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Review

Enhancing Micronutrients Bioavailability through Fermentation of Plant-Based Foods: A Concise Review

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Abstract: Plant-based foods are rich sources of vitamins and essential micronutrients. For the proper functioning of the human body and their crucial role, trace minerals (iron, zinc, magnesium, manganese, etc.) are required in appropriate amounts. Cereals and pulses are the chief sources of these trace minerals. Despite these minerals, adequate consumption of plant foods cannot fulfill the human body's total nutrient requirement. Plant foods also contain ample amounts of antinutritional factors such as phytate, tannins, phenols, oxalates, etc. These factors can compromise the bioavailability of several essential micronutrients in plant foods. However, literature reports show that fermentation and related processing methods can improve nutrient and mineral bioavailability of plant foods. In this review, studies related to fermentation methods that can be used to improve micronutrient bioavailability in plant foods are discussed.

Keywords: fermentation; antinutritional factors; micronutrients; bioaccessibility; bioavailability; plant foods; cereals; pulses

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1. Introduction

Health in general depends on food intake that meets the nutritional needs of consumers. Foods are also explored as an approach to inhibit the development of different disorders, especially those that are due to improper, deficient or excessive intake [1]. Nutrients (e.g., minerals) carry out different vital functions in body like development of strong bones to conduct nerve impulses for sustained health [2]. Due to lack of proper nutrition, macronutrients and micronutrient deficiency occurs leading to undernutrition. Excessive intake of these macro/ micronutrients also result in overnutrition leading to obesity and associated metabolic disorders [3]. In the absence of proper consumption of Zn, Fe and Ca severe malnutrition occurs (i.e., high risk of infection, anemia and osteoporosis, respectively). These micronutrients are adequately present in beverages and foods that fulfill body's daily needs; however, due to their low bioavailability, people face severe micronutrient deficiencies [4]. In the developing world, occurrence of micronutrient insufficiencies adversely affects the health of vulnerable people. The main factor for deficiency of key micronutrients (i.e., Zn, vitamin A, and Fe) is the limited bioavailability and poor diet quality [5]. To achieve sufficient intake of minerals, some countries recommend dietary guidelines to increase consumption of whole grains, as plant-based foods are excellent sources of nearly all the vital nutrients [6]. However, the presence of different antinutritional factors such as polyphenolics and phytic acids could impede the immense nutritional influence of whole grains [7,8]. Fermentation, cooking, soaking, puffing and germination are some of the traditional food processing methods used to reduce the antinutritional components and enhance protein digestibility [9–12]. Due to this, fermented foodstuffs have been a vital part of human nutrition and is essential in several developing nations where these are consumed as part of indigenous traditions [13–15] Fermented foods are produced by using lactic acid bacteria (LAB) comprised of a number of genera (e.g., *Pediococcus, Lactobacillus, Streptococcus, Lactococcus, Leuconostoc, Enterococcus*, etc.) that yield lactic acid as a major metabolite. The fermentation is carried out by bacteria, yeast, filamentous fungi or a combination of these [13,16]. During fermentation, the microbial metabolism enhances the macromolecules' digestibility and improves the bioavailability of macro/micronutrients and phytochemicals. For the removal of antinutrients, allergens and toxins, fermentation is considered as one of the most effective processing methods [17]. Phytic acid salts, also known by the name phytate or myo-inositol hexakisdihydrogen phosphate, are the central storage (1–5% by weight) form of both myo-inositol and phosphate in oilseeds, cereal grains, legumes, plant seeds and nuts [18]. Phytic acid salts commonly found in plant-based foods are shown in Table 1.

Table 1. Phytate content in common plant-based foods.

Plant Food	Phytate Content (%), Dry Weight Basis
Almonds	0.35–9.42
Beans	0.61–2.38
Brazil nuts	0.29–6.34
Cashew nuts	0.19–4.98
Chickpeas	0.28–1.60
Corn	0.72–6.39
Eggplant seed	1.42
Kiwi fruits	1.34
Lentils	0.27–1.51
Peas	0.22–1.22
Rapeseed	2.50–7.50
Rice	0.06–8.70
Sesame seed	1.44–5.36
Soybean	1.00–10.7
Tomato seed	1.66
Walnuts	0.20–6.69

Source: [19–22].

Phytic acid chelates the multivalent positive cations (e.g., Mg^{2+}, Zn^{2+}, Ca^{2+}, Fe^{2+}, Mn^{2+} and amino group derivatives in protein moieties), which leads to reduced nutrient solubility, bioavailability and absorption [16]. Fermentation also improves the mineral bioavailability by producing a phytase enzyme that degrades the phytic acids in plant foods. Such a phytic acid reduction may enhance the level of calcium, iron and zinc several-fold [23]. In this review, we emphasize the fermentation used to improve the bioavailability of minerals that could be further utilized to enhance the level of micronutrients in plant-based foods alleviating micronutrient deficiency.

2. Fermentation

Fermentation is a type of metabolic processing that oxidizes carbohydrates to release energy in absence of the external electron acceptors. LAB are acid-tolerant, catalase-negative, non-spore-forming, Gram-positive, fastidious, cytochrome deficient, aerotolerant and fermentative microorganisms [24,25]. As per the expert panel report of The International Scientific Association for Probiotics and Prebiotics (ISAPP), a fermented food is "food made through desired microbial growth and enzymatic conversions of food components" [26]. Primarily people consume processed foods; among those, fermented foods have been the very first ones. Fermented foods are linked to the cultural relationships between different nations and associated with its own population's nutritional status. Fermentation gained much interest of researchers to understand the mechanism and for commercialization of food products [27]. It is a typical method applied to improve the organoleptic, nutritional and shelf-life properties of food ingredients [28]. Fermented foods have several functional attributes that provide full benefits to the consumers (i.e., antioxidative properties, production of enzymes, probiotic potentials, antimicrobial features, bioactive peptides, etc.) [29]. Microorganisms used in fermentation can produce a range of enzymes (i.e., phytase, protease, lipase, amylase, etc.) that can hydrolyze lipids, carbohydrates and proteins into simple digestible constituents with desirable texture and taste. Microbial enzymes may also degrade different antinutritional such as protease inhibitors, tannins and phytates. This has increased much interest in using fermentation for the improvement of bioavailability and absorption of minerals present in plant seeds [30].

Use of microbial enzymes as human food ingredients remains a challenge from safety point of view [31]. Efforts were made to isolate microorganisms that can produce phytase and are safe for human consumption [32]. During food fermentation, endogenous enzymes are activated due to lower pH that contribute to the reduction of phytic acid. Fermentation improves mineral (i.e., Ca, Zn and Fe) bioavailability by producing phytases that reduce phytic acid constituents in plant-based foods [23,33]. Aside from this, fermentation is used as an enzymatic and microbial food processing method. Although it enhances the quality of raw food components by improving safety, antinutrients elimination, extended shelf-life, attractive flavor and nutritional enrichment [11], by lowering polyphenol and phytic acids, fermentation may also improve the bioavailability of minerals through production of organic acids [34]. There are different fermented foods (i.e., pearl millet fermented gruel, lamtoro tempeh, corn steep liquor, soybean tempeh, shalgam, gembus tempeh, kimchi, uttapam batter, sourdough, kara tempeh and other ethnic products) that can be used as a source for the isolation of phytase-producing LAB [35–39]. Graphical abstract represents that fermentation not only improve the plant food proteins and carbohydrates digestibility but also enhances minerals bioavailability by increasing phytase production that catalyzes removal of phosphate from phytic acid resulting into myo-inositol, phosphate and other minerals and nutrients.

3. Fermentation Affects Enzyme Activation to Improve the Nutritional Value of Plant-Based Food

In modern times, the food and nutrition safety processing of products derived from agriculture is very important. Due to developments such as urbanization, food produced and processed in the remote areas, for feeding purpose of the growing population, is transported into cities and towns. Moreover, due to seasonality, agricultural products should be processed so that foods can be accessible throughout the year [40].

In developing nations, legume and cereal starches provide major calories due to the high contents of carbohydrates in these crops [41]. Previous evidence shows that the fermentation process stimulates enzymes such as maltase and α-amylase that degrade starch into simple sugars and maltodextrins. Furthermore, studies have emphasized that, in the early fermentation phase, glucose is increased due to activated α-amylase and maltase [42–44]. Moreover, fermentation subsequently enhances the ethanol and carbon dioxide production and reduces the starch component in different varieties of millet in addition to facilitating phytase enzyme production and considerable reductions in pH [42,45,46].

Earlier literature reports show that the effect of fermentation on protein content is unpredictable, which could be due to different study times, designs of experiments and variations in the initial amino acid or protein profile of the foods. Some studies proposed that fermentation could increase or decrease the amino acid and protein contents of foods [47–49]. Due to the fermentation process, relative changes occur by dry matter loss because of the action of microorganisms when they metabolize and hydrolyze fats and carbohydrates as energy sources. However, plant protein digestibility increases during the fermentation process [40]. A previous study showed that, due to loss of carbohydrates, protein content was increased after 24 h of fermentation but arginine, glycine and lysine levels were reduced [43]. On the other hand, it has been reported that the use of amino acids as nutrients by fermenting microbes reduced the quality and content of proteins in certain fermented foods [50]. In general, the digestibility of plant proteins is much lower when compared to animal-derived proteins. Therefore, plant-derived proteins may affect the gastrointestinal environment, because of the increased protein excretion in the fecal matter. Thus, the undigested protein level could be reduced by increasing protein digestibility, which could reduce food allergies associated with decreased intestinal absorption of proteins [51].

Fermentation can also reduce the content of several plant compounds such as phytic acid, oxalate, tannins, carbohydrates and various protein complexes in addition to microbial production of digestive enzymes [10,52]. An in vitro study by Pranoto et al. [50] assessed the influence of 36 h natural fermentation and *Lactobacillus plantarum* on the digestibility of sorghum flour proteins. They found that protein digestibility was enhanced 92% and 47% by *L. plantarum* and natural fermentation, respectively. These findings suggest that *L. plantarum* increased the level of proteolytic enzymes better than natural fermentation, which led to better degradation of the protein–tannin complexes as well as other protein complexes to liberate amino acids and peptides [50].

Minerals present in plant products have very little bioavailability due to their formation of complexes with non-digestible matter. These minerals are bonded and entrapped in the complex matrices, which is the main factor responsible for the lower bioavailability. Fermentation is one of the suitable methods that could degrade these complexes to make minerals free, easily assessable and bioavailable [40,50]. The level of certain fermented food minerals such as zinc, calcium, iron and magnesium are increased by fermentation, which is connected with the reduced concentration of phytates [50,53]. Nonetheless, during fermentation, mineral content increases may also be due to the loss of dry matter, as fermenting microorganisms degrade proteins and carbohydrates [54]. By degrading phytates and oxalates, factors that form complexes with minerals, fermentation also enhances iron, phosphorous and calcium bioavailability [55,56]. This is because embedded minerals ions are loosened from the complex matrix by the fermentation process. Both α-amylase and phytase, which are produced during microbial fermentation, degrade starch and phytate contents, respectively, to loosen the complexes. Additionally, certain fermenting microbes can breakdown the dietary fiber materials to further loosen the food matrix [57]. Consequently, fermentation effects are also influenced by food composition, as other food constituents such as fibers could reduce specific mineral availability. To overcome these difficulties, seed germination and incubation of foods with polyphenol oxidase or phytase (through fermentation) could help enhance the availability of minerals by decreasing the phytate or tannin levels [58,59]. During fermentation, pH is reduced, which enhances the absorption of iron because of ferric iron conversion to the more readily absorbed ferrous iron. Furthermore, fermentation leads to an optimal pH environment, which is necessary for phytase activity to degrade phytate. Besides, if fermentation is preceded by grinding the food materials, there is enhanced mineral bioavailability. The positive effect of grinding is due to breaks in the cellular structure of the food material coupled with enlarged surface that facilitates dispersion of phytase for a more effective breakdown of phytate [40,46].

For a very long time, the significance of phytochemicals to the health and nutrition of humans was not well understood because they were considered as non-functional secondary metabolites of plants that are synthesized during plant development by shikimate pathways and phenyl propanoid biosynthesis [60,61]. However, fermentation has shown both adverse as well beneficial effects on phytonutrients. A previous study reported that LAB fermentation of soybean germs for 48 h considerably reduced tocopherol, glycosylated soyasaponin and phytosterol contents. For example, the phytosterol content was reduced from 4.2 to 1.1 mg/g at the end of the experiment. The findings suggest that the reduction of glycosylated soya saponins maybe because of their transformation from 2,3-dihydroxy-2,5-dihydroxy-6-methyl-4H-pyran-4-one (DDMP) to non-DDMP forms [62]. Wang et al. [63] evaluated fermentation effect on the antioxidant attributes of four types of cereals using *L. plantarum* and *Bacillus subtilis*. They concluded that, by using these starter cultures, there was a considerable increase in the total flavonoid and total phenolic acid contents [63]. Consequently, the capability of fermentation to enhance antioxidant attributes of foods can be explored as a gainful approach to alleviate the oxidative stress within the human body by consuming these foods [64–66].

Literature reports suggest dual effects of fermentation on the glycemic index (GI) of foods. Certain studies have confirmed that fermentation increased the GI [67–69], although some evidence indicates that GI decreased [70,71]. The low glycemic index of fermented foods may be due to the microbial conversion of glucose to short-chain organic acids such as propionic acid, acetic acid and lactic acid, which reduces the amount of glucose that is absorbed into blood circulation [72,73]. Ostman et al. [74] also suggested another mechanism for the lowering of glucose, which involves pH reduction by the lactic acid and consequent reduction in the activity of starch-hydrolyzing enzymes [74]. The mechanism of action for the acetic and propionic acids is different from the lactic acid mechanism; these organic acids reduced the gastric emptying rate in addition to decreasing the activity of enzymes [40]. This mechanism may be one of the reasons that sourdough bread reduces the postprandial glucose concentration and enhances glucose homeostasis in a healthy individual. Based on these data interpretations, it is reasonable to conclude that the natural fermentation of sugars and starch lead to formation of propionic and lactic acids that decrease glucose level in foods, which leads to low GI [71,73,75].

4. Influence of Fermentation on Micronutrients Bioavailability of Plant-Based Foods

In several countries, traditional fermented foods are a significant portion of their routine dietary needs, although, in certain countries, these foods are recommended for regular consumption [76]. Fermented foods consumptions are frequently associated with several health benefits. Certain fermented foods that comprise probiotics bacteria enhance nutritional attributes by improving mineral bioavailability and forming bioactive compounds [17]. Plant-derived food micronutrient bioavailability is usually improved by fermentation, which provides better shelf-life to foods and with enhanced gut microbial ecology that promotes a healthy status. These health benefits are mainly due to the activities of fermenting microorganisms known as probiotics, specifically the lactic acid producing type [77]. *Lactobacillus* and *Lactococcus* are the most frequently used LAB culture, although others, such as molds and yeast, are also used for fermentation purposes [78]. Due to these health benefits provided by fermented foods/products, fermentation may become an effective approach to mitigate the mineral deficiency concerns among the vulnerable populations, particularly in the developing nations where unprocessed pulses/cereals are significantly consumed [40].

Some evidence confirms that different fermentation processing methods improved the mineral bioavailability in plant-originated foods. A previous study confirmed the potential of five LAB strains in relation to mineral bioavailability improvement. The results confirm that *L. fermentum* B4655, *L. plantarum* B4495, *L. casei* B1922, *L. bulgaricus* CFR2028 and *L. acidophilus* B4496 strains of LAB reduced the phytic acid content when used for the soymilk fermentation at 37 °C for 24 h. Moreover, the results show an increase in the level of Mg and Ca of fermented soymilk when compared to the control [79]. Bahaciu et al. [80] recently investigated the effects of germination and fermentation (*Lactobacillus*) on the mineral bioavailability of soybean seeds. They detected that germination of soybean seeds for four days at 25 °C increased the level of Zn, Mg, Fe and Ca by 28.04%, 15.77%, 22.31% and 48.76%, respectively in comparison to control samples. Furthermore, they confirmed that germination followed by fermentation led to 40.87%, 43.41%, 59.56% and 53.4% increases for Zn, Mg, Fe and Ca, respectively, which are higher than values obtained for germination alone. In addition, optimal levels of mineral bioavailability were obtained in soybean seeds that germinated for four days at 25 °C followed by 72 h of lactic acid fermentation in a medium containing 3% saccharose [80]. Previous findings also confirm the effect of natural fermentation on mineral bioavailability in sorghum grain and finger millet. Results showed that natural fermentation reduced the phytic acid of sorghum grain and finer millet by 64.8% and 72.3% after 96 h, respectively. Furthermore, 39.0% and 54.3% of phytic acid levels decreased in sorghum grain and finger millet after 72 h of natural fermentation, respectively. The results show that 72–96 h of natural fermentation increased the bioavailability of calcium, manganese and iron in both finger millet and sorghum grains [81]. There is evidence that fermentation with *L. plantarum* strains reduced the phytic acid content and enhanced the availability of Ca, Zn and Fe of quinoa flour. For instance, a study confirmed that fermentation (16–18 h, at 30 °C) of quinoa flour by *L. plantarum* improved the iron content significantly when compared to unfermented samples in addition to substantial decrease in the phytic acid content. Furthermore, the highest phytic acid reduction (98%) was observed after fermentation of the germinated flour [82]. Moreover, Castro-Alba et al. [83] recently reported that fermentation (4 or 10 h, at 30 °C) of milled quinoa seeds using *L. plantarum* 299v reduced the phytic acid significantly and improved the bioavailability of minerals such as Ca, Fe, and Zn [83]. In another previous study, the effect of natural sourdough fermentation of wheat showed a much better improvement of copper and magnesium absorption in comparison to non-fermented wheat flour, using male Wistar rats. The authors found that fermented wheat flour samples by both natural fermentation as well as *Saccharomyces cerevisiae* enhanced Zn and Fe absorption. The results suggest that the reduction of phytic acid could be the reason for the enhanced mineral bioavailability [84]. The latest study by Chiş et al. [85] confirmed that fermentation of rice sourdough for 24 h with *L. Spicheri* DSM 15429 enhanced the level of manganese, zinc, copper, potassium, magnesium and calcium by 1.68, 1.92, 2.55, 1.98, 1.94 and 2.3 folds, respectively. Moreover, mineral levels improved by 0.7–1.52-fold after 24 h of spontaneous sourdough fermentation, compared to starting level before fermentation [85]. In addition, earlier research reported that fermentation by *Pediococcus pentosaceus* KTU05-8 and *P. pentosaceus* KTU05-9 strains, which are phytase-producing organisms, improved the whole meal wheat flour minerals (phosphorus, calcium, manganese, zinc, and iron) solubility by 30% [86]. Furthermore, Anastasio et al. [87] found that the phytase-producing LAB, (*L. plantarum* H5 and *Enterococcus faecium* A86) produced significant 98% increase in the solubility of iron and manganese when used for brown dough fermentation. In comparison, the non-phytase producing LAB strains produced lower mineral solubility during bacterial fermentation [87]. A previous study confirmed the potential of *Leuconostoc mesenteroides* FSC2 and *Lactobacillus pentosus* FSC1 in relation to the bioavailability of minerals content. The authors found that fermentation of carrot juice by *L. mesenteroides* FSC2 and *L. pentosus* FSC1 improved the solubility of minerals such as Cu, Zn, Fe and Mn by 1-, 1.2-, 1.5–1.7- and 2-fold, respectively. Furthermore, they showed that LAB-fermented juice improved the cellular (Caco-2 cell line) uptake of iron by 6–7-fold [88]. Giri et al. [89] recently confirmed the capability of *L. plantarum* L7 in favor of improving the bioavailability of minerals by preparing a rice-based fermented drink. The results show that the phytase activity of the LAB strain was responsible for the considerable increases in the iron, manganese, magnesium, calcium and sodium levels of the fermented drink [89]. Furthermore, other evidence confirms the ability of lactic acid fermentation of plant-based diet (cassava) in relation to the enhancement of Zn bioavailability using the rat model. Results have found absorption of Zn level was 40.2% in the animal model that consumed LAB-fermented cassava when compared to 16.5% in those that consumed the unfermented sample. In addition, higher zinc levels have been shown to be present in femur, serum and liver of animals that consumed a LAB-fermented diet [90]. A previous clinical study by Scheers et al. [91] confirmed that fermentation enhanced iron bioavailability in human volunteers who consumed a *L. plantarum* fermented vegetable diet when compared to the group who consumed the non-fermented diet [91]. A recent research study reported the impacts of fermentation on the bioavailability of Zn in hydrothermally treated, malted and native finger millet seeds. The authors found that *L. pentosus* CFR3 fermentation reduced the phytate content in the hydrothermally treated, malted, and native finger millet seed coat by 87.8%, 66.6%, and 56.7%, respectively. Moreover, the findings confirm that zinc in vitro bioaccessibility improved by 12.1%, 34.6% and 28.4% in hydrothermally treated, malted and native finger millet seed coat, respectively, after 24 h of fermentation [92]. Chawla et al. [93] evaluated the effect of fermentation on the in vitro Fe and Zn bioavailability in black-eyed pea (cowpea) flour by using Caco-2 cell line and gastrointestinal digestion study. They confirmed that 96 h of solid-state fermentation of black-eyed pea flour by *Aspergillus oryzae* led to enhanced in vitro bioaccessibility of Zn and Fe from 14.3% to 29.6% and 17.2% to 30.2%, respectively. The improved mineral bioaccessibility was attributed to the antinutritional content degradation during fermentation. Furthermore, after fermentation, Zn and Fe uptakes by Caco-2 cells were also enhanced from 18% to 28% and 22% to 32%, respectively [93]. Khodaii et al. [94] estimated the influence of lactic acid fermentation of bread dough on iron absorption using serum ferritin in rats and a Caco-2 cell line model. They showed that ferritin formation was considerably enhanced in the in vivo (serum) and in vitro (cell line) models in comparison to the controls when *L. acidophilus* was added into the dough [94]. Other previous evidence confirms that lactic fermentation could reduce the antinutrients content such as phytic acid, tannins and hence improve the mineral bioavailability of different cereals [95]. Carrizo et al. [96] confirmed the potential of *L. plantarum* strains fermented quinoa sourdough to prevent minerals and vitamin deficiency using an in vivo mouse model. The findings show that mice that consumed the *L. plantarum* CRL 1964 and *L. plantarum* CRL 2107-fermented pasta (quinoa) had enhanced blood levels of vitamins B9 and B2. Furthermore, supplementation of mice diet with fermented pasta led to 4.85, 0.37, 10.70 and 18.75 mg/dL blood levels of Mg^{+2}, Fe^{+2}, Ca^{+2} and P, respectively, compared to 3.34, 0.26, 9.90 and 9.85 mg/dL for the group that consumed the non-fermented diet [96]. Table 2 shows the studies related to the enhancement of mineral bioavailability using different fermentation methods.

Table 2. Studies showing that fermentation influence the bioavailability of the minerals.

Types of Food	Fermentation Organisms	Results	References
Soymilk	*Lactobacillus acidophilus* B4496, *Lactobacillus bulgaricus* CFR2028, *Lactobacillus casei* B1922, *Lactobacillus plantarum* B4495 and *Lactobacillus fermentum* B4655	Increased calcium and magnesium availability	[79]
Soybeans	Lactobacilli	Increased calcium (53.4%), iron (59.56%), magnesium (43.41%) and Zinc (40.87%) levels	[80]
Sorghum and finger millet	Natural fermentation	Improved solubility of Fe, Ca, Mg and Mn.	[81]
Quinoa seeds	*L. plantarum*	Iron solubility increased	[82]
Quinoa seeds	*L. plantarum*	Reduced phytic acid content and improved Zn, Fe and Ca availability	[83]
Wheat flour	*Saccharomyces cerevisiae* and natural fermentation	Increased the apparent absorption of Fe and Zn	[84]
Rice	*Lactobacillus Spicheri* DSM 15429	Improved levels of calcium (2.3-fold), magnesium (1.94-fold), potassium (1.98-fold), copper (2.55-fold), zinc (1.92-fold), and manganese (1.68-fold).	[85]
Wheat	*Pediococcus pentosaceus* strains KTU05-8 and KTU05-9	Increased solubility of iron, zinc, manganese and calcium and phosphorus (average of 30%).	[86]

Table 2. *Cont.*

Types of Food	Fermentation Organisms	Results	References
Carrot	*Lactobacillus pentosus* FSC1 and *Leuconostoc mesenteroides* FSC2	Improved mineral solubility: manganese (2.2–2.5-fold); iron (1.5–1.7-fold); Zinc (1.2-fold); Copper (1-fold). Cellular (Caco-2) uptake of ferrous iron in LAB fermented juice improved by 6 to 7-fold.	[88]
Rice	*L. plantarum* L7	Increased in the levels of free minerals like sodium, calcium, magnesium, manganese and iron	[89]
Cassava	Spontaneous fermentation	Increased bioavailability of zinc	[90]
Vegetable mix (carrots, turnips, white cabbage, parsnip, celery and onion)	*L. plantarum*	Bioavailability of iron increased	[91]
Finger millet seed	*L. pentosus* CFR3	Increased in the bioavailability and the in vitro bioaccessibility of zinc.	[92]
Black-eyed pea	*Aspergillus oryzae*	In vitro bioaccessibility of iron and zinc after 96 h of fermentation increased from 17.2% to 30.2% and 14.3% to 29.6%, respectively. Uptake of iron and zinc by Caco-2 cells similarly improved from 22% to 32% and 18% to 28%, respectively after fermentation.	[93]
Whole meal flour (bread)	*L. acidophilus*	Increased iron absorption; ferritin formation increased significantly compared to controls in the intestinal cells (in vitro)	[94]
Quinoa pasta	*L. plantarum* CRL 2017 and *L. plantarum* CRL 1964	Improved the nutritional status, improve calcium, iron and magnesium levels in the blood	[96]

5. Future Perspectives

Fermentation is a processing method that involves microorganism and their enzymes to carry out primary food matrix biochemical modifications. Fermentation not only improves the shelf-life and organoleptic properties of food products but also increases their nutrient bioavailability and bioaccessibility [40]. The microorganism that is most commonly used for food fermentation is LAB, which produce lactic acid that contributes to enhanced food preservation. Around 4000 years BC, LAB were used in the making of yogurt, when the Thracians farmed sheep. There are several commercial microbial enzymes that have been commonly used to enhance the functional value of plant phytochemicals, yet fermentation (lactic acid) is favored to advance the foods nutraceutical significance because it is not so expensive while increasing the overall nutritional and organoleptic properties [25]. Fermentation has gained much interest due to the considerable health benefits, which it imparts on food products. Besides, fermentation does not require any complicated equipment and needs very low energy input. Therefore, it could be a feasible solution for the developing nations to valorize local raw ingredients for improved local economies, in addition to being a suitable strategy to overcome malnutrition because it enhances the nutritional value of food products [97]. Several methods could possibly be used to improve product yield, reduce the cost and proficiency of fermentation procedures. Strategies that have been considered include developing technologies to simplify fermentation along with the development of new, more robust and effective cultures through old and current "omic" practices; the use of analytical technologies such as real-time monitoring systems to measure processing factors such as dissolved oxygen, pressure, temperature, pH, etc.; and automated fermenters with upgraded in-built controls to direct the fermentation process [17,98]. An emerging trend is the use of bacterial probiotics culture and cultures that could address the functionality and safety of the fermented product [99].

6. Conclusions

People all over the world are facing mineral deficiency concerns, especially in developing countries. This is because people consume ample amounts of cereals and pulses in their diets, and these plant foods are rich sources of minerals such as iron, zinc, magnesium, calcium, etc. However, these plant foods also contain high levels of antinutritional factors, especially phytic acid that binds and chelates these mineral ions to reduce absorption and bioavailability in the gut. Phytate hinders the absorption of micronutrients in the human diet because of the absence of intestinal phytase enzymes. The presence of the phytate and other antinutrient components makes micronutrients unavailable for human absorption and is one of the causes of mineral malnutrition worldwide. Several approaches have been used to increase the bioavailability of minerals ions from plant-based food. Fermentation is one of the best strategies that can be used traditionally and on an industrial scale to enhance mineral accessibility from plant foodstuffs. Fermentation processing methods that improve minerals availability could be transferred to local communities to improve minerals intake in the households. Studies have shown that natural fermentation and strain-specific fermentation provide better mineral bioavailability through a more effective degradation of the plant food's phytic acid content. It also provides viable environmental conditions (such as low pH) that help the growth of beneficial strain and enhance phytase activity. Additionally, during fermentation, metabolic activities of microbes improve the nutritional, physical and sensory properties of food products. Overall, the findings in this review suggest that selective/appropriate fermentation processing methods may be useful to produce functional foods with improved bioavailability of essential micronutrients, which could contribute to alleviated micronutrient deficiency.

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References

1. Muzquiz, M.; Varela, A.; Burbano, C.; Cuadrado, C.; Guillamón, E.; Pedrosa, M.M. Bioactive compounds in legumes: Pronutritive and antinutritive actions. Implications for nutrition and health. *Phytochem. Rev.* **2012**, *11*, 227–244. [CrossRef]
2. Gharibzahedi, S.M.T.; Jafari, S.M. The importance of minerals in human nutrition: Bioavailability, food fortification, processing effects and nanoencapsulation. *Trends Food Sci. Technol.* **2017**, *62*, 119–132. [CrossRef]
3. Oladiran, D.A.; Emmambux, N.M. Locally Available African Complementary Foods: Nutritional Limitations and Processing Technologies to Improve Nutritional Quality—A Review. *Food Rev. Int.* **2020**, 1–31.
4. Skibsted, L.H. Mineral nutrient interaction: Improving bioavailability of calcium and iron. *Food Sci. Biotechnol.* **2016**, *25*, 1233–1241. [CrossRef] [PubMed]
5. Nair, M.K.; Augustine, L.F.; Konapur, A. Food-based interventions to modify diet quality and diversity to address multiple micronutrient deficiency. *Front. Public Health* **2016**, *3*, 277. [CrossRef]

6. Schaffer-Lequart, C.; Lehmann, U.; Ross, A.B.; Roger, O.; Eldridge, A.L.; Ananta, E.; Bietry, M.F.; King, L.R.; Moroni, A.V.; Srichuwong, S.; et al. Whole grain in manufactured foods: Current use, challenges and the way forward. *Crit. Rev. Food. Sci. Nutr.* **2017**, *57*, 1562–1568. [CrossRef] [PubMed]
7. Raes, K.; Knockaert, D.; Struijs, K.; Van Camp, J. Role of processing on bioaccessibility of minerals: Influence of localization of minerals and anti-nutritional factors in the plant. *Trends Food Sci. Technol.* **2014**, *37*, 32–41. [CrossRef]
8. Ferruzzi, M.G.; Kruger, J.; Mohamedshah, Z.; Debelo, H.; Taylor, J.R. Insights from in vitro exploration of factors influencing iron, zinc and provitamin A carotenoid bioaccessibility and intestinal absorption from cereals. *J. Cereal Sci.* **2020**, 103126. [CrossRef]
9. Handa, V.; Kumar, V.; Panghal, A.; Suri, S.; Kaur, J. Effect of soaking and germination on physicochemical and functional attributes of horsegram flour. *J. Food Sci. Technol.* **2017**, *54*, 4229–4239. [CrossRef]
10. Samtiya, M.; Aluko, R.E.; Dhewa, T. Plant food anti-nutritional factors and their reduction strategies: An overview. *Food Prod. Process. Nutr.* **2020**, *21*, 1–14. [CrossRef]
11. Kumari, M.; Platel, K. Impact of soaking, germination, fermentation, and thermal processing on the bioaccessibility of trace minerals from food grains. *J. Food Process. Preserv.* **2020**, *44*, e14752. [CrossRef]
12. Hwang, J.; Kim, J.C.; Moon, H.; Yang, J.Y.; Kim, M. Determination of sodium contents in traditional fermented foods in Korea. *J. Food Compos. Anal.* **2017**, *56*, 110–114. [CrossRef]
13. Ansorena, D.; Astiasaran, I. Fermented foods: Composition and health effects. In *Encyclopedia of Food and Health*, 1st ed.; Caballero, B., Finglas, P., Toldra, F., Eds.; Academic Press: Oxford, UK, 2016; pp. 649–655. [CrossRef]
14. Kanwar, S.S.; Keshani. Fermentation of apple juice with a selected yeast strain isolated from the fermented foods of himalayan regions and its organoleptic properties. *Front. Microbiol.* **2016**, *7*, 1012. [PubMed]
15. Narzary, Y.; Brahma, J.; Brahma, C.; Das, S. A study on indigenous fermented foods and beverages of Kokrajhar, Assam, India. *J. Ethn. Foods* **2016**, *3*, 284–291. [CrossRef]
16. Waters, D.M.; Mauch, A.; Coffey, A.; Arendt, E.K.; Zannini, E. Lactic acid bacteria as a cell factory for the delivery of functional biomolecules and ingredients in cereal-based beverages: A review. *Crit. Rev. Food Sci. Nutr.* **2015**, *55*, 503–520. [CrossRef]
17. Shiferaw Terefe, N.; Augustin, M.A. Fermentation for tailoring the technological and health related functionality of food products. *Crit. Rev. Food Sci. Nutr.* **2020**, *60*, 2887–2913. [CrossRef] [PubMed]
18. Priyodip, P.; Prakash, P.Y.; Balaji, S. Phytases of probiotic bacteria: Characteristics and beneficial aspects. *Indian J. Microbiol.* **2017**, *57*, 148–154. [CrossRef]
19. Greiner, R.; Konietzny, U. Phytase for food application. *Food Technol. Biotechnol.* **2006**, *44*. Available online: https://www.ftb.com.hr/images/pdfarticles/2006/April-June/44-125.pdf (accessed on 20 January 2021).
20. Schlemmer, U.; Frølich, W.; Prieto, R.M.; Grases, F. Phytate in foods and significance for humans: Food sources, intake, processing, bioavailability, protective role and analysis. *Mol. Nutr. Food Res.* **2009**, *53*, S330–S375. [CrossRef] [PubMed]
21. Afinah, S.; Yazid, A.M.; Anis Shobirin, M.H.; Shuhaimi, M. Phytase: Application in food industry. *Int. Food Res. J.* **2010**, *17*, 13–21. Available online: http://www.ifrj.upm.edu.my/17%20(01)%202010/(2)%20IFRJ-2010-13-21%20Anis%20UPM.pdf (accessed on 20 January 2021).
22. Song, H.Y.; El Sheikha, A.F.; Hu, D.M. The positive impacts of microbial phytase on its nutritional applications. *Trends Food Sci. Technol.* **2019**, *86*, 553–562. [CrossRef]
23. Gupta, R.K.; Gangoliya, S.S.; Singh, N.K. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *J. Food Sci. Technol.* **2015**, *52*, 676–684. [CrossRef]
24. Leroy, F.; De Vuyst, L. Lactic acid bacteria as functional starter cultures for the food fermentation industry. *Trends Food Sci. Technol.* **2004**, *15*, 67–78. [CrossRef]
25. Rollan, G.C.; Gerez, C.L.; LeBlanc, J.G. Lactic fermentation as a strategy to improve the nutritional and functional values of pseudocereals. *Front. Nutr.* **2019**, *6*, 98. [CrossRef] [PubMed]
26. Marco, M.L.; Sanders, M.E.; Gänzle, M.; Arrieta, M.C.; Cotter, P.D.; De Vuyst, L.; Hill, C.; Holzapfel, W.; Lebeer, S.; Hutkins, R.; et al. The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on fermented foods. *Nat. Rev. Gastroenterol. Hepatol.* **2021**, 1–13.
27. El Sheikha, A.F.; Hu, D.M. Molecular techniques reveal more secrets of fermented foods. *Crit. Rev. Food Sci. Nutr.* **2020**, *60*, 11–32. [CrossRef] [PubMed]
28. Kaprasob, R.; Kerdchoechuen, O.; Laohakunjit, N.; Sarkar, D.; Shetty, K. Fermentation-based biotransformation of bioactive phenolics and volatile compounds from cashew apple juice by select lactic acid bacteria. *Process Biochem.* **2017**, *59*, 141–149. [CrossRef]
29. Tamang, J.P.; Shin, D.H.; Jung, S.J.; Chae, S.W. Functional properties of microorganisms in fermented foods. *Front. Microbiol.* **2016**, *7*, 578. [CrossRef] [PubMed]
30. Dhull, S.B.; Punia, S.; Kumar, R.; Kumar, M.; Nain, K.B.; Jangra, K.; Chudamani, C. Solid state fermentation of fenugreek (Trigonella foenum-graecum): Implications on bioactive compounds, mineral content and in vitro bioavailability. *J. Food Sci. Technol.* **2020**, 1–10. [CrossRef]
31. Brodmann, T.; Endo, A.; Gueimonde, M.; Vinderola, G.; Kneifel, W.; de Vos, W.M.; Salminen, S.; Gómez-Gallego, C. Safety of novel microbes for human consumption: Practical examples of assessment in the European Union. *Front. Microbiol.* **2017**, *8*, 1725. [CrossRef]

32. Sun, Z.; Yue, Z.; Yang, X.; Hao, X.; Song, M.; Li, L.; Chen, C.; Chu, C.; Li, C. Efficient phytase secretion and phytate degradation by recombinant *Bifidobacterium longum* JCM 1217. *Front. Microbiol.* **2019**, *10*, 796. [CrossRef] [PubMed]
33. García-Mantrana, I.; Yebra, M.J.; Haros, M.; Monedero, V. Expression of bifidobacterial phytases in *Lactobacillus casei* and their application in a food model of whole-grain sourdough bread. *Int. J. Food Microbiol.* **2016**, *216*, 18–24. [CrossRef] [PubMed]
34. Rousseau, S.; Kyomugasho, C.; Celus, M.; Hendrickx, M.E.; Grauwet, T. Barriers impairing mineral bioaccessibility and bioavailability in plant-based foods and the perspectives for food processing. *Crit. Rev. Food Sci. Nutr.* **2020**, *60*, 826–843. [CrossRef] [PubMed]
35. Damayanti, E.; Ratisiwi, F.N.; Istiqomah, L.; Sembiring, L.; Febrisiantosa, A. Phytate degrading activities of lactic acid bacteria isolated from traditional fermented food. In *AIP Conference Proceedings, Melville, NY, USA, 17 March 2017*; AIP Publishing LLC: Melville, NY, USA; p. 020053.
36. Saraniya, A.; Jeevaratnam, K. In vitro probiotic evaluation of phytase producing Lactobacillus species isolated from Uttapam batter and their application in soy milk fermentation. *J. Food Sci. Technol.* **2015**, *52*, 5631–5640. [CrossRef]
37. Sharma, N.; Kondepudi, K.K.; Gupta, N. Screening of Ethnic Indian Fermented Foods for Effective Phytase Producing Lactic Acid Bacteria for Application in Dephytinization of Phytate Rich Foods. *Int. J. Sci. Res. Biol. Sci.* **2019**, *6*, 1–7. [CrossRef]
38. Uslu, F.M.; Kizilkaya, E.G.; Yigittekin, E.S.; Gencoglu, M.; Toroglu, S.; Dincer, S. Phytase characterization and production from Lactobacillus plantarum strain on corn steep liquor. *J. Appl. Biol. Sci.* **2016**, *10*, 64–66. Available online: http://www.jabsonline.org/index.php/jabs/article/view/504/507 (accessed on 16 January 2021).
39. Sharma, N.; Angural, S.; Rana, M.; Puri, N.; Kondepudi, K.K.; Gupta, N. Phytase producing lactic acid bacteria: Cell factories for enhancing micronutrient bioavailability of phytate rich foods. *Trends Food Sci. Technol.* **2020**, *96*, 1–12. [CrossRef]
40. Nkhata, S.G.; Ayua, E.; Kamau, E.H.; Shingiro, J.B. Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. *Food Sci. Nutr.* **2018**, *6*, 2446–2458. [CrossRef] [PubMed]
41. Chaves-López, C.; Serio, A.; Grande-Tovar, C.D.; Cuervo-Mulet, R.; Delgado-Ospina, J.; Paparella, A. Traditional fermented foods and beverages from a microbiological and nutritional perspective: The Colombian heritage. *Compr. Rev. Food Sci. Food Saf.* **2014**, *13*, 1031–1048. [CrossRef]
42. El Hag, M.E.; El Tinay, A.H.; Yousif, N.E. Effect of fermentation and dehulling on starch, total polyphenols, phytic acid content and in vitro protein digestibility of pearl millet. *Food Chem.* **2002**, *77*, 193–196. [CrossRef]
43. Osman, M.A. Effect of traditional fermentation process on the nutrient and antinutrient contents of pearl millet during preparation of Lohoh. *J. Saudi Soc. Agric. Sci.* **2011**, *10*, 1–6. [CrossRef]
44. Adejuwon, K.P.; Osundahunsi, O.F.; Akinola, S.A.; Oluwamukomi, M.O.; Mwanza, M. Effect of Fermentation on Nutritional Quality, Growth and Hematological Parameters of Rats Fed Sorghum-Soybean-Orange flesh Sweet Potato Complementary Diet. *Food Sci. Nutr.* **2021**, *9*, 639–650. [CrossRef] [PubMed]
45. Annor, G.A.; Tyl, C.; Marcone, M.; Ragaee, S.; Marti, A. Why do millets have slower starch and protein digestibility than other cereals? *Trends Food Sci. Technol.* **2017**, *66*, 73–83. [CrossRef]
46. Castro-Alba, V.; Lazarte, C.E.; Perez-Rea, D.; Carlsson, N.G.; Almgren, A.; Bergenståhl, B.; Granfeldt, Y. Fermentation of pseudocereals quinoa, canihua, and amaranth to improve mineral accessibility through degradation of phytate. *J. Sci. Food Agric.* **2019**, *99*, 5239–5248. [CrossRef]
47. Mohapatra, D.; Patel, A.S.; Kar, A.; Deshpande, S.S.; Tripathi, M.K. Effect of different processing conditions on proximate composition, anti-oxidants, antinutrients and amino acid profile of grain sorghum. *Food Chem.* **2019**, *271*, 129–135. [CrossRef] [PubMed]
48. Ketnawa, S.; Ogawa, Y. Evaluation of protein digestibility of fermented soybeans and changes in biochemical characteristics of digested fractions. *J. Funct. Foods.* **2019**, *52*, 640–647. [CrossRef]
49. Çabuk, B.; Nosworthy, M.G.; Stone, A.K.; Korber, D.R.; Tanaka, T.; House, J.D.; Nickerson, M.T. Effect of fermentation on the protein digestibility and levels of non-nutritive compounds of pea protein concentrate. *Food Technol. Biotechnol.* **2018**, *56*, 257–264. [CrossRef]
50. Pranoto, Y.; Anggrahini, S.; Efendi, Z. Effect of natural and *Lactobacillus plantarum* fermentation on in-vitro protein and starch digestibilities of sorghum flour. *Food Biosci.* **2013**, *2*, 46–52. [CrossRef]
51. Untersmayr, E.; Jensen-Jarolim, E. The role of protein digestibility and antacids on food allergy outcomes. *J. Allergy Clin. Immunol.* **2008**, *121*, 1301–1308. [CrossRef]
52. Hassan, G.F.; Yusuf, L.; Adebolu, T.T.; Onifade, A.K. Effect of fermentation on mineral and anti-nutritional composition of cocoyam (Colocasia esculenta linn). *Sky J. Food Sci.* **2015**, *4*, 42–49. Available online: http://www.skyjournals.org/sjfs/pdf/2015/Jun/Hassan%20et%20al%20pdf.pdf (accessed on 20 January 2021).
53. Ahmed, M.I.; Xu, X.; Sulieman, A.A.; Na, Y.; Mahdi, A.A. The effect of fermentation time on in vitro bioavailability of iron, zinc, and calcium of kisra bread produced from koreeb (*Dactyloctenium aegyptium*) seeds flour. *Microchem. J.* **2020**, *154*, 104644. [CrossRef]
54. Day, C.N.; Morawicki, R.O. Effects of fermentation by yeast and amylolytic lactic acid bacteria on grain sorghum protein content and digestibility. *J. Food Qual.* **2016**, *2018*, 1–8. [CrossRef]
55. Ogu, G.I.; Orjiakor, P.I. Microbiological and nutritional qualities of fermented melon seed shells. *Int. J. Life Sci.* **2017**, *1*, 1–9. [CrossRef]

56. Hajimohammadi, A.; Mottaghitalab, M.; Hashemi, M. Effects of microbial fermented sesame meal and enzyme supplementation on the intestinal morphology, microbiota, pH, tibia bone and blood parameters of broiler chicks. *Ital. J. Anim. Sci.* **2020**, *19*, 457–467. [CrossRef]
57. Liang, J.; Han, B.Z.; Nout, M.R.; Hamer, R.J. Effects of soaking, germination and fermentation on phytic acid, total and in vitro soluble zinc in brown rice. *Food Chem.* **2008**, *110*, 821–828. [CrossRef]
58. Towo, E.; Matuschek, E.; Svanberg, U. Fermentation and enzyme treatment of tannin sorghum gruels: Effects on phenolic compounds, phytate and in vitro accessible iron. *Food Chem.* **2006**, *94*, 369–376. [CrossRef]
59. Sarvani, B.H.; Suvarna, V.C.; Kumar, K.H.; Ranadev, P.; Girisha, H.C. Effect of Processing and Fermentation on Functional Properties and on Anti-nutritional Factors in Horse Gram (*Macrotyloma uniflorum*). *Curr. J. Appl. Sci. Technol.* **2020**, 38–45. [CrossRef]
60. Zhang, G.; Xu, Z.; Gao, Y.; Huang, X.; Zou, Y.; Yang, T. Effects of germination on the nutritional properties, phenolic profiles, and antioxidant activities of buckwheat. *J. Food Sci.* **2015**, *80*, H1111–H1119. [CrossRef] [PubMed]
61. Lara, M.V.; Bonghi, C.; Famiani, F.; Vizzotto, G.; Walker, R.P.; Drincovich, M.F. Stone fruit as biofactories of phytochemicals with potential roles in human nutrition and health. *Front. Plant. Sci.* **2020**, *11*, 1323. [CrossRef]
62. Hubert, J.; Berger, M.; Nepveu, F.; Paul, F.; Daydé, J. Effects of fermentation on the phytochemical composition and antioxidant properties of soy germ. *Food Chem.* **2008**, *109*, 709–721. [CrossRef]
63. Wang, C.Y.; Wu, S.J.; Shyu, Y.T. Antioxidant properties of certain cereals as affected by food-grade bacteria fermentation. *J. Biosci. Bioeng.* **2014**, *117*, 449–456. [CrossRef]
64. Dhull, S.B.; Punia, S.; Kidwai, M.K.; Kaur, M.; Chawla, P.; Purewal, S.S.; Sangwan, M.; Palthania, S. Solid-state fermentation of lentil (*Lens culinaris* L.) with Aspergillus awamori: Effect on phenolic compounds, mineral content, and their bioavailability. *Legume Sci.* **2020**, *2*, 37. [CrossRef]
65. Mutshinyani, M.; Mashau, M.E.; Jideani, A.I.O. Bioactive compounds, antioxidant activity and consumer acceptability of porridges of finger millet (*Eleusine coracana*) flours: Effects of spontaneous fermentation. *Int. J. Food Prop.* **2020**, *23*, 1692–1710. [CrossRef]
66. Ali, S.S.; Ahsan, H.; Zia, M.K.; Siddiqui, T.; Khan, F.H. Understanding oxidants and antioxidants: Classical team with new players. *J. Food Biochem.* **2020**, *44*, 13145. [CrossRef] [PubMed]
67. Ihediohanma, N.C. Determination of the glycemic indices of three different cassava granules (Garri) and the effect of fermentation period on their glycemic responses. *Pak. J. Nutr.* **2011**, *10*, 6–9. [CrossRef]
68. Ihekoronye, A.I.; Ngoody, P.O. *Tropical Roots and Tubers Crops in Integrated Food Science and Technology for the Tropics*; Macmillan: London, UK, 1985; pp. 266–282.
69. Uchechi, O.N.C.; Esther, B.P.T.; Doobue, M.H. In vitro digestibilities, predicted glycemic index and sensory evaluation of biscuits produced from composite flours of wheat and processed tiger nut. *GSC Biol. Pharm. Sci.* **2020**, *10*, 164–172.
70. Mlotha, V.; Mwangwela, A.M.; Kasapila, W.; Siyame, E.W.; Masamba, K. Glycemic responses to maize flour stiff porridges prepared using local recipes in Malawi. *Food Sci. Nutr.* **2016**, *4*, 322–328. [CrossRef] [PubMed]
71. Chun Ng, C.W.; Ismail, A.F.; Zaini Makhtar, M.M.; Fikri Jamaluddin, M.N.; Tajarudin, H.A. Conversion of food waste via two-stage fermentation to controllable chicken Feed Nutrients by local isolated microorganism. *Int. J. Recycl. Org. Waste Agric.* **2020**, *9*, 33–47.
72. Östman, E.; Granfeldt, Y.; Persson, L.; Björck, I. Vinegar supplementation lowers glucose and insulin responses and increases satiety after a bread meal in healthy subjects. *Eur. J. Clin. Nutr.* **2005**, *59*, 983–988. [CrossRef]
73. Ashaolu, T.J.; Ashaolu, J.O.; Adeyeye, S.A. Fermentation of prebiotics by human colonic microbiota in vitro and short-chain fatty acids production: A critical review. *J. Appl. Microbiol.* **2021**, *130*, 677–687. [CrossRef]
74. Östman, E.M.; Nilsson, M.; Elmståhl, H.L.; Molin, G.; Björck, I.M.E. On the effect of lactic acid on blood glucose and insulin responses to cereal products: Mechanistic studies in healthy subjects and in vitro. *J. Cereal Sci.* **2002**, *36*, 339–346. [CrossRef]
75. Scazzina, F.; Del Rio, D.; Pellegrini, N.; Brighenti, F. Sourdough bread: Starch digestibility and postprandial glycemic response. *J. Cereal Sci.* **2009**, *49*, 419–421. [CrossRef]
76. Chilton, S.N.; Burton, J.P.; Reid, G. Inclusion of fermented foods in food guides around the world. *Nutrients* **2015**, *7*, 390–404. [CrossRef] [PubMed]
77. Chileshe, J.; Talsma, E.F.; Schoustra, S.E.; Borgonjen-Van den Berg, K.J.; Handema, R.; Zwaan, B.J.; Brouwer, I.D. Potential contribution of cereal and milk based fermented foods to dietary nutrient intake of 1-5 years old children in Central province in Zambia. *PLoS ONE* **2020**, *15*, e0232824. [CrossRef] [PubMed]
78. Kårlund, A.; Gómez-Gallego, C.; Korhonen, J.; Palo-oja, O.M.; El-Nezami, H.; Kolehmainen, M. Harnessing Microbes for Sustainable Development: Food Fermentation as a Tool for Improving the Nutritional Quality of Alternative Protein Sources. *Nutrients* **2020**, *12*, 1020. [CrossRef] [PubMed]
79. Rekha, C.R.; Vijayalakshmi, G. Bioconversion of isoflavone glycosides to aglycones, mineral bioavailability and vitamin B complex in fermented soymilk by probiotic bacteria and yeast. *J. Appl. Microbiol.* **2010**, *109*, 1198–1208. [CrossRef] [PubMed]
80. Bahaciu, G.V.; Nicolae, C.G.; Șuler, A.D.; Segal, R. Germinated and Lactic Fermented Soybean Seeds, a Natural Alternative for Healthy Bones. A Scientific Approach. *Bull. UASVM Food Sci. Technol.* **2018**, *75*. [CrossRef]

81. Makokha, A.O.; Oniang'o, R.K.; Njoroge, S.M.; Kamar, O.K. Effect of traditional fermentation and malting on phytic acid and mineral availability from sorghum (*Sorghum bicolor*) and finger millet (*Eleusine coracana*) grain varieties grown in Kenya. *Food Nutr. Bull.* **2002**, *23*, 241–245. [CrossRef]
82. Valencia, S.; Ulf, S.; Ann-Sofie, S.; Ruales, J. Processing of quinoa (*Chenopodium quinoa*, Willd): Effects on in vitro iron availability and phytate hydrolysis. *Int. J. Food Sci. Nutr.* **1999**, *50*, 203–211. [CrossRef]
83. Castro-Alba, V.; Lazarte, C.E.; Perez-Rea, D.; Sandberg, A.S.; Carlsson, N.G.; Almgren, A.; Bergenståhl, B.; Granfeldt, Y. Effect of fermentation and dry roasting on the nutritional quality and sensory attributes of quinoa. *Food Sci. Nutr.* **2019**, *7*, 3902–3911. [CrossRef]
84. Lopez, H.W.; Duclos, V.; Coudray, C.; Krespine, V.; Feillet-Coudray, C.; Messager, A.; Demigné, C.; Rémésy, C. Making bread with sourdough improves mineral bioavailability from reconstituted whole wheat flour in rats. *Nutrition* **2003**, *19*, 524–530. [CrossRef]
85. Chiş, M.S.; Păucean, A.; Man, S.M.; Bonta, V.; Pop, A.; Stan, L.; Pop, C.R.; Mureşan, V.; Muste, S. Effect of rice flour fermentation with Lactobacillus spicheri DSM 15429 on the nutritional features of gluten-free muffins. *Foods* **2020**, *9*, 822. [CrossRef]
86. Cizeikiene, D.; Juodeikiene, G.; Bartkiene, E.; Damasius, J.; Paskevicius, A. Phytase activity of lactic acid bacteria and their impact on the solubility of minerals from wholemeal wheat bread. *Int. J. Food Sci. Nutr.* **2015**, *66*, 736–742. [CrossRef] [PubMed]
87. Anastasio, M.; Pepe, O.; Cirillo, T.; Palomba, S.; Blaiotta, G.; Villani, F. Selection and use of phytate-degrading LAB to improve cereal-based products by mineral solubilization during dough fermentation. *J. Food Sci.* **2010**, *75*, M28–M35. [CrossRef] [PubMed]
88. Bergqvist, S.W.; Andlid, T.; Sandberg, A.S. Lactic acid fermentation stimulated iron absorption by Caco-2 cells is associated with increased soluble iron content in carrot juice. *Br. J. Nutr.* **2006**, *96*, 705–711.
89. Giri, S.S.; Sen, S.S.; Saha, S.; Sukumaran, V.; Park, S.C. Use of a potential probiotic, *Lactobacillus plantarum* L7, for the preparation of a rice-based fermented beverage. *Front. Microbiol.* **2018**, *9*, 473. [CrossRef]
90. Lazarte, C.E.; Vargas, M.; Granfeldt, Y. Zinc bioavailability in rats fed a plant-based diet: A study of fermentation and zinc supplementation. *Food Nutr. Res.* **2015**, *59*, 27796.
91. Scheers, N.; Rossander-Hulthen, L.; Torsdottir, I.; Sandberg, A.S. Increased iron bioavailability from lactic-fermented vegetables is likely an effect of promoting the formation of ferric iron (Fe^{3+}). *Eur. J. Nutr.* **2016**, *55*, 373–382. [CrossRef]
92. Amritha, G.K.; Dharmaraj, U.; Halami, P.M.; Venkateswaran, G. Dephytinization of seed coat matter of finger millet (*Eleusine coracana*) by *Lactobacillus pentosus* CFR3 to improve zinc bioavailability. *LWT* **2018**, *87*, 562–566. [CrossRef]
93. Chawla, P.; Bhandari, L.; Sadh, P.K.; Kaushik, R. Impact of Solid-State Fermentation (*Aspergillus oryzae*) on Functional Properties and Mineral Bioavailability of Black-Eyed Pea (*Vigna unguiculata*) Seed Flour. *Cereal Chem.* **2017**, *94*, 437–442. [CrossRef]
94. Khodaii, Z.; Zadeh, M.N.; Kamali, J.; Natanzi, M.M. Enhanced iron absorption from lactic acid fermented bread (an in vivo/ex vivo study). *Gene Rep.* **2019**, *15*, 100389. [CrossRef]
95. Kaur, K.D.; Jha, A.; Sabikhi, L.; Singh, A.K. Significance of coarse cereals in health and nutrition: A review. *J. Food Sci. Technol.* **2014**, *51*, 1429–1441. [CrossRef] [PubMed]
96. Carrizo, S.L.; de LeBlanc, A.D.M.; LeBlanc, J.G.; Rollán, G.C. Quinoa pasta fermented with lactic acid bacteria prevents nutritional deficiencies in mice. *Food Res. Int.* **2020**, *127*, 108735. [CrossRef]
97. Tsafrakidou, P.; Michaelidou, A.M.; G Biliaderis, C. Fermented Cereal-based Products: Nutritional Aspects, Possible Impact on Gut Microbiota and Health Implications. *Foods* **2020**, *9*, 734. [CrossRef]
98. Panikuttira, B.; O'Shea, N.; Tobin, J.T.; Tiwari, B.K.; O'Donnell, C.P. Process analytical technology for cheese manufacture. *Int. J. Food Sci. Technol.* **2018**, *53*, 1803–1815. [CrossRef]
99. Gupta, S.; Abu-Ghannam, N. Probiotic fermentation of plant-based products: Possibilities and opportunities. *Crit. Rev. Food Sci. Nutr.* **2012**, *52*, 183–199. [CrossRef] [PubMed]