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Research Article

The Impact of Food Chemical Composition on the Absorption of Vitamins and Minerals in the Human Body

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Abstract. The absorption of vitamins and minerals from food is a critical factor influencing human health and nutrition. This literature review examines how the chemical composition of food including naturally occurring inhibitors and enhancers affects the bioavailability of essential micronutrients. Emphasis is placed on the role of compounds such as phytates, oxalates, tannins, and polyphenols in reducing absorption, as well as the enhancing effects of vitamin C, dietary fats, heme iron, organic acids, and specific amino acids. Understanding these interactions provides insight into optimizing nutrient uptake through dietary choices, traditional food preparation methods, and targeted public health strategies.

Keywords: nutrient absorption, vitamins, minerals, bioavailability, food composition, inhibitors, enhancers

INTRODUCTION

Vitamins and minerals are essential for human health, yet many populations suffer from inadequate intake. Over two billion people worldwide are estimated to be deficient in key micronutrients such as iron, iodine, vitamin A, zinc, and folate, contributing to anemia, impaired immunity, and developmental issues (Melse-Boonstra & Brouwer, 2021). Even as food availability has increased globally, the nutrient density of many staples has declined. For instance, iron content in grains has dropped by nearly 50% over the past century (Stein et al., 2007). This underlines the importance of not only dietary quantity but also bioavailability the fraction of an ingested nutrient that is absorbed and utilized by the body.

Bioavailability is influenced not just by human physiological factors but also by the food matrix itself. As Melse-Boonstra and Brouwer (2021) emphasize, understanding the interaction between nutrients and other food components is crucial for ensuring effective nutrient delivery through the diet. This approach aligns with modern nutrition science, which has shifted from reductionist nutrient-based views to food-based paradigms (Fardet & Rock, 2018). The food matrix a term encompassing the structural and chemical composition of food plays a key role in regulating how nutrients are released and absorbed in the gastrointestinal tract.

Many naturally occurring compounds in plant-based foods can inhibit nutrient absorption. Phytates, found in whole grains and legumes, are well-documented inhibitors of iron, zinc, and calcium uptake due to their ability to bind minerals and form insoluble complexes (Hurrell & Egli, 2010). Oxalates, present in foods like spinach and rhubarb, reduce calcium bioavailability by forming calcium oxalate (Gupta et al., 2013). Polyphenols and tannins, common in tea, coffee, and some legumes, can also impair non-heme iron absorption (Tako & Glahn, 2012). Lectins and saponins in legumes and grains interfere with the intestinal absorption of multiple minerals (Gupta et al., 2013), and glucosinolates in cruciferous vegetables are known to inhibit iodine absorption, potentially affecting thyroid function (Gupta et al., 2013).

Conversely, several dietary components enhance mineral and vitamin absorption. Ascorbic acid (vitamin C) significantly improves non-heme iron absorption by reducing ferric to ferrous iron and forming soluble complexes (Teucher et al., 2004). Animal proteins, particularly from meat, fish, and dairy, contain peptides and amino acids that increase the solubility and uptake of minerals such as iron and calcium (Reinhold et al., 1981). Casein phosphopeptides in milk products help stabilize calcium and keep it in a soluble form for better absorption (Scholz-Ahrens et al., 2007). Lactose in dairy may also promote calcium absorption by affecting intestinal permeability (Gupta et al., 2013). Fat-soluble vitamins (A, D, E, and K) require dietary lipids and bile salts to form micelles and be absorbed; hence, consuming these vitamins with fats enhances their bioavailability (Tang et al., 2017).

Cooking can further influence bioavailability. Thermal treatments like boiling or steaming often reduce anti-nutrient levels such as; phytates and lectins and can deactivate glucosinolates. Cooking with small amounts of oil can enhance absorption of fat-soluble vitamins (Tang et al., 2017). However, overcooking may degrade heat-sensitive vitamins, like vitamin C and some B-vitamins. The type of cooking method, duration, and food composition all interact to influence nutrient retention and absorption.

This review aims to explore how food's chemical composition excluding industrial food processing affects the absorption of vitamins and minerals. We highlighted the roles of anti-nutrients, enhancers, and cooking practices in regulating bioavailability. Understanding these interactions is essential for guiding dietary recommendations, designing nutrient-rich meals, and addressing micronutrient deficiencies worldwide.

Naturally Occurring Inhibitors of Vitamin and Mineral Absorption

Plant-derived "anti-nutrients" can significantly impair the absorption of essential vitamins and minerals. Compounds such as phytates, oxalates, polyphenols, lectins, saponins, and glucosinolates interfere with nutrient uptake by chelating minerals, binding to digestive enzymes or transport proteins, and damaging intestinal cells (Gupta et al., 2015; Kumar et al., 2019). These mechanisms especially affect the bioavailability of iron, zinc, calcium, and certain vitamins in plant-based diets.

Phytates

Phytates (inositol hexaphosphate), common in cereals, legumes, and seeds, form insoluble complexes with divalent minerals like iron (Fe^{2+}), zinc (Zn^{2+}), and calcium (Ca^{2+}), reducing their bioavailability (Frontela et al., 2008; Kumar et al., 2010). Studies have shown that high dietary phytate intake correlates with reduced mineral absorption, while enzymatic degradation using phytase improves bioavailability (Hurrell & Egli, 2010).

Oxalates

Oxalates, found in foods such as spinach, beet greens, and nuts, also reduce mineral absorption—particularly calcium by forming insoluble salts (Noonan & Savage, 1999). For example, despite its high calcium content, spinach yields poor calcium bioavailability due to oxalate binding (Weaver & Heaney, 2006).

Polyphenols

Polyphenols, especially tannins in tea, coffee, legumes, and some fruits, bind to minerals and proteins to form complexes that are poorly absorbed (Sandberg, 2002; Petry et al., 2016). Non-heme iron absorption is especially inhibited by high polyphenol content, with studies reporting a reduction of up to 60% (Hurrell et al., 1999).

Lectins

Lectins are carbohydrate-binding proteins found in legumes and grains that resist digestion and may impair nutrient absorption by damaging intestinal mucosa or binding nutrients (Vasconcelos & Oliveira, 2004). Undercooked legumes high in active lectins have been shown to reduce the bioavailability of iron and zinc (Liener, 1994).

Saponins

Saponins, present in soybeans, quinoa, and some herbs, can interfere with lipid and fat-soluble vitamin absorption by forming insoluble complexes and disrupting cell membranes (Shi et al., 2004). Though mild, these effects can be relevant in populations with limited dietary diversity.

Glucosinolates

Found in cruciferous vegetables (e.g., broccoli, cabbage), glucosinolates can hinder iodine absorption by competing with iodide uptake in the thyroid, thereby affecting iodine status and potentially causing goiter (Mithen, 2001). This mechanism illustrates indirect inhibition of mineral utilization through interference with metabolism rather than gut absorption.

Together, these naturally occurring food constituents may reduce the efficiency of vitamin and mineral uptake in the human digestive system. Although normal food preparation methods (e.g., soaking, cooking, fermentation) can mitigate these effects, anti-nutrients remain a concern in plant-based diets that rely heavily on raw or unprocessed foods (Gibson et al., 2010).

Naturally Occurring Enhancers of Vitamin and Mineral Absorption

While several naturally occurring food components inhibit nutrient absorption, others can significantly enhance the bioavailability of vitamins and minerals. These compounds function by improving solubility, protecting nutrients from degradation, facilitating active transport, or modifying the intestinal environment. Key enhancers include vitamin C, dietary fats, heme iron, certain amino acids, and fermentation byproducts such as organic acids.

Vitamin C and Non-Heme Iron Absorption

Vitamin C (ascorbic acid) is one of the most potent enhancers of non-heme iron absorption. It reduces ferric iron (Fe^{3+}) to the more soluble ferrous form (Fe^{2+}) and forms stable complexes that remain soluble in the alkaline environment of the small intestine (Teucher et al., 2004). These complexes prevent the precipitation of iron and reduce the inhibitory effects of phytates and polyphenols (Hurrell & Egli, 2010). Human studies have consistently shown that adding ascorbic acid to meals increases iron absorption two- to threefold, particularly in plant-based diets (Hallberg et al., 1989).

Dietary Fat and Fat-Soluble Vitamins

Fat is essential for the absorption of fat-soluble vitamins—namely vitamins A, D, E, and K. These vitamins are incorporated into micelles in the presence of dietary fat and bile salts, which are then absorbed in the small intestine (Reboul, 2017). Even small amounts of fat (as little as 3–5 g per meal) significantly improve the absorption of these vitamins (Tang et al., 2005). Moreover, the type of fat may influence bioavailability; unsaturated fats tend to be more effective than saturated fats (Haskell et al., 1999).

Heme Iron

Heme iron, found in meat, poultry, and fish, is absorbed much more efficiently than non-heme iron from plant sources. It is taken up intact by specific heme transporters in the small intestine, bypassing inhibitors such as phytates and tannins (Hurrell & Egli, 2010). In mixed meals, the presence of heme iron can also enhance the absorption of non-heme iron—a phenomenon known as the "meat factor" (Conrad & Umbreit, 2000). This synergistic effect makes animal-based sources of iron particularly valuable in diets at risk of iron deficiency.

Fermentation and Organic Acids

Fermentation of plant-based foods produces organic acids such as lactic acid, which can increase mineral solubility and reduce the inhibitory effects of phytates. Lactic acid, in particular, enhances non-heme iron and zinc absorption by lowering intestinal pH and forming soluble mineral complexes (Lopez et al., 2003). For example, fermented cereals and sourdough breads have been shown to improve iron bioavailability compared to their unfermented counterparts (Leenhardt et al., 2005).

Amino Acids and Peptides

Certain amino acids and small peptides can form soluble complexes with minerals, especially zinc and calcium, facilitating their transport across the intestinal mucosa. For example, cysteine and histidine have been shown to increase zinc bioavailability, while casein phosphopeptides derived from milk proteins enhance calcium absorption (Heaney et al., 2001; Sandström, 1997). These peptide-mineral complexes protect minerals from forming insoluble precipitates and enhance their uptake via specific transporters.

Synergistic Food Combinations

Combining foods that contain enhancers with those that contain inhibitors can significantly influence nutrient uptake. For instance, consuming citrus fruits rich in vitamin C alongside iron-fortified cereal can offset the inhibitory effects of phytates (Hallberg & Hulthén, 2000). Similarly, pairing fat-soluble vitamin-rich vegetables (e.g., carrots or spinach) with oil or avocado enhances carotenoid and vitamin K absorption (Unlu et al., 2005).

DISCUSSION

The absorption of vitamins and minerals from food is a complex, highly regulated physiological process influenced by a range of intrinsic and extrinsic factors. This review has shown that the chemical composition of food specifically the presence of inhibitors and enhancers plays a critical role in determining nutrient bioavailability. Understanding these interactions is essential for optimizing dietary strategies to prevent micronutrient deficiencies.

One of the most consistent findings across the literature is the dual role of plant-based diets. While rich in vitamins and essential minerals, these diets often contain high levels of anti-nutritional factors such as phytates, oxalates, tannins, and lectins (Gupta et al., 2015; Kumar et al., 2019). These compounds bind minerals or interfere with intestinal absorption, particularly affecting iron, zinc, and calcium. For instance, phytates reduce the bioavailability of iron and zinc by forming insoluble complexes (Frontela et al., 2008), while oxalates impede calcium uptake (Noonan & Savage, 1999).

Conversely, the presence of natural enhancers in food can significantly offset these negative effects. Ascorbic acid (vitamin C) enhances non-heme iron absorption by reducing Fe^{3+} to Fe^{2+} and forming soluble complexes (Teucher et al., 2004). Similarly, dietary fat is crucial for the absorption of fat-soluble vitamins, while fermentation (e.g., sourdough or lactic acid fermentation) improves mineral bioavailability by degrading phytates (Leenhardt et al., 2005). These mechanisms underline the importance of food synergy: how the combination of foods within a meal can enhance or impair nutrient absorption (Hallberg & Hulthén, 2000; Unlu et al., 2005).

Interestingly, traditional food preparation methods such as cooking, soaking, and fermentation—often overlooked in modern diets have evolved precisely to reduce anti-nutrients and improve nutrient availability. For example, sourdough fermentation lowers pH and activates endogenous phytase enzymes that degrade phytate, significantly increasing iron absorption from whole grain bread (Lopez et al., 2003). This traditional knowledge is supported by modern nutritional science and has practical implications for food fortification programs and dietary guidelines.

Moreover, the interaction between nutrients themselves can influence absorption. Calcium and iron compete for absorption at high doses, while certain amino acids promote mineral uptake by forming soluble complexes (Heaney et al., 2001; Sandström, 1997). Therefore, dietary patterns should consider not just the amount of nutrients consumed, but their chemical context within a meal.

Overall, a deeper understanding of these interactions can support public health interventions to improve micronutrient status especially in populations relying on plant-based diets or facing food insecurity. Nutrition education, meal planning, and food fortification programs should integrate knowledge of food composition and nutrient bioavailability to be truly effective.

CONCLUSION

The chemical composition of food is a key determinant of vitamin and mineral absorption in the human body. This review has highlighted how naturally occurring substances in food such as phytates, oxalates, and polyphenols can significantly inhibit nutrient absorption, while others such as vitamin C, dietary fats, heme iron, and organic acids enhance it. These interactions emphasize the importance of not only what we eat but how we combine, prepare, and process our food.

Given the global prevalence of micronutrient deficiencies, especially iron, vitamin A, and zinc, addressing bioavailability is crucial. Strategies that consider both inhibitors and enhancers are likely to be more effective than those based on nutrient content alone.

Recommendations

1. Nutrition policies should emphasize meal composition that includes both nutrient-rich foods and bioavailability enhancers (e.g., pairing legumes with vitamin C-rich fruits).
2. Soaking, fermenting, and cooking should be encouraged, especially for plant-based foods, to reduce anti-nutritional factors.
3. Food fortification programs must consider both the form of the nutrient and the food matrix to ensure absorption. For instance, using chelated forms of iron or adding ascorbic acid to iron-fortified foods.
4. Awareness campaigns should teach the public how to enhance nutrient absorption using everyday food choices such as drinking citrus juice with iron-rich meals.
5. More clinical and population-based studies are needed to understand how common food pairings impact long-term nutrient status.

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