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Review

The effect of food processing on the amount of trace elements and their bioavailability: a review

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ABSTRACT

Trace elements are compounds that are essential in small amounts for biochemical reactions and to maintain human health. Almost all foods can contain varying amounts of these metals. In this study, the effects of food processing on the content of trace metals are investigated. Extensive interpretations of processing, including aspects of food production and specific examples of changes in metal content due to processing will be discussed. Pre-consumption food processing to improve rheological properties and increase shelf life is inevitable, which changes the bioavailability and amount of these compounds in different directions depending on the process. The amount of these trace metals in the food product can be affected by various conditions such as heating, fermentation, food additives, etc. The main factor in reducing trace elements in food, especially the use of heat in a special method and on the other hand, factors such as fermentation can also increase the bioavailability of these elements.

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1. Introduction

Nowadays, with the clarification of the importance of trace metal elements in the function of body cells and maintaining health throughout life due to involvement in biochemical reactions, many people have drawn attention to the daily consumption of significant amounts of these elements through food. Trace elements are present in the human body in very small amounts and less than 0.01 present.

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They are important for growth, development, maintenance and recovery. These compounds have different roles: some of them are essential components of enzymes, where they absorb substrate molecules and facilitate their conversion into final products (1).

Copper (Cu), zinc (Fe), manganese (Mn), nickel (Ni), iron (Fe), etc. are among the metals that are essential for human health in small amount. Trace elements create two-sided effects on the lives of animals, especially humans. These elements represent potentially toxic factors, on the other hand, they are essentially needed to support growth and provide protection against disease. Micronutrient deficiencies occur due to low intake of minerals, their loss or lack of absorption in the body (2). The main way to supply these metals is to consume food, especially products of animal origin.

Despite having high amounts of vitamins, plant nutrients are deficient in trace elements, and on the other hand, low amounts of trace elements due to their special structure are less absorbable than animal products (3-5). The amount of these elements largely depends on the environmental conditions of the plant or animal. The biggest challenges in this regard are the preservation of these compounds until consumption by the consumer, increasing the biological access of these compounds in food and their consumption in sufficient and appropriate amounts (6-8). on the other hand, trace elements and elements have been important and noteworthy issues in recent years, not only in terms of health but also in terms of food safety because in case of excessive consumption or less than the required amount, it can lead to safety risks for the consumer (9).

As mentioned earlier, in addition to the presence of the desired metals in sufficient quantities in the nutrient, their bioavailability in the body and in the intestine, is another important issue .In this regard, many factors are involved, including the solubility of the compound in the intestine, which depends on the pH of the intestine, the formation of complexes with trace elements is also a reducing factor for bioavailability, such as the effect of phytate on Fe and Cu, etc. The presence of heavy metals in food can also reduce the absorption of trace elements, therefore, food processes that also affect the amount of these metals are also important in this regard (10).

Today, due to the need for long-term storage of food, the use of food processing techniques is inevitable, and traditional technologies such as heating, fermentation, mechanical processes, etc. each make a significant contribution to maintaining, eliminating, increasing the amount of this trace elements and their bioavailability in food. The effect of food processing on the amount and bioavailability of trace metals depends on the type of process and conditions of use, its intensity and the state of the metal in the food product (11,12).

The metal content of food is affected by a variety of factors from environmental conditions during growth to manipulation, processing, preparation and post-harvest cooking techniques, for example, while post-harvest manipulation steps, such as washing, generally remove metal contaminants, the metal content of some commodities grown in contaminated soil increases (13). It has been shown that performing thermal processing on food products by different methods of boiling, using steam, frying, etc. causes the loss of high amounts of trace elements, especially in plant products during the thermal process and after boiling the food, metal compounds are removed from the food matrix and their amount in the food composition decreases (6).

Additives and food components that are added during processing themselves contain some metal compounds in their composition that increase the content of trace metals in the food. On the other hand, the bioavailability of the studied metals, despite the presence of phytates in various grains and plant compounds, which has been reduced by using the fermentation process during processing, will increase significantly during the fermentation process, the anti-nutritional effect of this compound is removed from the trace elements by breaking the covalent bonds of the inositol ring phosphate by the enzyme phytase resulting from the activity of microorganisms (14). In products that need to separate the outer shell, such as cereals, despite the reduction of anti-nutritional compounds and increased bioavailability of mineral elements and compounds, most of their trace elements are removed from the food by this process, this decrease is more noticeable in metals such as Fe, Zn, Cu, Mn and selenium (Se) than in other compounds (15).

The rest of this study is devoted to Fe, Zn and Cu and the effect of important food processing on their preservation or elimination during the process .These elements are very useful for humans and have an effect on normal metabolic functions even at low levels.

2. Effect of processing on trace elements

2.1. Iron

Fe plays a number of roles in the body's biological system. Its main function is in the system of hemoglobin in the blood and myoglobin in the muscles and it has a fundamental role in oxygen transport .It also plays an essential role in enzyme systems, protein synthesis, RNA structure, nervous system as well as enzyme systems (16,17). Per capita intake of this element is different for men and women. In women, due to blood loss over time, the need for Fe is higher and is approximately equal to 29 mg/day, and in men is approximately equal to 13 mg/day (18). Iron deficiency in the diet will lead to many diseases, the most important of which is anemia due to Fe deficiency. In children, it reduces cognitive development and the immune system, which leads to increased susceptibility to infectious diseases. If anemia persists, especially in pregnant women, the risk of miscarriage and mental illness in the fetus increases (19-21). Fe is one of the most important trace elements in food, especially of animal origin. Refrigeration is an unavoidable process in most food-related industries, but studies show that it does not affect the amount of Fe or its bioavailability (22). Mohamed EA et al. showed that the shell removal process in cereals caused a slight decrease in Fe content (approximately 1%) but did not increase its bioavailability (approximately 3-5%) compared to the dehydration state (22). This reduction in the amount of Fe due to peeling is directly related to the reduction in the dry matter content of the food (23). Kimura M et al. investigated the effect of different types of cooking on the amount of trace elements in food samples. They showed that in general, the reduction of Fe in food depends on two factors: the type of food product and the cooking method. Cooking plant-based ingredients less than animal foods causes iron loss, and in this regard, the least amount of Fe loss is related to spinach and the highest amount is related to pickles, fried eggs and boiled meat. Regarding spinach, if using the method of using steam, the highest amount of reduction in Fe is observed, which is about 93%. Considering to a variety of traditional cooking methods in a variety of foods, it is expected to reduce their Fe content by about 25%. However, if microwaves are used to cook products, the use of slow heating in plant foods and rapid heating in animal foods causes the amount of Fe loss to be almost zero. In addition, in the case of rice, if pre-cooking is done on it, it can also increase the amount of Fe available (24).

Yaseen AAE in its study on the effect of processing conditions on the content of trace elements in pasta has shown that among the various processes performed on pasta, including extrusion, drying and baking, the most effect on the amount of iron related to cooking and then it is related to the drying process, especially with high heat during drying, the amount of Fe will decrease by about 14.3% (25). Amaro - López MA et al. conducted their study on the effect of processing on trace elements of asparagus. They showed that peeling, washing and blanching significantly reduce the amount of asparagus iron. But most of the reduction has been related to blanching. The average amount of Fe in asparagus is 175 mg/kg, which is reduced to 75 mg/kg due to the enzyme removal process (26).

It can be concluded that the most important factor affecting the amount of Fe in food is its solubility in water and this factor along with heat causes a further reduction of Fe in food. Due to the loss of Fe during food processing and iron deficiency in most communities and on the other hand to prevent the adverse effects of Fe, food enrichment using new technologies such as nano-enclosure as one of the stages of food processing which can be very effective (27, 28).

Other studies on the effect of food frequency on iron levels are summarized in Table 1.

2.2. Zinc

Previous studies have shown that 17% of the world's population suffers from zinc deficiency, with a higher proportion of those from low-income countries (29, 30). On the other hand, in addition to the amount of Zn consumed, another factor that affects the amount of Zn in the body is the amount and ability of the body to absorb Zn, so people with liver cirrhosis or inflammation of the intestine are deficient in Zn (31, 32). The body needs Zn depending on the age of the person. In an adult, 10-14 mg of Zn is needed daily, also, the need of more adolescents and children for Zn is obvious (18). Zn plays an essential role in the activity of enzymes and acts as a cofactor in their structure, most of the proteins in the body are attached to Zn (19).

Table 1. Effect of food processing on iron content

Food	Type of processing	Result	Source
Chicken breast muscle	Thermal process (Boiling)	130 °F, 150 °F, 165 °F and 195 °F were measured on the amount of iron in chicken breast muscle meat, which showed the greatest decrease at 195 °F. The amount of iron increases from 75 micrograms per 100 g of raw meat to 15 micrograms in cooked meat	**(52)**
Rice	Boiling	On average, about 41% iron reduction was observed among the 3 rice cultivars tested	**(53)**
Cocoa beans	Dry and roast	In this study, two methods for roasting cocoa have been investigated. It has been shown that if the cocoa beans are dried first and then roasted in a traditional way with less time, the amount of residual iron is more and about 53 mg per 100 g and the amount of iron in raw cocoa beans has been approximately between 59-55 mg per 100 g.	**(54)**
Yogurt	Nanomulsion	Protect more iron from heat and prevent fat oxidation that is accelerated by iron.	**(55)**
Quinoa flour	Fermentation	The amount of iron in raw quinoa seeds was about 52.3 mg per kg, which reached 50.2 mg after fermentation.	**(49)**
Bambara ground nuts	Soaking	The amount of iron in the raw brain is equal to 4.9 mg per 100 g, which is equal to 3.8 mg after soaking.	**(56)**
	Cooking	If cooked for 60 min, the amount of iron in the brain was found to be 3.6 mg per 100 g, and if cooked for 120 min, it was found to be equal to 3.4 mg per 100 g.	
	Peeled	In this case, the amount of iron decreases from 4.9 mg to 4.3 mg.	

Zn also plays an essential role in the transcription process of genes as an essential element (33). Due to Zn deficiency, the risk of insulin resistance, hepatic steatosis (fatty liver disease) and hepatic encephalopathy, especially in people with chronic liver disease (31), myocardial infarction (MI), chronic heart failure (CHF) and cardiovascular complications (34), immune system defects (35) increase. Paying attention to a diet rich in Zn and on the other hand recognizing the processes that affect the amount of Zn in food processing is important in preventing a deficiency of this essential element. Min Wang et al. conducted a study on the amount of Zn in raw and processed wheat, which contained between 30-34 mg/kg of wheat, depending on the type of wheat and the place of cultivation. After processing wheat and turning it into products such as bread and biscuits, it loses a significant amount of Zn and the average amount of Zn in these products is equal to 12.56 mg per kg. The highest amount of Zn is related to steamed bread and the lowest amount is related to noodles with approximately 45 and 3, respectively (34).

Anna Czech et al. in their study in 2019 on the amount of Zn in citrus, skin and pulp of 8 types of citrus fruits including lemon, orange, red, green and white grapefruit, etc. showed that the amount of Zn in the whole citrus fruit is about 0.11 up to 0.26 mg per 100 g of fruit, of which 27% is stored in the pulp and 28% in the skin. Therefore, peeling citrus will reduce the amount of Zn by 28% and fruit juices without pulp will generally lose 55% of their Zn. Also, the highest amount of Zn is related to green grapefruit, which is equal to 0.26 mg per 100 g (35).

Meat is a very important food in the diet that in addition to the vitamins needed, it also contains important trace elements such as Fe and Zn in its tissue. According to studies by Lombardi-Boccia et al. On the amount of trace elements on 4 types of raw and cooked meat from different secretory parts, it has been shown that the amount of Zn increases slightly after cooking meat, so that the amount of Zn in raw beef fillet is equal to 4 mg per 100 g of meat and after cooking this amount reaches 5.62 mg per 100 g of meat. It seems that this increase in Zn content in cooked meat is due to the decrease in moisture, and on the other hand, the lack of Zn content is due to the cooking method, which is from oven heat and without the use of water, which allows the preservation of trace elements, especially Zn (36).

Therefore, the effect of food processing on Zn depends on many factors. The high solubility of Zn in water and water vapor has caused the use of wet heating during blanching or boiling, wet heating causes the loss of this element, and if dry heat is used to prepare the desired food composition can be an important factor in preserving this trace element. On the other hand, some of the Zn content in the skin of products such as cereals, fruits and citrus is stored. Peeling operations cause the loss of these amounts of Zn, and in this regard, the use of soil enrichment processes during the cultivation of these products can lead to an increase in total Zn content in the product .Other studies on the effect of food processing on Zn levels are summarized in Table 2.

Table 1. Effect of food processing on zinc content

Food	Type of processing	Result	Reference
Beans	Soaking	Bean processing was performed by two methods of boiling with previous soaking and boiling without previous soaking, which is shown. If the beans are soaked before cooking, 91% of the zinc in the beans is preserved, while in the soaked and cooked seeds, only 75% of the zinc element remains.	(57)
Chenopodium species	Cooking	Zinc content in raw sample = 2.7 mg per 100 g Zinc content in fried sample = 2.3 mg per 100 g The amount of zinc in the sample cooked under pressure = 2.3 mg per 100 g.	(58)
Moringa oleifera seeds	Cooking	Raw sample content = 0.39% Zinc content in roasted sample for 10 min = 1.04% Roasted sample for 20 min = 1.15% Roasted sample for 30 min = 1.16%	(59)

2.3. Copper

According to the Food and Drug Administration (FDA) updated nutrition and supplements labels (January 2020), the daily intake of copper for adults and children 4 years and older is 0.9 mg (FDA 2018). Cu is one of the essential minerals for humans, animals and plants that the human body needs in small amounts to maintain good health.

This required amount can be met through diet, geographical area and processing operations affect the copper content in food. Food sources rich in Cu include meat, liver, kidneys, seafood, whole grains, nuts, etc. Also, water that passes through Cu pipes can help get copper through the diet. Therefore, the diet consumed has an important effect on the amount of Cu absorption, so that a diet rich in protein, especially animal protein, increases the bioavailability of this element.While diet with high levels of ascorbic acid has a negative effect on the bioavailability of this element by reducing the activity of ceruloplasmin enzyme. Also, because of the interaction between Fe and Cu, due to the disruption of the use of one element in the absence of the other, consuming foods with high iron may upset the Cu balance in the body (37). In addition, the consumption of high-fiber foods due to the effect of alpha-cellulose or phytates on Cu consumption can upset the balance of Cu in the body (38).

Cu in enzymes such as superoxide dismutase, homocyanin, cytochrome c oxidase is required for oxidation-reduction reactions. ، It also helps transmit nerve messages, Fe metabolism, and connective tissue synthesis by being able to transfer electrons into structural and functional proteins. Metallothionein, tyrosinase, homocyanin, ceruloplasmin and amine oxidase are Cu-containing enzymes in humans that are involved in various systems such as the respiratory, immune and nervous systems. For example, cytochrome c oxidase is essential for brain function and energy supply to the brain (39).

It is involved in many physiological processes such as fetal and neonatal development, improving brain function and development, bone strength, Fe metabolism, glucose and cholesterol, pigment formation, and improving immune function. Different food processes affect the amount of copper in food. Carla Mota et al. conducted a study on the effect of cooking on trace metals in cereals and rice, in which 83% of the Cu in rice was reduced during rice boiling (40).The Cu content in raw grains ranged from 0.490 mg per 100 g to 0.572 mg per 100 g. In cooked nutrient cereal samples, the values were 0.437 mg/100 g in steamed buckwheat. Quinoa, and cooked buckwheat offer significantly lower content ($p<0.05$) compared to raw. Shane Michael Heffernan et al. showed that the amount of Cu in cheese decreased during dehydration (41).The use of Cu utensils for cooking as well as food storage in the refrigerator causes the transfer of Cu metal from these utensils to food. .Also, an acidic environment with a pH of 4 provides more migration of copper metal during cooking and cold storage than other pH. While pH is 7, the lowest rates of Cu metal migration occur from Cu vessels to food (42).

According to the study of Mihucz et al. (2018), when cooking rice using three different methods, a significant loss of elements was observed. With increasing the volume of cooking water, the concentrations are substantially reduced. The loss of essential elements is increased by placing them on the surface of rice grains, which makes them easily removed through washing and cooking. In this study, the essential element that was less affected by cooking (43). Other studies on the effect of food processing on Cu and a few other trace elements levels are summarized in Table 3.

3. Guides to improving the bioavailability of trace element

Bioavailability is generally used to mean a component that is absorbed for biological activity in the body. Bioavailability means a food component that can be absorbed in the intestine, and biological activity is a set of processes that the body performs in order to enable the absorption of nutrients by the intestine (44,45).

Important and effective factors in bioavailability are the possibility of solubility of the element in the gastrointestinal tract, the type of element, the presence or absence of inhibitors such as phosphates, phytates, tannins, oxalates and carbonates, and finally the presence or absence of similar compounds (Such as heavy metals) (46,47). The effect of two main factors of fermentation and heating on the bioavailability of trace elements is described in the relevant sections.

3.1. Effect of fermentation on bioavailability of trace elements

LUO et al. conducted a study on the degradation effect of Faba bean phytate in two different ways on bioavailability of zinc and iron. Phytate degradation was performed using the addition of the enzyme phthase, which enhances the internal phytase effect of Faba bean and thus improves the bioavailability of iron and zinc. On the other hand, in this study, it was shown that incubation at 55°C along with stirring at 60 rpm significantly improves the biological availability of these two elements (48)

Table 2. Effect of food processing on cu and a few other trace elements content

Food	Trace element	Type of processing	Result	Reference
Sea bream	Cu	fried in sunflower oil steamed sea bream	Raw sample content=1.9 mg per kg fried in sunflower oil content = 1.2 mg per steamed sea bream content=1.2 mg per kg	(60)
Rainbow trout	Mn	Baked	The amount of manganese in raw rainbow trout is 0.78 mg / kg. In Baked samples, this amount has been reduced to 0.32 mg / kg.	(61)
Horse, lamb, ostrich	Cu	cooking	Horse: Cu content in raw fillet =0.12 mg per 100 g Cu content in cooked fillet=0.19 mg per 100 g Lamb: Cu content in raw sample=0.10 mg per 100 g Cu content in cooked sample=0.15 Ostrich: Cu content in raw fillet=0.10 mg per 100 g Cu content in cooked fillet=0.16 mg per 100 g	(36)
Colocasia esculenta (L) Schott	Mg	boiling	Mg content in raw sample=344.2 mg per 100 g Mg content in cooked sample=317.5 mg per 100 g cooking method: First, the washed samples were dried in air, then boiled for 20 min at 100 °C, and then dried in the open air for 20 min.	(62)

Vanesa Castro-Alba et al. in their study on the effect of fermentation and drying on the bioavailability of trace metals in quinoa seeds showed that the amount of phytate in raw quinoa flour is approximately 8 g/kg, which after fermentation for 4 h reached 2.20 g and fermented and roasted in quinoa flour, the amount of phytate was the same. Which shows the effective effect offermentation on phytate levels and subsequently improves bioavailability, especially for Fe, Cu, Zn, Mn and Ca. Also, this process did not have a significant effect on sensory characteristics including taste, smell and texture between raw and fermented quinoa flour (49).

Therefore fermentation process improves the bioavailability of important minerals and trace elements due to the production of enzymes such as phytase, which break down mineral inhibitors.

3.2. Effect of heat on the bioavailability of trace elements

In a study by Moreda- Piñeiro et al. on the bioavailability of metals in seafood, the samples tested were several species of seaweed, mollusks and a variety of fish. In the case of seaweed, both raw and cooked and canned samples were present in the study. Measurement of bioavailability was performed for 10 metals, especially Fe, Zn, Cu and Mn, which in seaweed bioavailability of cooked samples Is the lowest amount, which is due to the reduction in the amount of metals due to cooking (50).

Hemalatha et al. In their study on the effect of pressurized and microwave heating on the bioavailability of iron and zinc in cereals and legumes showed that, in general, in the case of Zn in legumes, bioavailability is reduced by applying heat in both ways but in the case of cereals, the results have been different. For example, the difference in bioavailability in the raw rice sample, cooked under heat pressure and microwave, significantly, the raw sample has more bioavailability than the other two cases. But in the case of raw sample wheat, heated under pressure and under microwave heating, the bioavailability was about the same. In the case of sorghum, the bioavailability of the sample on which the heat was applied under pressure was significantly higher than in the raw state and exposed to microwaves and Fe in both cereals and legumes due to heating has significantly increased the bioavailability of Fe in food, but depending on the product, the effect of heat under pressure and microwave has been different. For example, in rice, the heat from microwave was more effective in this increase, but in the case of sorghum, heat under pressure was more effective (51). As a result, according to the above, since food processing is a set of processes, each of which has a specific impact on bioavailability, in general, it cannot be said that food processing increases or decreases bioavailability. Even in the case of the thermal process, the results obtained from different studies and products are different. Although heating in seafood reduces the bioavailability of rare metals, it has the opposite effect on cereals and legumes. The effect of the thermal process on biological access depends on the type of food and the method of heat application.

4. Conclusion

Previous studies have shown that the transfer as well as the loss of trace elements occurs at various stages of food processing until consumption. The growth of plants in soil rich in trace elements increases these elements in plants and then by feeding the animal increases the content of these elements in the body of animals. The presence of elements in equipment and food storage containers can cause them to migrate to the food. On the other hand, thermal processes, especially boiling and blanching due to the presence of water, cause the elimination of these elements in the food. Food processes depending on the type of processing material and also the processing method and conditions can increase or decrease the bioavailability of elements, in which fermentation is a clear example of increasing the bioavailability of elements by reducing the content of phytate.

Conflict of interest

All authors state that there is no conflict of interest.

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