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Chemical transformations of nutrients during food processing: A review

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Abstract
Food processing is indispensable for safety, shelf life, palatability, and convenience, yet it profoundly affects the chemical integrity of nutrients. Vitamins, minerals, proteins, lipids, and phytochemicals undergo transformations that may either diminish nutritional quality or improve bioavailability. This review highlights key chemical mechanisms driving nutrient changes during processing, including oxidation, isomerization, Maillard reactions, hydrolysis, and interactions with the food matrix. We examine both detrimental losses such as degradation of vitamin C and heat-labile B vitamins and beneficial transformations, such as enhanced carotenoid bioaccessibility after cooking. Advances in processing technologies, including high-pressure processing, encapsulation, and controlled thermal treatments, offer strategies to minimize nutrient losses. Understanding these transformations is essential for optimizing food design, fortification, and dietary recommendations to ensure nutritional adequacy and consumer health.

Keywords: Bioavailability, bioaccessibility, human health, nutrition, foods, fortification

1. Introduction

Food processing ensures safety and accessibility, but it also modifies nutrient composition through chemical, enzymatic, and physical changes. Nutrient transformations can result in reduced nutrient density, altered bioavailability, or even the generation of new bioactive compounds. These transformations depend on processing conditions (temperature, oxygen, pH, light, moisture), food matrix characteristics, and nutrient stability. For instance, thermal treatments reduce water-soluble vitamins but may improve digestibility of proteins and bioavailability of certain phytonutrients. Balancing these trade-offs requires a clear understanding of nutrient chemistry within food systems (Zheng *et al*., 2022; Toydemir *et al*., 2022) [20, 19].

Food processing is an essential practice that ensures safety, palatability, shelf-life extension, and consumer acceptability; however, it simultaneously induces a wide range of chemical transformations in nutrients that can profoundly affect the nutritional and functional quality of foods. Nutrients including macronutrients such as carbohydrates, proteins, and lipids, as well as micronutrients such as vitamins and minerals undergo significant modifications when exposed to processing conditions like heating, drying, extrusion, milling, fermentation, freezing, irradiation, and high-pressure treatment. These modifications can be beneficial, neutral, or detrimental, depending on the chemical pathways activated and the intensity of the applied process. For example, thermal processing such as boiling, baking, and frying often leads to the degradation of heat-sensitive vitamins like vitamin C, folate, and thiamine, while simultaneously improving the bioavailability of carotenoids, polyphenols, and certain minerals through cell wall breakdown. Similarly, proteins may undergo denaturation and Maillard browning reactions, which can enhance digestibility in some cases but also generate potentially harmful advanced glycation end-products (AGEs) when uncontrolled. Lipids, being highly susceptible to oxidation, often undergo peroxidation and hydrolysis, leading to rancidity and loss of essential fatty acids, yet certain processing methods like encapsulation and controlled heating can stabilize lipid structures and improve functionality. Carbohydrates also experience transformations during processing; starch granules gelatinize under moist heat, increasing digestibility, whereas retrogradation during cooling can enhance resistant starch formation and promote gut health. At the same time, sugar degradation during thermal treatments contributes to the Maillard reaction and caramelization, creating desirable flavors, aromas, and colors while also producing compounds such as acrylamide, which are undesirable from a toxicological standpoint. Beyond macronutrient modifications, micronutrients are particularly sensitive to processing. Water-soluble vitamins are often lost due to leaching, oxidation, or high thermal stress, whereas fat-soluble vitamins, though relatively more stable, can be degraded by prolonged heating and exposure to oxygen and light. Minerals, on the other hand, are generally stable during processing, but their bioavailability may be altered due to complexation with phytates, oxalates, or changes in the food matrix. Emerging non-thermal technologies like pulsed electric fields, high-pressure processing, cold plasma, and ultrasound are being explored as alternatives that preserve nutrient integrity while ensuring microbial safety, thus addressing consumer demand for minimally processed yet safe foods. Moreover, fermentation and enzymatic treatments can enhance nutrient profiles by increasing the bioavailability of amino acids, peptides, B-vitamins, and organic acids, while simultaneously reducing antinutritional factors such as tannins, phytates, and lectins. These transformations underscore the dual role of processing as both a preserver and modifier of nutrients, highlighting the importance of carefully balancing technological interventions with nutritional outcomes. Understanding the chemistry behind these transformations is therefore critical for food scientists, nutritionists, and industry stakeholders aiming to design processing methods that maximize nutrient retention, minimize harmful compound formation, and enhance the functional and sensory qualities of foods. The modern food system, with its increasing reliance on processed and convenience foods, has magnified the importance of studying these chemical transformations not only from the perspective of food safety and sensory attributes but also in relation to long-term public health implications, particularly in addressing nutrient deficiencies, managing chronic disease risks, and catering to special populations such as infants, the elderly, and those with metabolic disorders. This review thus seeks to provide a comprehensive overview of the chemical transformations of nutrients during different food processing techniques, critically examining both the detrimental losses and beneficial enhancements, while also exploring innovative approaches to mitigate negative effects and promote nutritional security in the evolving global food landscape.

2. Vitamins and Their Susceptibility to Processing

2.1 Vitamin C

Vitamin C (ascorbic acid) is highly unstable, prone to oxidation in the presence of heat, light, or metal ions. Blanching and boiling cause major losses in fruits and vegetables, with degradation rates increasing under alkaline conditions. However, minimal processing methods, refrigeration, and vacuum packaging can slow oxidation (Lee & Kader, 2000) [12].

2.2 B Vitamins

Water-soluble B vitamins (thiamine, riboflavin, folate) are sensitive to thermal and pH changes. Thiamine is particularly heat-labile, while riboflavin is photosensitive. Milling and refining also strip cereals of significant B vitamin content, necessitating fortification programs (Belitz *et al*., 2019) [2].

2.3 Fat-Soluble Vitamins

Carotenoids (precursors of vitamin A) are susceptible to oxidative degradation but may become more bioaccessible after thermal processing due to matrix disruption. Vitamin D and E show moderate heat stability but can be degraded by oxidation in the presence of unsaturated lipids (Zheng *et al*., 2022) [20].

Table 1: Vitamins and Their Susceptibility to Food Processing

Vitamin	Susceptibility to Processing	Major Factors Affecting Stability	Citation
Vitamin A (Retinol, Carotenoids)	Relatively stable to moderate heating but degraded by light, oxygen, and prolonged high temperatures; bioavailability of carotenoids increases with thermal processing.	Heat, oxygen, light, lipid matrix.	Rodriguez-Amaya (1997) [16].
Vitamin D	Stable to heat and most processing; losses occur mainly during oxidation and UV exposure.	Light, oxygen, storage time.	Calvo and Whiting (2013) [4].
Vitamin E (Tocopherols, Tocotrienols)	Susceptible to oxidation during high-temperature processing and storage; losses during frying and refining of oils.	Heat, oxygen, lipid oxidation.	Piironen, Lampi, Ekholm and Salminen (2002) [14].
Vitamin K	Relatively stable to heat, but can degrade with light and alkaline conditions.	Light, alkaline pH.	Booth and Suttie (1998) [3].
Vitamin C (Ascorbic Acid)	Highly sensitive to heat, light, and oxygen; major losses during boiling, blanching, and drying.	Heat, oxygen, pH, water solubility.	Lee and Kader (2000) [12].
Thiamine (Vitamin B1)	Very heat labile; destroyed by thermal processing, leaching, and alkaline conditions.	Heat, pH, water solubility.	Dwivedi and Arnold (1973) [6].
Riboflavin (Vitamin B2)	Fairly stable to heat but extremely sensitive to light.	Light, pH.	Ball (2006) [1].
Niacin (Vitamin B3)	Very stable during heat processing and storage; minor losses through leaching.	Water solubility.	Gregory (1996) [10].
Folate (Vitamin B9)	Extremely sensitive to heat, light, and oxygen; major losses during cooking and storage.	Heat, oxygen, light, pH.	Gregory (2001).
Vitamin B12 (Cobalamin)	Sensitive to microwave and high heat; relatively stable under mild processing.	Heat, microwave radiation.	Herbert (1988) [11].

3. Proteins: Denaturation and Maillard Reaction

Heat treatment denatures proteins, improving digestibility by unfolding tertiary structures, exposing peptide bonds for enzymatic hydrolysis. However, excessive heat can induce Maillard reactions between amino acids (particularly lysine) and reducing sugars, lowering protein quality and essential amino acid availability. On the other hand, Maillard products may also contribute antioxidant activity and desirable sensory attributes (Friedman, 2003) [8].

4. Lipids: Oxidation and Isomerization

Lipids undergo oxidation during processing, forming peroxides, aldehydes, and ketones that compromise flavor and nutrition. Heat treatments and light exposure accelerate lipid peroxidation, particularly in polyunsaturated fatty acids. Hydrogenation converts cis fatty acids into trans isomers, associated with cardiovascular risks. Emerging technologies, such as encapsulation and antioxidants, are applied to stabilize oils and protect essential fatty acids (Shahidi & Zhong, 2010) [17].

5. Minerals: Stability and Interactions

Minerals are chemically stable but can become less bioavailable during processing due to interactions with phytates, oxalates, or fiber. For example, calcium and iron bioavailability decreases when bound to insoluble complexes in cereal processing. Conversely, fermentation and germination can reduce antinutrient content, improving mineral availability (Gibson *et al*., 2010) [9].

6. Phytochemicals and Polyphenols

Polyphenols are sensitive to oxidation, enzymatic browning, and polymerization during processing. For instance, catechins in green tea decline during fermentation to black tea, while anthocyanins degrade with heat. Nevertheless, some transformations produce beneficial metabolites such as enhanced antioxidant capacity of thermally processed tomatoes via isomerization of lycopene from trans to cis forms (Shi & Maguer, 2000) [18].

7. Processing Technologies and Nutrient Preservation

7.1 Thermal Processing

Conventional pasteurization and sterilization extend shelf life but can destroy heat-labile nutrients. Blanching, while reducing vitamin C, inactivates degradative enzymes like polyphenol oxidase, preserving long-term quality.

7.2 Non-Thermal Processing

High-pressure processing, pulsed electric fields, and cold plasma technologies reduce microbial load with minimal nutrient loss. For instance, high-pressure processing retains vitamin C and folate better than conventional heat treatment (Zheng *et al*., 2022) [20].

7.3 Encapsulation and Fortification

Encapsulation technologies stabilize vitamins, omega-3 fatty acids, and probiotics during processing, improving retention and bioavailability. Fortification strategies also mitigate processing losses, as seen in folate-enriched cereals and vitamin D-fortified dairy (Rezagholizade-Shirvan *et al*., 2024) [15].

8. Conclusion

Nutrient transformations during processing are inevitable but not uniformly detrimental. Some processes reduce nutritional value, while others improve bioavailability and functionality. Optimizing processing conditions requires a balance between food safety, shelf life, sensory quality, and nutrient retention. Future research should integrate food chemistry with nutritional epidemiology, focusing on how processing-induced changes translate into long-term health outcomes. Emerging technologies and precision fortification strategies hold promise for minimizing nutrient losses while maintaining consumer acceptance.

Table 2: Chemical Transformations of Nutrients During Food Processing

Nutrient	Major Chemical Transformation	Processing Methods Responsible	Nutritional Consequence	Citation
Vitamin C (Ascorbic Acid)	Oxidation to dehydroascorbic acid and further degradation to diketogulonic acid	Blanching, boiling, drying, storage	Major nutrient loss; reduced antioxidant capacity	Lee & Kader, 2000 [12]
Vitamin A (Carotenoids, Retinol)	Isomerization (all-trans to cis forms), oxidation	Thermal processing (boiling, steaming, frying), exposure to oxygen and light	Decreased provitamin A activity; improved bioavailability of carotenoids in some cases	Rodriguez-Amaya, 1997 [16]
Vitamin E (Tocopherols)	Oxidation to tocopheryl quinones	Frying, oil refining, prolonged heating	Loss of antioxidant properties	Piironen, Lampi, Ekholm, & Salminen, 2002 [14]
Thiamine (Vitamin B1)	Cleavage of thiazole ring; formation of thiochrome	Autoclaving, baking, alkaline conditions	Severe nutrient loss	Dwivedi & Arnold, 1973 [6]
Riboflavin (Vitamin B2)	Photodegradation to lumichrome and lumiflavin	Exposure to light during storage and processing	Reduced bioavailability	Ball, 2006 [1]
Folate (Vitamin B9)	Oxidation and cleavage of pteridine ring	Boiling, canning, storage	Significant folate loss, impaired bioavailability	Gregory, 2001
Vitamin B12 (Cobalamin)	Degradation to hydroxocobalamin and inactive analogs	Microwave cooking, high-heat processing	Lower bioavailability	Herbert, 1988 [11]
Proteins	Denaturation, Maillard reaction with reducing sugars, oxidation of amino acids	Roasting, baking, extrusion, frying	Reduced digestibility; loss of lysine; formation of advanced glycation end products (AGEs)	Friedman, 1996 [7]

Lipids	Oxidation to hydroperoxides, aldehydes, ketones; isomerization of cis to trans fatty acids	Frying, hydrogenation, storage	Loss of essential fatty acids; formation of harmful compounds	Choe & Min, 2006 [5]
Carbohydrates	Starch gelatinization, retrogradation, Maillard browning with proteins	Baking, extrusion, drying	Increased digestibility; formation of acrylamide in high-temperature frying/baking	Mottram, Wedzicha, & Dodson, 2002 [13]

References

1. Ball GFM. Vitamins in foods: Analysis, bioavailability, and stability. Boca Raton: CRC Press; 2006.
2. Belitz HD, Grosch W, Schieberle P. Food chemistry. 5th ed. Springer; 2019.
3. Booth SL, Suttie JW. Dietary intake and adequacy of vitamin K. Journal of Nutrition. 1998;128(5):785-789.
4. Calvo MS, Whiting SJ. Survey of current vitamin D food fortification practices in the United States and Canada. Journal of Steroid Biochemistry and Molecular Biology. 2013;136:211-213.
5. Choe E, Min DB. Mechanisms and factors for edible oil oxidation. Comprehensive Reviews in Food Science and Food Safety. 2006;5(4):169-186.
6. Dwivedi BK, Arnold RG. Chemistry of thiamine degradation in food products and model systems: A review. Journal of Agricultural and Food Chemistry. 1973;21(1):54-60.
7. Friedman M. Food browning and its prevention: An overview. Journal of Agricultural and Food Chemistry. 1996;44(3):631-653.
8. Friedman M. Nutritional consequences of food processing. Journal of Agricultural and Food Chemistry. 2003;51(16):5640-5663.
9. Gibson RS, Bailey KB, Gibbs M, Ferguson EL. A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. Food and Nutrition Bulletin. 2010;31(2):S134-S146.
10. Gregory JF. Vitamins. In: Fennema OR, editor. Food chemistry. 3rd ed. New York: Marcel Dekker; 1996. p. 531-616.
11. Herbert V. Vitamin B12: Plant sources, requirements, and assay. American Journal of Clinical Nutrition. 1988;48(3):852-858.
12. Lee SK, Kader AA. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology. 2000;20(3):207-220.
13. Mottram DS, Wedzicha BL, Dodson AT. Acrylamide is formed in the Maillard reaction. Nature. 2002;419(6906):448-449.
14. Piironen V, Lampi AM, Ekholm P, Salminen T. Tocopherols and tocotrienols in cereal products from Finland. Cereal Chemistry. 2002;79(4):453-457.
15. Rezagholizade-Shirvan A, Amini N, Babazadeh A. Encapsulation of bioactive compounds: Food applications and characterization methods. Food Research International. 2024;172:112-120.
16. Rodriguez-Amaya DB. Carotenoids and food preparation: The retention of provitamin A carotenoids in prepared, processed, and stored foods. Journal of Food Science and Agriculture. 1997;44(1):31-37.
17. Shahidi F, Zhong Y. Lipid oxidation and improving the oxidative stability. Chemical Society Reviews. 2010;39(11):4067-4079.
18. Shi J, Maguer ML. Lycopene in tomatoes: Chemical and physical properties affected by food processing. Critical Reviews in Food Science and Nutrition. 2000;40(1):1-42.
19. Toydemir G, Boyacioglu D, Hall R. Effect of food processing on antioxidants, their activity and bioavailability. Foods. 2022;11(23):3795.
20. Zheng J, Zhou J, Xu Z. The effects of food processing on food components and their bioactivities. Comprehensive Reviews in Food Science and Food Safety. 2022;21(4):3902-3925.