an increasing number of selected studies published over time. Since 2016, a large number of studies (more than 100) have been published where it can also be observed within each year a wider distribution of studies among the five topic groups than in previous years.

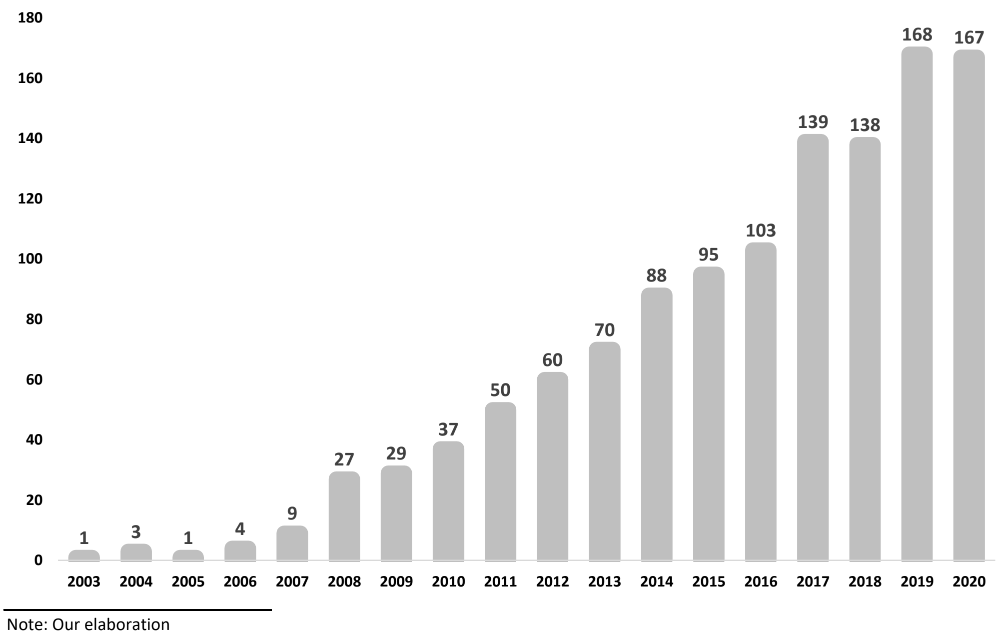

Figure 1. Number of papers published by year.

All 1189 abstracts were checked for relevance and divided into the five dimensions of the definition types studied.

Then the countries with the highest number of articles (>30) in our sample were examined. Table 3 shows the complete list of countries that were considered for the review. The results suggest that studies are concentrated in those countries with the most relevant issues, related to malnutrition, health problems, agronomic practices, economic and market decisions, etc.

India is the most frequent target (260 papers), USA (244), followed by China (157). For European countries, United Kingdom (66), Italy and Spain with 62 papers, Poland (55), and Germany (51) stand out.

The study of the definition and use of biofortified products has received and is still receiving a considerable attention from the academic world, as evidenced by the large and growing number of papers that continue to be published today.

The assumptions summarized above show that there is an interest in biofortified products and its effects are becoming more and more intense, both in the academic and business world, which is now looking at these products as a great opportunity to increase its competitive advantage.

Table 3. Frequency of papers by review countries.

Countries	Frequency	Countries	Frequency	Countries	Frequency
India	260	Spain	62	Belgium	30
United States	244	Mexico	59	Turkey	30
China	157	Poland	55		
Brazil	125	Germany	51		
Australia	81	Kenya	45		
United Kingdom	66	Colombia	38		
Pakistan	63	Canada	38		
Italy	62	South Africa	35		

Note: Our elaboration.

For the analysis of the second research question proposed in the introduction (RQ2) we have adopted the main framework for the conceptualization of biofortification.

In relation to the authors′ areas of study and research, five dimensions [23] were chosen closely linked to the definition of biofortified products:

1. Reduction of world hunger;
2. Human health;
3. GMOs;
4. Agronomy, herbaceous crops;
5. Economics and the market.

Regarding the biofortification research area addressed in the articles in our sample, the results show that 375 out of 1189 papers (31.5%) consider the “agronomy, herbaceous cultivation” dimension of biofortification to some extent. In addition, 339 papers (28.5%) address the “human health” dimension of biofortification and 201 papers (16.9%) only talk about the “GMO” dimension. Finally, 153 articles (12.9%) study only the “economy and market” dimension; 72 articles (6.1%) the “reducing world hunger” dimension. 49 articles (4.1%) have mixed dimensions, of which 36 articles consider “agronomy, herbaceous cultivation” and “GMO” dimensions, 13 “human health” and “GMO” dimensions (see Table 4).

Table 4. Types of definitions studied in the papers.

Types of Biofortificaton studied	Frequency	%
Agronomy, herbaceous cultivation	375	31.5%
Human health	339	28.5%
OGM	201	16.9%
Economy and market	153	12.9%
Reducing hunger in the world	72	6.1%
Mixed	49	4.1%
Total	**1189**	**100.0%**

Note: Our elaboration.

3.2. The Complexity of Dimensions of the Biofortified Products

The literature on biofortification processes and related products is quite complex, it is possible to trace the different contributions to at least four main lines of research:

1. Society and food security, with the social implications of food accessibility that can be identified in the context of human health and hunger reduction in global phenomena;
2. Technical-normative definition of biofortified products, in contrast or in relation to the definition of GMOs;
3. Market and marketing in different territorial contexts;
4. Cultivation, factors influencing agronomic technical choices.

The following four sub-sections will briefly highlight the identified groups of papers, analyzing the key features of the selected research. The information provided will be useful in describing the implications for future research.

3.2.1. Biofortification, Human Health and Reducing Hunger

For the first group of papers, the most important contribution starts with a reflection on how micronutrient malnutrition, known as hidden hunger [5], is a serious problem for more than half of the world′s population, especially for women and pre-school children [4].

Biofortification is considered a new method to support public health to combat major nutritional deficiencies (vitamin A, iron, zinc), especially in developing countries. Food crops such as rice, wheat, maize, and potatoes are enriched with micronutrients through cultivation techniques [24–26]. A distinction is then made between poor and rich countries. This is because the huge majority of the world′s population consumes foods composed of cereals (rice, corn, wheat, soya, cassava), the so-called "staple crops." These crops basically meet the caloric requirements, but have a low bioavailability of essential trace elements. In underdeveloped countries, this limitation is particularly widespread, as a varied and balanced diet, with a daily intake of fruit, vegetables, meat and fish, sufficient to provide the necessary doses of vitamins and minerals, is not always possible [5,27,28]. In industrialized countries, the situation is different, as inadequate nutrition is not linked to a lack of food, but rather to its misuse. In addition to vitamins and minerals, which are necessary for good health, there are compounds such as "phytonutrients," which help our bodies to increase cell metabolism [29,30]. The carotenoids and polyphenols are often linked together in an antioxidant diet [31,32].

3.2.2. Biofortification and Technical-Normative Definition

The research addresses a definition approach of biofortified products/fields and the regulation of so-called novel foods, the production of which in terms of food law principles and requirements are largely identified in EU Reg. 178/2002 and 2283/2015 and in the European Food Safety (EFSA).

The literature shows that the techniques for obtaining biofortified products, such as enriched products, inevitably lead to several elements of contact with functional food [33]. On the basis of this consideration, it is necessary to attribute the possible classifications of functional products, which can take the form of fortified food (foods obtained through a technological process of fortification that makes them more nutritious), enriched food (in which the percentage of one or more nutrients already present in nature is increased), supplementary food (subcategory of fortified foods) [9,10].

The definition of functional foods, produced at institutional level (e.g., ILSI Europe in the context of the European Concerted Action on Functional Food Science—Concert Action "FUFOSE") is not, as is well-known, unambiguous, to the point that it has led to the inclusion in the sector of products that are not (e.g., pharmaceutical and herbal products with common beneficial/curative properties) and that cannot boast these characteristics [34,35]. Today functional foods are considered as such if they represent "a normal daily food" (they are not food supplements or a medicine, nutraceuticals or herbal products in tablet form); if they are presented to the consumer in a manner consistent with the content of EU Regulation 1924/2006 on nutrition and health claims made on foods; if they contain claims relating to the improvement of a biological function or claims relating to the reduction of the risk of disease occurrence [36,37].

According to the literature, biofortification is generated through various strategies, such as genetic engineering (genetic manipulation of nucleotide sequences), certain classical genetic techniques (e.g., cross-pollination) or agronomic techniques (soil or leaf fertilization), as also provided for in some EU national regulations [38,39]. With regard to cultivation techniques, a broad scientific debate is underway, prompted, among other things, by the concerns expressed by the Codex Alimentarius Commission, a commission set up by FAO and the World Health Organization to draw up a set of rules and regulations on fortification [7,38,39]. While emphasizing the positive public health results of biofortification, it introduced the basis for a debate on aspects such as production method, plant selection, genetic modification, and agronomic practices, leading to a conclusive distinction between "biofortification" and "conventional fortification." The fortification technique consists of adding nutrients already during the production process, while biofortification seems to produce both increased nutrients from agronomic practices and modern biotechnology techniques (GMOs), confusing the consumer, who may believe that there are better ways to increase the nutrient content of a food than others [40–42]. Thus, different areas of overlap emerge between fortified or supplementary foods and functional foods, together included in the category of so called "novel foods" [43,44]. GMO products, food additives, flavorings, and food supplements are excluded from the list of novel foods [44].

Despite the definitional confusion, the interest is increasingly expressed toward the carrier food, that is, the "vector food" [45].

3.2.3. Biofortification, Economy, and Market

In the third working group, in "market and marketing" studies, the research question is often aimed at gathering information on the concept of biofortification, to understand the association that is made by the market and consumer, but also to analyze how biofortification is understood, the positions for and against biofortification, the associated benefits arising from biofortification and the consumption of products associated with nutrition, but also cues for names and logos to communicate the idea of biofortification chosen by consumers [46,47].

In a face-to-face study of 34% of farmers and 66% of consumers in Nigeria, it was found that half of farmers and consumers were familiar with the concept of "fortifying crops" [48–50]. Of this percentage, 66% linked it to crops containing added vitamins, 21% understood the concept of biofortification, and 21% understood that crops grow faster and 16% understood that fertilizers or chemicals should be added to improve crops. The idea and belief among consumers that they are attracted by products and brands that refer to nutritional claims is also widespread [51].

Given the nutritional benefits of biofortification, most consumers want all foods in their diet to be biofortified [52,53].

A consumer choice tool may be the label. Food labels are, as are well-known, the means by which the producer communicates useful information about the food to the consumer. The label, is identified as a guarantee of quality and a certain, beneficial effect [54–58].

Therefore, the terms "biofortification" and "biofortified food" on the product label are important elements of consumer assessment [59].

According to other studies, one way to raise consumer awareness of biofortified crops, foods and market demand for these products have been and are through the use of social marketing [47,60–62]. Social marketing of biofortified crops was created to increase awareness and understanding of concepts such as hidden hunger. It explains the behaviors that a person or a community can do to limit the incidence of hidden hunger. Consequently, it is essential to use different techniques from those used in marketing commercial products, so social marketing has a considerable role to play [47,62,63].

The aim is to increase knowledge about nutrition, preparation, and consumption [64,65].

As can be seen from this review, communication and marketing also change with changing consumer behavior. In fact, a particularity of biofortified products is that they have agronomic, aesthetic, organoleptic, and food characteristics and are suitable for transport and storage. But the requirement that differentiates it substantially from other products is that biofortified varieties have a higher nutrient content, which influences the color [66]. For example, orange sweet potatoes were not accepted in the market due to the orange color not being identified by consumers, but later found that the orange color was more attractive to children [67].

In this group of studies, the debate often focuses on the "consumer revolution," typical of rich countries due to the growth in per capita income and the choice of food increasingly influenced by socio-cultural, ethical, and religious factors and ad hoc trends. In this context, the focus of the contributions was on increasing consumption in quantitative terms, which generates overweight and obesity, with particular attention to the younger sections of the population [64,68,69]; on the series of scandals in the agrifood sector and the emergence of the problem of safeguarding and protecting the health of the final consumer; on the "junk food" typical of the daily diet, made up of snacks and packaged foods without nutritional value and with considerable chemical additives [64,65]; on sedentariness, on the various pathologies of modern society [50].

3.2.4. Biofortification, Cultivation, Factors Influencing Agronomic Technical Choices

The international scientific community has intensified its efforts to promote development and dissemination of biofortified crops. According to an estimate conducted by HarvestPlus in 2017 (see Figure 2), there are currently more than 150 biofortified varieties, bundled in 12 crops, that have been authorized in 30 countries [70–73].

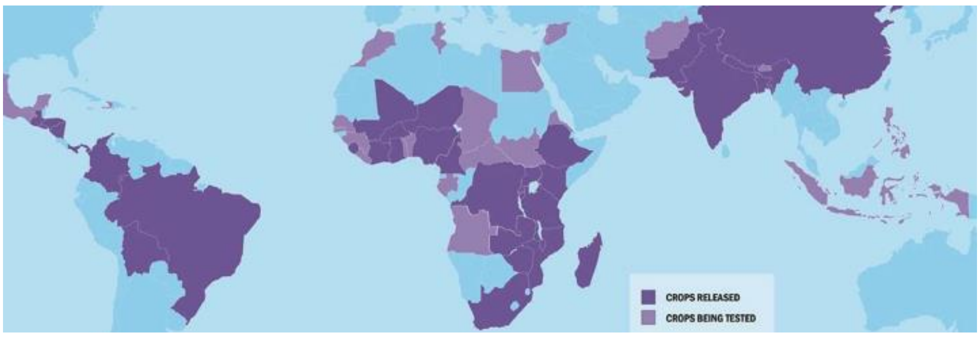

Figure 2. In purple, crops currently released commercially. In lilac, crops being tested [70].

Biofortification of staple crops can be achieved through three different approaches, transgenic, conventional, and agronomic, based on biotechnology, breeding, and the use of mineral fertilizers, respectively [2,74]. Regardless of the method used, only with a multidisciplinary approach is it possible to "measure the nutritional value of biofortified products such as bio-accessibility and bio-availability [75,76].

In Figure 3, as highlighted by Garg, M.; it can be seen that several biofortified crops, including wheat, rice, maize, potato, and tomato were obtained through the application of all three strategies listed above [2,77].

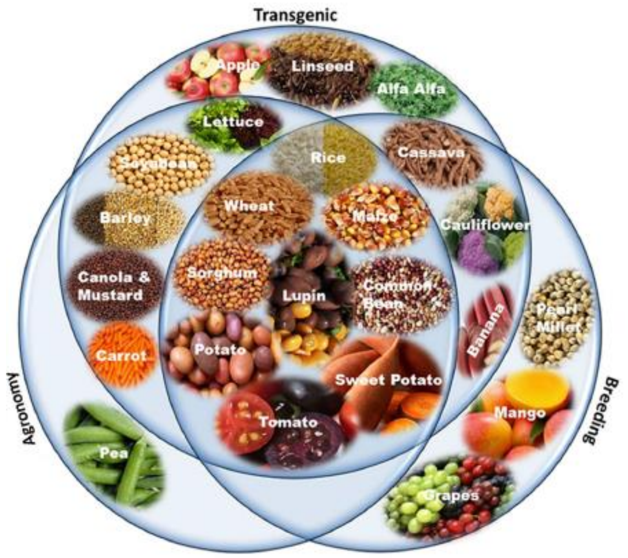

Figure 3. Biofortified crops harvested through the three different approaches: agronomic; traditional breeding; transgenic [2].

The current results in genomic biofortification are certainly useful for the development of biofortified products as a sustainable solution to the problem of "hidden hunger," to solve the lack of micronutrients, thus serving for human health and as an economic saver [77–82].

Several biofortified crops have been developed with very encouraging results to counteract vitamin deficiency [53,76,83].

In this context, the new perspective of biofortification is that of "tailor-made plant nutrition" to obtain products for specific population groups, so-called "tailored foods." In order to achieve this objective, the most suitable cultivation systems seem to be those without soil, because they allow a more appropriate management of plant nutrition, regulating the presence of the main nutrients in the plants by regulating the presence of the main mineral elements (calcium, iodine, zinc, selenium, silicon, iron, silicon, iron, etc.,) which are beneficial to human health or which may sometimes be harmful to consumers with specific metabolic alterations [75,84–86].

The major problems associated with the development of biofortified transgenic crops are the long and complicated breeding cycles and/or the lack of genetic variability in the germplasm, which make the traditional breeding approach time-consuming, expensive, and sometimes impractical [26,74]. On the other hand, the public negatively perceives them and the slow regulatory processes are required for their approval.

To date, however, many crops produced through such approaches are subject to the same legal and social constraints as conventional GMO varieties [1,87].

4. Discussion, Limitations, and Future Research

The first results of this review is that interest in pursuing research related to biofortified products has increased since 2016. It is also noticeable that most of the studies are concentrated in those countries that show an interest related to biofortified products; with India and the United States leading the way, a lot of research has been conducted in developing countries, followed by some European countries.

As the current bias in the definition of biofortified products depends on regional political, socio-economic, and environmental characteristics, which are sometimes equated with GMO products, this may hinder the generalization of results [88]. Based on the results emerging from the collected data, it is therefore considered that further research targeted at biofortified products is needed.

The heterogeneity of the papers, the diversity of the methodologies applied and the different fields of study made it very difficult to summarize and compare the results obtained.

Of the various approaches to biofortification, the agronomic approach has certainly provided the best results in terms of quantity of papers, followed by GMOs and economic approaches.

This review examines what the literature on biofortified has to say on these topics. It discusses in turn the role played in the development process and the interactions between this and other economic sectors.

We therefore wanted to identify the main fields of application for biofortified products, also in relation to the authors′ interests. This review has shown that interest in biofortified products and their effects on consumers in emerging countries is gradually growing [89,90]. In fact, in several developing countries, biofortification is considered a valuable tool to counteract food insecurity issues, although in these countries biofortification requires increasing public investment in agricultural research and infrastructure to be successful [11,12,91].

In order to optimize biofortification research aimed at improving human health, it is extremely important to encourage collaboration between actors who can work closely together: growers, biotechnologists, chemists, nutritionists, doctors, epidemiologists [92].

Unfortunately, such collaboration is difficult to implement because researchers in the various categories not only speak different scientific languages but also often set different goals for their papers.

Another limitation related to the difficulty of generalizing the results is that they do not refer to a single research field, but concern cross-sectional investigations covering a wider number of sectors. The complexity of the phenomenon and the need to conduct further investigations provide scholars with ample scope for new research or literature reviews.

It is to be hoped that future research will deal with the various areas simultaneously, possibly using a uniform methodology, so that the results obtained can be adequately compared and an unambiguous interpretative model can be formulated.

However, interdisciplinary research would be the ideal solution to lay the foundations for a new field of investigation based on biofortified products and thus promoting human health [32].

As already emphasized in other parts of the work, the greatest limitation to the spread of biofortification, which also emerges from the examination of the works covered by the literature review, is obviously represented by the absence of a single definition of biofortified products adopted at international level that can clarify the scope of work for the various stakeholders and thus promote unambiguousness of the objectives to be achieved. All this would be a useful starting point to allow for the creation of a globally recognized specific regulatory framework covering all stages of the supply chain, which could lead to clear development and research objectives, greater credibility and acceptance of biofortified products by end consumers [6,15,93], greater assurance of food and environmental safety, as well as increased attractiveness to industry and mechanisms to facilitate commercial activities.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/asi4020030/s1, Excel S1: Database for assessment of several approaches to biofortified products: a literature review.

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