RESEARCH PAPER

Recent updates on dietary bioactives and their mechanism of digestion, absorption and cellular transport – An overview

Anjana Thampy[1]*, Durkalakshmi K.K[1], N Deepa Sathish[2], M Pushpa Devi[3], Sweata Rani Rai[4], Sanjana Kumar[5], and Joy Gethsia[5]

[1]*Assistant Professor, Division of Nutrition and Dietetics, School of Life Sciences, JSS Academy of Higher Education and Research, Ooty, Tamil Nadu, India*
[2]*Associate Professor and Head, Department of Food Processing Technology and Management, PSGR Krishnammal College for Women, Coimbatore, Tamil Nadu, India*
[3]*Assistant Professor, Department of Clinical Nutrition, Kongunadu Arts and Science College, Coimbatore, Tamil Nadu, India*
[4]*Assistant Professor, Department of Food Science & Nutrition Management, J.D. Birla Institute (affiliated to Jadavpur University), Kolkata, West Bengal, India*
[5]*Ph.D. Scholar, Division of Nutrition and Dietetics, School of Life Sciences, JSS Academy of Higher Education and Research, Ooty, Tamil Nadu, India*
***Correspondance at**: dr.anjanathampy@gmail.com*

Received: 24th April, 2026; Revised: 20th May 2026; Accepted: 30th June, 2026; Available Online: 10th July, 2026

ABSTRACT

The significance of a healthy diet for preserving general health has become increasingly apparent in the past couple of decades. Bioactive compounds are phytochemicals that are naturally present in foods and have health benefits that go beyond basic nutrition. They have become an integral part of balanced diet due to added physiological advantages, including anti-inflammatory and antioxidant qualities that help prevent sickness. They are commonly found in plant-based foods such as fruits, vegetables, grains, legumes, and food by-products. Bioactive compounds are commonly present inside complicated food matrices. Key examples of major category include polyphenols, carotenoids, alkaloids, phytosterols, organosulfur compounds, bioactive peptides and more with compounds such as quercetin, catechin, lutein, β-carotene, β-sitosterol, glucoraphanin, allicin, limonene, caffeine, diosgenin, inulin, fructooligosaccharides, omega-3 fatty acids, vitamins C and E, and compounds such as resveratrol and melatonin. Together, these bioactives contribute antioxidant, anti-inflammatory, cardioprotective, anticancer, immunomodulatory, metabolic, and gut health-promoting effects, highlighting their importance in functional foods and disease prevention. This study sets itself apart from previous research by combining key areas of dietary bioactives with a current overview, sources, functions, classification, with an emphasis on the mechanisms of digestion, absorption and cellular transport aspects into a single exhaustive framework.

Keywords: Bioactives, Polyphenols, Disease, Food, Health, Nutrition

How to cite this article: Thampy A, Durkalakshmi KK, Sathish ND, Devi MP, Rai SR, Kumar S, Gethsia J, Recent updates on dietary bioactives and their mechanism of digestion, absorption and cellular transport – An overview. Int J Drug Deliv Technol. 2026;16(6): 715-729. DOI: 10.25258/ijddt.16.6.110
Source of support: Nil.
Conflict of interest: None

INTRODUCTION

Bioactive compounds are phytochemicals that are naturally present in foods and have health benefits that go beyond basic nutrition. Phenolic acids, flavonoids, anthocyanins, carotenoids, and other secondary metabolites are examples of these chemicals. They are commonly found in plant-based foods such as fruits, vegetables, grains, legumes, and food by-products. In contrast to required nutrients like carbohydrates, proteins, lipids, vitamins, and minerals that support fundamental metabolic processes and give energy, bioactive compounds provide added physiological advantages, including anti-inflammatory and antioxidant qualities that help prevent sickness[1]. Higher levels of bioactive chemicals are found in outer structural layers such peels, pericarp, aleurone layers, bran, and shells, where they are usually present in bound forms. Bioactive compounds are commonly present inside complicated food matrices[2]. According to Bortolini et al., 2022, the bioaccessibility of these compounds, which governs their release during digestion, is equally as crucial to their health consequences as their concentration. It has been proven that processing procedures, including extrusion, milling, germination, and moderate heat treatments, break up the food matrix and enhance the release and bioaccessibility of bound phenolic compounds. The potential of bioactive chemicals to modulate oxidative stress, inflammation, and metabolic pathways is substantially tied to their biological activity[3]. It has been

**Author for Correspondence: dr.anjanathampy@gmail.com*

established that polyphenols and related phytochemicals prevent oxidative damage at the cellular level by effectively scavenging reactive oxygen species (ROS) and reactive nitrogen species (RNS)[4]. Further, it has been demonstrated that bioactive compounds can influence glucose metabolism, cause apoptosis in abnormal cells, and inhibit essential metabolic enzymes like lipase and α-amylase[5]. The value of bioactive compounds is especially obvious in plant-based and vegan diets, where they are crucial in decreasing the risk of chronic diseases like cancer, diabetes, and heart disease[6].

In addition, current research emphasized that the rising usage of bioactives in functional foods is a reflection of their relevance in preventive nutrition; by 2025, the worldwide functional food market is estimated to expand to a value of roughly USD 275.77 billion. The increasing need for meals augmented with health-promoting bioactive compounds is demonstrated by this market increase. In order to enhance nutritional quality and enable scientifically supported health claims, bioactive compounds are increasingly being used in the manufacturing of functional foods[3]. Betancur-Ancona et al., 2025 demonstrated that meals' functional characteristics are improved by adding dietary fibres and polyphenols, while Belen et al., 2025 shown that processing methods including encapsulation, extrusion, and germination enhance the stability and bioaccessibility of bioactives in products like snacks, beverages, and baked goods. Basic nutritional profiling has given way to more complex research on bioactive compounds that includes genotype-specific variability, processing optimization, and biological validation through in vitro and in vivo investigations[1]. Aguirre-Rodriguez et al., 2024 emphasized the sustainable valorization of underutilized crops and agri-food by-products, particularly from Andean and Asian nations, highlighting current research trends that connect functional food innovation with sustainability goals[7]. When considered collectively, these findings demonstrate the importance of bioactive compounds in food for preserving human health, averting illness, and creating future dietary strategies.

This review uniquely integrates all the major dietary bioactives, sources, classification and functional role as well as mechanisms of digestion, absorption and cellular transport. It encompasses a recent overview, delivering an exhaustive framework.

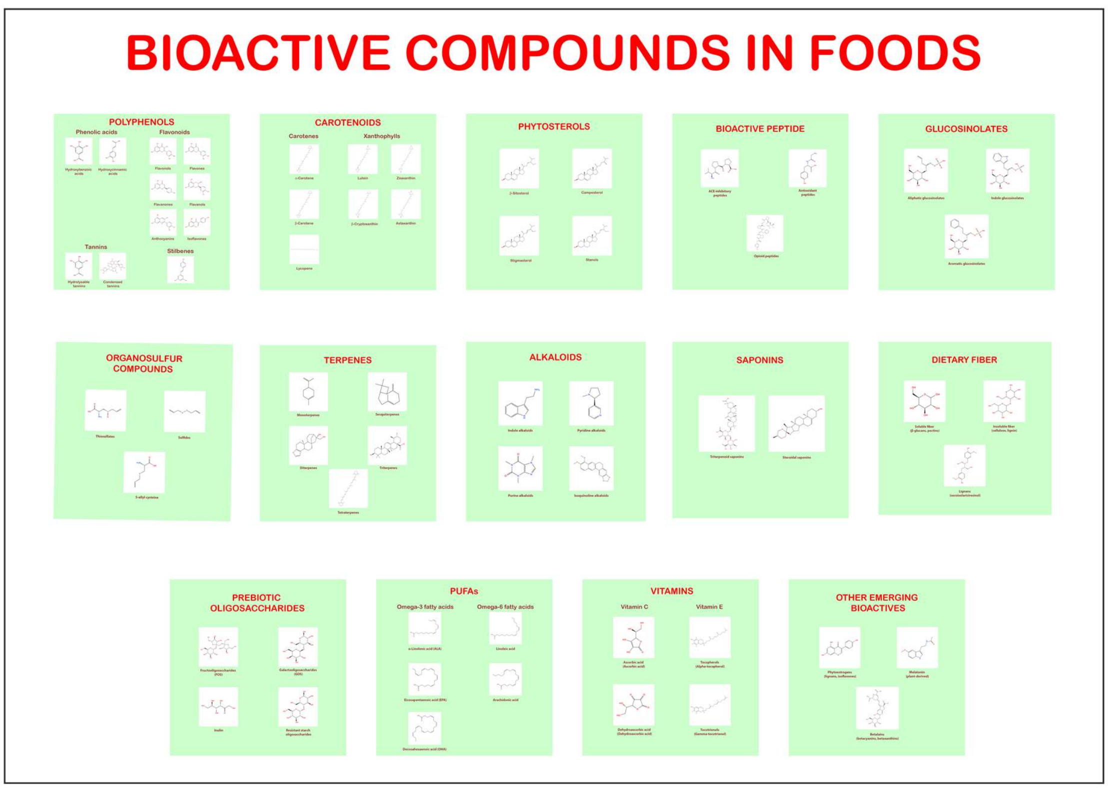

Figure 1. Framework of bioactive constituents

Bioactive Constituents in Food

Figure 1 presents a comprehensive overview of major bioactive constituents found in foods along with their representative chemical structures. It highlights the structural diversity of bioactives responsible for various health-promoting functions. Major bioactives are categorized into polyphenols (flavonoids, phenolic acids, lignans) with strong antioxidant properties; carotenoids such as β-carotene and lutein, which function as antioxidants and vitamin A precursors; phytosterols that reduce cholesterol absorption; bioactive peptides with antioxidant, antimicrobial, and antihypertensive effects. Other key groups include glucosinolates, organosulfur compounds, terpenes, alkaloids, saponins, all researched for their pharmacological and protective effects. Dietary fibres, and prebiotic oligosaccharides are known to support gut health and microbiota balance, while polyunsaturated fatty acids (PUFAs), vitamins (E and C), and other emerging bioactives contribute antioxidant, anti-inflammatory, cardioprotective, anticancer, immunomodulatory, metabolic health effects. Food-derived bioactive compounds, their origins, and functional properties are summarized in Table 1 below.

Table 1. Sources and functional role of bioactives

Class	Compounds	Sources	Functional Role	Reference
Polyphenols	**Phenolic acids:** Hydroxybenzoic acids, such as vanillic acid and gallic acid	Cruciferous veggies	Phenolic acid is easily absorbed and has a low molecular weight.	(Agagunduz et al., 2022)[8]
		Ziziphora tenuior, Ferulago angulata, and Bunium persicum essential oils (measured as GAE)	Oxidation inhibition and antioxidant activity	(Mohammadi et al., 2021)[9]
		Pulses: faba beans, red kidney beans, black beans, pinto beans, navy beans, chickpeas, yellow split peas, green split peas, and red and green lentils	Antioxidant characteristics	(Sanchez-Velazquez et al., 2021)[10]
		Bark of Syzygium cumini (gallic acid)	Antioxidant	(Pai et al., 2022)[11]
	Phenolic acids: Hydroxycinnamic acids, such as caffeic and ferulic acids	Cruciferous veggies	Antioxidant; prevent DNA damage and carcinogen-DNA binding	(Agagunduz et al., 2022)[8]
		Ferulic acid: bran	Ferulic acid is an antidiabetic since it inhibits α-amylase/glucosidase	(Mounika et al., 2022)[12]
		Brans cereal (ferulic acid)	Antimicrobial, antioxidant, anti-inflammatory, and health-promoting properties	(Gil-Martin et al., 2022)[13]
	Flavonoids: Flavonols (kaempferol, quercetin)	Cruciferous veggies	Cause apoptosis, prevent cell division, and have anti-inflammatory and antioxidant capabilities.	(Agagunduz et al., 2022)[8]

		Z. tenuior, F. angulata, and B. persicum essential oils (measured as QE)	Activity of antioxidants	(Mohammadi et al., 2021)[9]
		Onion peels (quercetin); apple pomace (quercetin, catechins)	Antimicrobial, antioxidant, anti-inflammatory, and health-promoting properties	(Gil-Martin et al., 2022)[13]
		BSA nanoparticles loaded with quercetin and casein micelles loaded with both curcumin and quercetin	Enhanced stability and antioxidant activity; enhanced bioavailability and anticancer effect	(Mohammadian et al., 2020)[14]
		Acer okamotoanum (afzelin, isoquercitrin, and quercitrin); kaempferol (directly tested chemical)	Decreased triglycerides; prevented lipid buildup and adipogenesis	(Sandner et al., 2020)[15]
		Fruits, veggies, tea, and chocolate	Reduce inflammation, blood pressure, insulin resistance, and lipid profiles	(Kussmann et al., 2023)[16]
	Flavonoids: Flavones (apigenin, luteolin)	Cruciferous veggies	Antioxidant; cause apoptosis and stop the growth of malignant cells	(Agagunduz et al., 2022)[8]
		Dried flower powder from Hangbaiju (Chrysanthemum morifolium Ramat)	Antioxidant, anti-inflammatory, anti-hypertensive, and anti-cancer actions are among the health-promoting qualities	(Song et al., 2022)[17]
	Flavonoids: Flavanones (naringenin, hesperidin)	Citrus peels (naringin, hesperidin)	Antimicrobial, anti-inflammatory, antioxidant, and health-promoting qualities	(Gil-Martin et al., 2022)[13]
		Caenorhabditis elegans was used to evaluate hesperidin.	Reduced buildup of fat	(Sandner et al., 2020)[15]
	Flavonoids: Flavanol (epigallocatechin gallate, catechin)	Apple pomace (catechins)	Antimicrobial, anti-inflammatory, antioxidant, and health-promoting qualities	(Gil-Martin et al., 2022)[13]

		Green tea; EGCG examined in Drosophila and C. elegans	Decreased triglycerides, decreased fat storage, and changed lipid metabolism	(Sandner et al., 2020)[15]
		Chocolate and cocoa	Immunological, digestive, and cardiovascular health through anti-inflammatory effects	(Kussmann et al., 2023)[16]
	Flavonoids: Anthocyanins (delphinidin, cyanidin)	Cyanidin-3-glucoside (92.5%); fermented black glutinous rice (also known as tapai)	Anticancer, anti-inflammatory, and antioxidant qualities	(Fauziyah et al., 2023)[18]
		Mashua tubers, particularly those with the purple genotype	Activity of antioxidants	(Coloma et al., 2022)[19]
		wine leftovers	Reduction of oxidative stress and antiviral activity against respiratory infections	(Mounika et al., 2022)[12]
		Anthocyanins found in grape and berry pomace	UV-protective, antibacterial, anti-inflammatory, and antioxidant	(Gil-Martin et al., 2022)[13]
		Anthocyanins (Drosophila test)	Decreased inflammation of the adipose tissue	(Sandner et al., 2020)[15]
		Fruits and vegetables	Colorants (additives for food)	(Pai et al., 2022)[11]
	Flavonoids: Isoflavones (daidzein, genistein)	Cruciferous veggies	Stop Akt signaling and cause colorectal cancer cells to undergo apoptosis.	(Agagunduz et al., 2022)[8]
	Tannins: Tannins that hydrolyze	Black glutinous rice	Anticancer, anti-inflammatory, and antioxidant qualities	(Fauziyah et al., 2023)[18]
		Mashua tubers	Antioxidant and antimicrobial properties	(Coloma et al., 2022)[19]
	Tannins: Proanthocyanidins, which are condensed tannins	Mashua tubers	Antioxidant and antimicrobial properties	(Coloma et al., 2022)[19]
		Pomegranate skin and pineapple peel (fruit by-products)	Antioxidant activity (alterations in DPPH radical scavenging activity linked to	(Saleh et al., 2021)[20]

			polymerization or degradation)	
		Shells of nuts	Antimicrobial, anti-inflammatory, antioxidant, and health-promoting qualities	(Gil-Martin et al., 2022)[13]
	Stilbenes: Resveratrol	Nuts and grapes	Decreases Aβ and tau pathology, activates sirtuins, and encourages nonamyloidogenic APP processing.	(Islam et al., 2022)[21]
		Pomace from grapes	cardiovascular health (prevents atherosclerosis in animal studies, decreases LDL).	(Mounika et al., 2022)[12]
		Resveratrol found in grape pomace and grape skins	Antimicrobial, anti-inflammatory, antioxidant, and health-promoting qualities	(Gil-Martin et al., 2022)[13]
		Fruits, veggies, and tea	Reduce inflammation, blood pressure, insulin resistance, and lipid profiles	(Kussmann et al., 2023)[16]
Carotenoids	**Carotenes:** α-Carotene	Cruciferous veggies	Antioxidant: prevent proliferation and reduce reactive oxygen species	(Agagunduz et al., 2022)[8]
	Carotenes: β-Carotene	Cruciferous veggies	Suppresses NF-κB signaling and triggers apoptosis	(Agagunduz et al., 2022)[8]
		Mashua tubers (yellow genotype highest)	source of provitamin A	(Coloma et al., 2022)[19]
		Beans (pulses), peas, faba beans, and chickpeas	Antioxidant capacity (improvement of AOX, bleaching of β-carotene)	(Sanchez-Velazquez et al., 2021)[10]
	Carotenes: Lycopene	Cruciferous veggies	Antioxidant; suppresses COX-2/ERK1/2 to prevent proliferation	(Agagunduz et al., 2022)[8]
		Lycopene in tomato pomace	Antioxidant and health-promoting qualities	(Gil-Martin et al., 2022)[13]
		Lycopene-encapsulated whey protein isolate nanoparticles	Increased bioavailability	(Mohammadian et al., 2020)[14]

	Xanthophylls: Lutein	Cruciferous veggies	Reduction of reactive oxygen species and antioxidant	(Agagunduz et al., 2022)[8]
	Xanthophylls: Zeaxanthin	Cruciferous veggies	Reduction of reactive oxygen species and antioxidant	(Agagunduz et al., 2022)[8]
Phytosterols	β-Sitosterol	Cruciferous vegetable seed oils	Cardioprotective and anticancer effects	(Agagunduz et al., 2022)[8]
Bioactive Peptides	Peptides that are antioxidants	Human milk and Infant formula (bioactive proteins)	Bioactive proteins with antioxidant properties	(Almeida et al., 2021)[22]
		Pulses (protein hydrolysates from beans, lentils, peas, and chickpeas)	Antioxidant activity and the fight against oxidative damage	(Sanchez-Velazquez et al., 2021)[10]
	Peptides with antimicrobial properties	Human milk and Infant formula (bioactive proteins)	Antimicrobial action against fungus and bacteria	(Almeida et al., 2021)[22]
		Hexaplex trunculus peptides	Antimicrobial action	(Chakraborty and Joy et al., 2020)[23]
	Immunomodulatory peptides	Human milk and Infant formula (bioactive proteins)	Impacts of immunomodulation	(Almeida et al., 2021)[22]
Glucosinolates	Aliphatic glucosinolates	Cruciferous veggies	Cancer-protective qualities that help prevent colorectal cancer	(Agagunduz et al., 2022)[8]
	Indole glucosinolates	Cruciferous veggies	Break down into indoles, which stop tumor growth and spread and cause apoptosis.	(Agagunduz et al., 2022)[8]
	Aromatic glucosinolates	Cruciferous veggies	Bioactive degradation products that have anti-cancer capabilities	(Agagunduz et al., 2022)[8]
Organosulfur Compounds	Sulfides (diallyl disulfide, diallyl sulfide)	Diallyl disulfide with green tea	Reduced expression of lipogenic genes (SREBP-1, FAS, SCD-1)	(Sandner et al., 2020)[15]
Terpenoids	Monoterpenes (menthol, limonene)	Bunium persicum essential oils (also mentioned with BP-EO components)	Antioxidant activity and radical scavenging	(Mohammadi et al., 2021)[9]
		Pectin and whey protein nanofibrils	Enhanced photostability and solubility	(Mohammadian et al., 2020)[14]l., 2022)

		created limonene microcapsules		
		Essential oils	Antimicrobial	(Abedelmaksoud et al., 2025)[24]
	Tetraterpenes (carotenoids)	Cruciferous veggies	Antioxidant; prevent the growth of cancer cells and reduce oxidative stress	(Agagunduz et al., 2022)[8]
		Mashua tubers	Activity of antioxidants	(Coloma et al., 2022)[19]
		Z. tenuior, F. angulata, and B. persicum essential oils	Oxidation inhibition and antioxidant activity	(Mohammadi et al., 2021)[9]
		Pulses (beans, peas, chickpeas, and lentils)	Antioxidant potential	(Sanchez-Velazquez et al., 2021)[10]
		Cakes, biscuits, and papad with wheatgrass powder added	Antioxidant potential	(Halim et al., 2024)[25]
		Pomace from tomatoes (lycopene)	Antioxidant and health-promoting qualities	(Gil-Martin et al., 2022)[13]
		Fiber from cashew apples (Anacardium occidentale L.)	Health-promoting, anti-inflammatory, and antioxidant qualities	(Sucupira et al., 2020)[26]
		Plant-based foods	Anticancer, anti-inflammatory, and antioxidant	(Abedelmaksoud et al., 2025)[24]
Saponins	Triterpenoid saponins	Pulses (beans, peas, chickpeas, and lentils)	Decreased by processing; bioactive substances that are antinutritional	(Sanchez-Velazquez et al., 2021)[10]
Dietary Fiber	Soluble fiber (pectins, β-glucans)	Cruciferous veggies	Lower the risk of colorectal cancer; meta-analyses have demonstrated a protective impact	(Agagunduz et al., 2022)[8]
		Mashua tubers	Promotes intestinal health	(Coloma et al., 2022)[19]
	Insoluble fiber (lignin, cellulose)	Cruciferous veggies	Lower the risk of colorectal cancer; meta-analyses have demonstrated a protective impact	(Agagunduz et al., 2022)[8]
		Mashua tubers	Promotes intestinal health	(Coloma et al., 2022)[19]
	Lignans, such as secoisolariciresinol	Fruits, veggies, and tea	Reduce inflammation, blood pressure, insulin resistance, and lipid profiles	(Kussmann et al., 2023)[16]
Prebiotic	FOS stands for	Human milk	Encourage a healthy	(Almeida et al.,

Oligosaccharides	fructooligosaccharides.	substitutes and infant formula (prebiotics)	microbiome and avoid allergies and atopic dermatitis	2021)[22]
	Galactooligosaccharides (GOS)	Human milk substitutes and infant formula (prebiotics)	Encourage a healthy microbiome and avoid allergies and atopic dermatitis	(Almeida et al., 2021)[22]
		Scarlet runner beans (white Ayocote, purple Ayocote, black Ayocote, Judación de La Granja) are Phaseolus coccineus L.	Prebiotic oligosaccharide levels were supported.	(Redondo-Cuenca et al., 2022)[27]
PUFAs	α-Linolenic acid (ALA) is a kind of omega-3 fatty acid.	Chia oil	Reduced amounts of triglycerides and lipids	(Sandner et al., 2020)[15]
	Eicosapentaenoic acid (EPA) is an omega-3 fatty acid.	Mollusks, such as mussels and oysters	NutritioUS PUFA	(Chakraborty and Joy et al., 2020)[23]
	Docosahexaenoic acid (DHA) is an omega-3 fatty acid.	Human milk and Infant formula (LC-PUFAs)	Development of the brain and eyes; enhanced visual acuity	(Almeida et al., 2021)[22]
	Arachidonic acid is an omega-6 fatty acid.	Human milk and Infant formula (LC-PUFAs)	Development of the brain and eyes; defense against infections and allergies	(Almeida et al., 2021)[22]
Vitamins	Ascorbic acid is vitamin C.	Cruciferous veggies, such as broccoli and kale	Antioxidant; helps prevent cancer	(Agagunduz et al., 2022)[8]
		Mashua tubers	Antioxidant (implied by tests of antioxidant activity); nutritional vitamin	(Coloma et al., 2022)[19]
		Mollusks (total vitamin content)	Nutritious vitamin	(Chakraborty and Joy et al., 2020)[23]
		Fiber from cashew apples (Anacardium occidentale L.)	Health-promoting, anti-inflammatory, and antioxidant qualities	(Sucupira et al., 2020)[26]
	Tocopherols (α, β, γ, δ) are vitamin E.	Cruciferous veggies	Reduce inflammation, produce detoxifying enzymes, and act as an antioxidant	(Agagunduz et al., 2022)[8]
		Mollusks (total vitamin content)	Nutritious vitamin	(Chakraborty and Joy et al., 2020)[23]
	Tocotrienols (α, β, γ, δ) are vitamin E.	Cruciferous veggies	Inhibit NF-κB/STAT3 and COX-2/5-LOX;	(Agagunduz et al., 2022)[8]

			anticancer actions	
Other Emerging Bioactives	Phytosterogens (isoflavones, lignans)	Cruciferous vegetable seed oils	Cardioprotective and anticancer effects	(Agagunduz et al., 2022)[8]
		Fruits, veggies, and tea	Reduce inflammation, blood pressure, insulin resistance, and lipid profiles	(Kussmann et al., 2023)[16]

GAE- Gallic Acid Equivalents, QE- Quercetin Equivalents, BSA- Bovine Serum Albumin, EGCG- Epigallocatechin Gallate, APP- Amyloid Precursor Protein, Aβ- Amyloid Beta, LDL- Low-density Lipoprotein, NF-Kb- Nuclear Factor Kappa-Light-Chain-enhancer of Activated B Cells, COX-2- Cyclooxgenase-2, ERK1/2- Extracellular Signal-Regulated Kinase ½, STAT3- Signal Transducer and Activator of Transcription 3, 5-LOX- 5-Lipoxygenase, ROS- Reactive Oxygen Species, AOX- Antioxidant Capacity, DPPH- 2,2-Diphenyl-1-picrylhydrazyl, FAS- Fatty Acid Synthase, SCD-1- Stearoyl-CoA Desaturase-1, SREBP-1- Sterol Regulatory Element-Binding Protein-1, PUFAs- Polyunsaturated Fatty Acids, ALA- Alpha-Linolenic Acid, EPA- Eicosapentaenoic Acid, DHA- Docosahexaenoic Acid, LC-PUFAs- Long- Chain Polyunsaturated Fatty Acids, FOS- Fructooligosaccharides, GOS- Galactooligosaccharides.

Mechanism of digestion, bioactive absorption, and cellular transport mechanism

The absorption and transportation of bioactive compounds in cells are influenced by interactions within the food matrix, digestion in the gastrointestinal tract, metabolic changes, and factors related to the host. The effectiveness of bioactives relies on how compounds are released from the food matrix, their stability during digestion, absorption in the intestine, metabolism, and uptake by cells. Whole-food matrices that include lipids, proteins, and fibers can protect bioactives from breaking down while also improving their stability, controlled release, incorporation into micelles, and bioavailability. Lipid-rich matrices particularly boost the absorption of fat-soluble compounds like carotenoids and vitamins by aiding micellization and transport in the intestine. In contrast, fibers and certain antinutritional factors may lower bioaccessibility[28.] Furthermore, the nutritional synergy found in whole-food systems tends to enhance bioavailability more effectively than isolated compounds[29]. During digestion in the gastrointestinal tract, bioactive compounds go through a series of changes in the mouth, stomach, intestines, and colon, influenced by digestive enzymes, pH levels, bile salts, and gut microbiota. Studies simulating digestion have shown that conditions in the stomach may initially boost the release of phenolics and antioxidants from fiber and protein matrices, while intestinal conditions often decrease their stability[30]. Digestible carbohydrates break down quickly, while resistant polysaccharides and dietary fibers ferment in the colon, leading to the production of short-chain fatty acids like acetate, propionate, and butyrate. These fatty acids help maintain gut barrier integrity, improve insulin sensitivity, and support a balanced microbiome[31]. Bile acids are also key in digesting and absorbing lipids by improving their solubility and regulating metabolic signaling through FXR and TGR5 receptors[32]. Bioactive absorption mainly happens in the small intestine through methods like passive diffusion, facilitated diffusion, active transport, receptor-mediated transport, paracellular pathways, and endocytosis. Polyphenols typically absorb through passive diffusion, while vitamins, peptides, fatty acids, and glucose-related compounds usually rely on transporter-mediated pathways such as SGLT1 and GLUT2[33]. However, absorption often faces limitations due to low solubility, high molecular weight, hydrophobicity, chemical instability, mucus barriers, enzymatic breakdown, and first-pass metabolism[34.] Glycosylated phenolics generally have lower absorption rates than their aglycone forms, while gut microbiota can further change many compounds into bioactive metabolites that significantly contribute to their physiological effects[35]. After absorption, bioactive compounds undergo extensive phase I and phase II metabolism. This process includes reactions like glucuronidation, sulfation, methylation, hydrolysis, and hydroxylation, resulting in metabolites that often have different functions compared to their parent compounds[36.] Cellular models, including Caco-2, HT-29, and HepG2 cells, show that intestinal and liver tissues are key sites for the biotransformation and transport of bioactives. Phenolic compounds may be absorbed, metabolized inside cells, deconjugated, and then released back into the bloodstream as secondary metabolites. This suggests that circulating metabolites, rather than the original compounds, may drive many biological effects[37]. To improve stability and absorption, new delivery systems have been created. These include nanoencapsulation, nanoemulsions, liposomes, hydrogels, solid lipid nanoparticles, nanostructured lipid carriers, phytosomes, and biopolymer-based carriers. These systems enhance solubility, oxidative stability, interaction with mucosal surfaces, membrane passage, controlled release, and targeted delivery[38]. The mechanisms of release are influenced by diffusion, swelling, enzymatic breakdown, and responses to pH, while factors such as particle size, porosity, hydrophobicity, and matrix composition also affect transport efficiency[33]. Thus, emerging nanotechnology-based strategies present hopeful methods for improving digestive stability, intestinal absorption, cellular uptake, and targeted bioactivity of bioactive compounds derived from food[39]. Figure 2 illustrates the digestion, intestinal absorption, and bloodstream transport of food-derived bioactive compounds. It highlights their cellular uptake and subsequent bioactive effects, including antioxidant, anti-inflammatory, and signaling functions. Digestive processing, cellular absorption pathways, and bioavailability outcomes of food-derived bioactives are presented in Table 2.

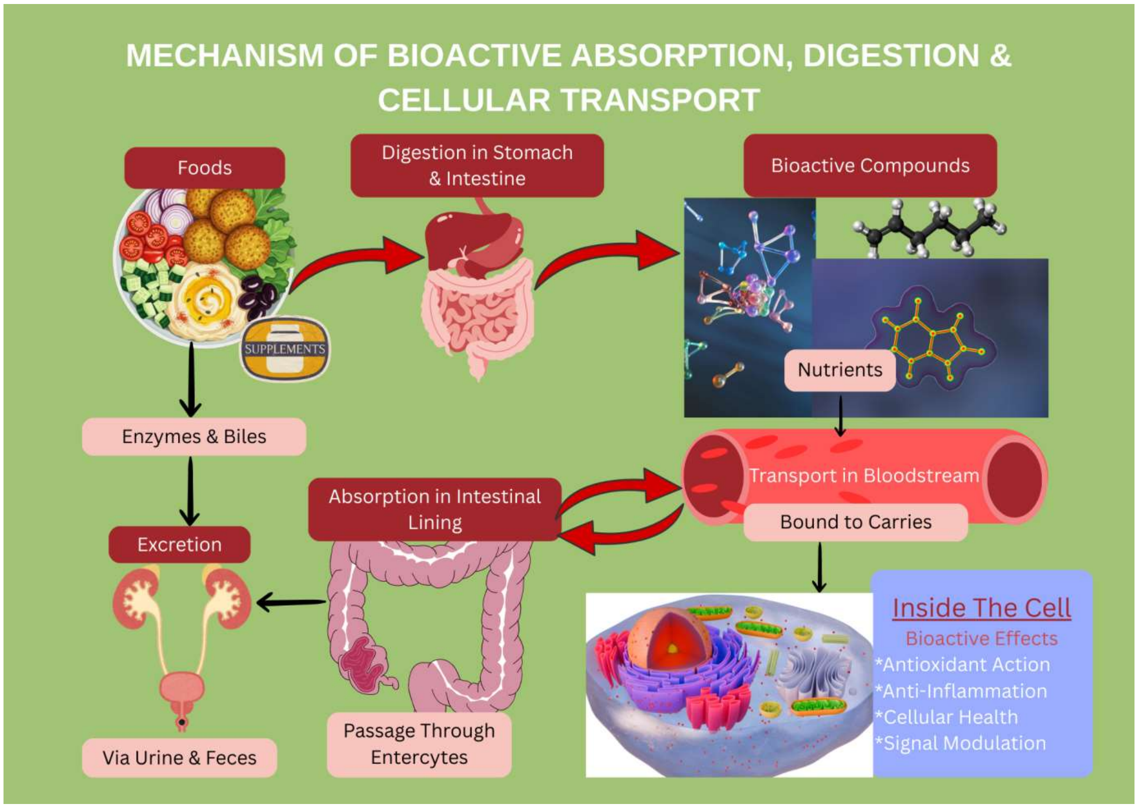

Figure 2. Mechanism of digestion, bioactive absorption, and cellular transport

Table 2. Digestive processing, cellular absorption pathways, and bioavailability outcomes of food-derived bioactives

Bioactive	Digestive Mechanism	Cellular Transport / Absorption Mechanism	Bioavailability Outcomes & Mechanistic	Reference
Krill oil (formulation WPI-CS-KO)	In vitro digestion of the intestines (bile salts, lipase, pH 7.0) and stomach (pepsin, pH 2.5)	Bioactives are protected from intestinal absorption by encapsulation after controlled release	The chitosan shell protects during stomach transit, intestinal bioavailability is 74.36%, WPI makes up the majority of the layer, and antioxidant preservation is enhanced. The gastric bioavailability is below 1.79 percent.	(He et al., 2025)[40]
UAE-ORP polysaccharides	Gastrointestinal fluid simulation	Functions locally in the intestines with low systemic absorption	Fluorescence peaked in the colon after 1–6 hours and persisted for 24 hours; high molecular weight polysaccharides that are stable in the stomach; bioactivity mostly through microbiota modification	(Zhang et al., 2025)[5]

Polyphenols and betalains in beetroot	Simulated digestion (pH and enzyme-mediated release)	Transpithelial transfer of Caco-2	Increased intestinal bioaccessibility; 46–57% absorption; fibers and carbohydrates improve solubility; mycotoxins may enhance absorption by rupturing the gut barrier	(Paula et al., 2025)[41]
β- and α-Asarone	Through oral administration (first-pass metabolism)	Diffusion to the brain, heart, and liver throughout the body	Low oral bioavailability (~5–15%) is caused by rapid metabolism; administration of nanotechnology (SLNs, SMEDDS, mPEG-PLA) increases bioavailability up to five times while reducing toxicity.	(Qiu et al., 2025)[42]
Bioactives of camu-camu	The intestinal, stomach, and oral phases of in vitro digestion	Food matrix-dependent absorption, such as that found in MD or WP	Liquid matrices encourage diffusion, encapsulation stops stomach breakdown, intestinal absorption potential is raised, and protein/fat matrices delay but sustain release	(Garcia-Chacon et al., 2024)[43]
Cruciferous vegetables (broccoli, cabbage, kale, cauliflower, radish, turnip)	Myrosinase hydrolyzes glucosinolates in the gut; when heating renders them inactive, the gut bacteria breaks them down; phenolics hydrolyze to aglycones.	ITCs conjugate with glutathione; phenolics conjugated (methylation, sulfation, glucuronidation); tocopherols absorbed via chylomicrons; carotenoids absorbed via micelles	Carotenoids require dietary fat for absorption; conjugation promotes excretion or circulation; α-tocopherol is selectively retained.	(Agagunduz et al., 2022)[8]
Polyphenol-rich foods (tea, fruits, vegetables, cocoa/chocolate)	Enzymatic hydrolysis in digestion; gut microbiota alters phenolics	Absorption as conjugated forms in plasma	Microbiota modification and antioxidant activity are examples of functional consequences.	(Kussmann et al., 2023)[16]

WPI- Whey Protein Isolate, CS- Chitosan, KO- Krill Oil, WPI-CS-KO- Whey Protein Isolate-Chitosan-Krill Oil formulation, UAE- Ultrasound-Assisted Extraction, ORP-Okra (Abelmoschus esculentus) Residue Polysaccharides, Caco-2- Human Colorectal Adenocarcinoma Cell Line, SLNs- Solid Lipid Nanoparticles, SMEDDS- Self-Micro emulsifying Drug Delivery System, mPEG-PLA- Methoxy Poly(ethylene glycol)-Poly(Lactic acid), INFOGEST-International Network of Food Digestion (standardized in vitro digestion protocol), MD- Maltodextrin, WP- Whey Protein, ITCs- Isothiocyanates, α- Alpha, β- Beta, Ph-Potential of Hydrogen.

CONCLUSION

Food-derived bioactive compounds play a key role in promoting health and preventing disease. They offer benefits such as antioxidant, anti-inflammatory, metabolic, and microbiota-modulating effects. However, the positive impacts of these compounds depend on how well they are digested, absorbed, transported in cells, and their overall bioavailability. These factors are affected by how food interacts with itself, the methods used to process it, conditions in the gut, and individual differences in the host. New technologies in encapsulation, nanodelivery systems, and functional food formulation show promise for improving the stability, release, and absorption of bioactives. There is also increasing evidence about how gut microbiota interacts with food and the importance of personalized nutrition. This emphasizes the need to understand how individual differences affect the metabolism and response to bioactives. Future research should aim to develop standardized models for assessing bioavailability, validate findings through human clinical trials, and explore new bioactive sources in a sustainable way to make the most of their benefits. A solid grasp of these processes will be crucial for creating next-generation functional foods and nutrition strategies that aim to enhance long-term human health.

REFERENCES

1. Betancur-Ancona D, Pérez-Navarrete C, Chel-Guerrero L, Sosa-Crespo I, Sandoval-Peraza VM. Functional, bioactive, and sensory properties of nutraceutical beverages enriched with passion fruit (Passiflora edulis) peel fiber. Food Chemistry Advances. 2025 Jun 1;7. doi:10.1016/j.focha.2025.101005

2. Pejcz E, Tiupova A, Lachowicz-Wiśniewska S, Wiśniewski R, Wojciechowicz-Budzisz A, Harasym J. Mild extrusion enhances bioactive retention and starch digestibility in pigmented corn: Phenotype-dependent effects for functional food development. Innovative Food Science and Emerging Technologies. 2025 Aug 1;104. doi:10.1016/j.ifset.2025.104165

3. Bortolini DG, Maciel GM, Fernandes I de AA, Pedro AC, Rubio FTV, Branco IG, et al. Functional properties of bioactive compounds from Spirulina spp.: Current status and future trends. Food Chemistry: Molecular Sciences. 2022 Dec 30;5. doi:10.1016/j.fochms.2022.100134

4. Sharma S, Kataria A, Singh B. Effect of thermal processing on the bioactive compounds, antioxidative, antinutritional and functional characteristics of quinoa (Chenopodium quinoa). LWT. 2022 Apr 15;160. doi:10.1016/j.lwt.2022.113256

5. Zhang J, Bai Y, Lu K, Sun Y, Li J, ZhuqianWang, et al. Structural characterization, functional properties, bioactivity and oral absorption characterstics of Oudemansiella raphanipies polysaccharides. Food Chem X. 2025 Oct 1;31. doi:10.1016/j.fochx.2025.103076

6. Huda MN, Lu S, Jahan T, Ding M, Jha R, Zhang K, et al. Treasure from garden: Bioactive compounds of buckwheat. Food Chem. 2021 Jan 15;335. doi:10.1016/j.foodchem.2020.127653 PubMed PMID: 32739818.

7. Aguirre-Rodríguez A, Duarte-Casar R, Rojas-Le-Fort M, Romero-Benavides JC. Food uses, functional activities, and bioactive compounds of three Ecuadorian Vasconcellea fruits: Bibliometric analysis and review. J Agric Food Res. 2024 Sep 1;17. doi:10.1016/j.jafr.2024.101244

8. Ağagündüz D, Şahin TÖ, Yilmaz B, Ekenci KD, Duyar Özer Ş, Capasso R. Cruciferous Vegetables and Their Bioactive Metabolites: From Prevention to Novel Therapies of Colorectal Cancer. Evidence-based Complementary and Alternative Medicine. Hindawi Limited; 2022. doi:10.1155/2022/1534083

9. Mohammadi M, Khorshidian N, Gharibzahedi SMT. The Extended Oxidative and Sensory Stability of Traditional Dairy-Based Oil with Steam-Distilled Essential Oils Extracted from the Bioactive-Rich Leaves of Ziziphora tenuior, Ferulago angulata, and Bunium persicum. J Food Qual. 2021;2021. doi:10.1155/2021/6613198

10. Sánchez-Velázquez OA, Ribéreau S, Mondor M, Cuevas-Rodríguez EO, Arcand Y, Hernández-Alvarez ÁJ. Impact of processing on the in vitro protein quality, bioactive compounds, and antioxidant potential of 10 selected pulses. Legume Science. 2021 Jun 1;2(2). doi:10.1002/leg3.88

11. Pai S, Hebbar A, Selvaraj S. A critical look at challenges and future scopes of bioactive compounds and their incorporations in the food, energy, and pharmaceutical sector. Environmental Science and Pollution Research. Springer Science and Business Media Deutschland GmbH; 2022. p. 35518–41. doi:10.1007/s11356-022-19423-4 PubMed PMID: 35233673.

12. Mounika A, Ilangovan B, Mandal S, Shraddha Yashwant W, Priya Gali S, Shanmugam A. Prospects of ultrasonically extracted food bioactives in the field of non-invasive biomedical applications – A review. Ultrasonics Sonochemistry. Elsevier B.V.; 2022. doi:10.1016/j.ultsonch.2022.106121 PubMed PMID: 35987106.

13. Gil-Martín E, Forbes-Hernández T, Romero A, Cianciosi D, Giampieri F, Battino M. Influence of the extraction method on the recovery of bioactive phenolic compounds from food industry by-products. Food Chemistry. Elsevier Ltd; 2022. doi:10.1016/j.foodchem.2021.131918 PubMed PMID: 35085901.

14. Mohammadian M, Waly MI, Moghadam M, Emam-Djomeh Z, Salami M, Moosavi-Movahedi AA. Nanostructured food proteins as efficient systems for the encapsulation of bioactive compounds. Food Science and Human Wellness. Elsevier B.V.; 2020. p. 199–213. doi:10.1016/j.fshw.2020.04.009

15. Sandner G, König A, Wallner M, Weghuber J. Functional foods - dietary or herbal products on obesity: application of selected bioactive compounds to target lipid metabolism. Current Opinion in Food Science. Elsevier Ltd; 2020. p. 9–20. doi:10.1016/j.cofs.2020.09.011

16. Kussmann M, Abe Cunha DH, Berciano S. Bioactive compounds for human and planetary health. Frontiers in Nutrition. Frontiers Media SA; 2023. doi:10.3389/fnut.2023.1193848 PubMed PMID: 37545571.

17. Song G, Liu J, Shui R, Sun J, Weng Q, Qiu S, et al. Effect of steam explosion pretreatment on the composition and bioactive characteristic of phenolic

compounds in Chrysanthemum morifolium Ramat cv. Hangbaiju powder with various sieve fractions. Food Sci Nutr. 2022 Jun 1;10(6):1888–98. doi:10.1002/fsn3.2805

18. Fauziyah N, Ifie I, Syarief O, Darniadi S. Impact of hydrocolloid and foaming agent on the physicochemical, microstructural and bioactive characteristics of foam-mat freeze-dried tapai (fermented black glutinous rice) powder. Food Sci Nutr. 2023 Jan 1;11(1):578–89. doi:10.1002/fsn3.3098
19. Coloma A, Flores-Mamani E, Quille-Calizaya G, Zaira-Churata A, Apaza-Ticona J, Calsina-Ponce WC, et al. Characterization of Nutritional and Bioactive Compound in Three Genotypes of Mashua (Tropaeolum tuberosum Ruiz and Pavón) from Different Agroecological Areas in Puno. Int J Food Sci. 2022;2022. doi:10.1155/2022/7550987
20. Saleh M, Amro L, Barakat H, Baker R, Reyash AA, Amro R, et al. Fruit By-Product Processing and Bioactive Compounds. J Food Qual. 2021;2021. doi:10.1155/2021/5513358
21. Islam F, Khadija JF, Harun-Or-Rashid M, Rahaman MS, Nafady MH, Islam MR, et al. Bioactive Compounds and Their Derivatives: An Insight into Prospective Phytotherapeutic Approach against Alzheimer's Disease. Oxidative Medicine and Cellular Longevity. Hindawi Limited; 2022. doi:10.1155/2022/5100904 PubMed PMID: 35450410.
22. Almeida CC, Mendonça Pereira BF, Leandro KC, Costa MP, Spisso BF, Conte-Junior CA. Bioactive Compounds in Infant Formula and Their Effects on Infant Nutrition and Health: A Systematic Literature Review. International Journal of Food Science. Hindawi Limited; 2021. doi:10.1155/2021/8850080
23. Chakraborty K, Joy M. High-value compounds from the molluscs of marine and estuarine ecosystems as prospective functional food ingredients: An overview. Food Research International. Elsevier Ltd; 2020. doi:10.1016/j.foodres.2020.109637 PubMed PMID: 33233216.
24. Abedelmaksoud TG, Younis MI, Altemimi AB, Tlay RH, Ali Hassan N. Bioactive Compounds of Plant-Based Food: Extraction, Isolation, Identification, Characteristics, and Emerging Applications. Food Science and Nutrition. John Wiley and Sons Inc; 2025. doi:10.1002/fsn3.70351
25. Halim MA, Chowdhury RI, Tahosin A, Rahman MT, Ove TA, Sheikh MM, et al. Exploring bioactive compounds and antioxidant potentials in cake, biscuits, and papad innovations with wheatgrass powder (Triticum aestivum L.). Food Chemistry Advances. 2024 Jun 1;4. doi:10.1016/j.focha.2024.100705
26. Sucupira NR, Sabino LB de S, Gondim Neto L, Gouveia ST, Figueiredo RW de, Maia GA, et al. Evaluation of cooking methods on the bioactive compounds of cashew apple fibre and its application in plant-based foods. Heliyon. 2020 Nov 1;6(11). doi:10.1016/j.heliyon.2020.e05346
27. Redondo-Cuenca A, Pedrosa MM, Sanz MDT, Alvarado López AN, Garcia-Alonso A. Influence of high-pressure processing on nutritional composition and bioactive compounds of Phaseolus coccineus L. J Food Sci. 2022 Dec 1;87(12):5289–302. doi:10.1111/1750-3841.16361 PubMed PMID: 36316801.
28. Debri RP, De Lorenzo A, Conte R, Peluso G. Functional Foods as Vehicles for Bioactive Compounds: Chemical and Nutritional Perspectives on Health and Disease Prevention. International Journal of Molecular Sciences. Multidisciplinary Digital Publishing Institute (MDPI); 2026. doi:10.3390/ijms27052293
29. El-Saadony MT, Saad AM, Mohammed DM, Alkafaas SS, Abd El-Mageed TA, Fahmy MA, et al. Plant bioactive compounds: extraction, biological activities, immunological, nutritional aspects, food application, and human health benefits—A comprehensive review. Frontiers in Nutrition. Frontiers Media SA; 2025. doi:10.3389/fnut.2025.1659743
30. Coelho MC, Ribeiro TB, Oliveira C, Batista P, Castro P, Monforte AR, et al. In vitro gastrointestinal digestion impact on the bioaccessibility and antioxidant capacity of bioactive compounds from tomato flours obtained after conventional and ohmic heating extraction. Foods. 2021 Mar 1;10(3). doi:10.3390/foods10030554
31. Zeng JY, Yang X, Xiao JH, Yang Y, Zhang MS, Liu RM. Recent advances in studying natural bioactive polysaccharides with in vitro gastrointestinal digestion models. Discover Food. Springer Nature; 2025. doi:10.1007/s44187-025-00433-3
32. Wu D, Liu J, Guo Z, Wang L, Yao Z, Wu Q, et al. Natural bioactive compounds reprogram bile acid metabolism in MAFLD: Multi-target mechanisms and therapeutic implications. International Immunopharmacology. Elsevier B.V.; 2025. doi:10.1016/j.intimp.2025.114708 PubMed PMID: 40306110.
33. Rahman M, Teimouri S, Roy PR, Raposo A, Alturki HA, Kasapis S. Strategies for Regulating the Release Kinetics of Bioactive Compounds from Biopolymeric Hydrogels. Gels. Multidisciplinary Digital Publishing Institute (MDPI); 2025. doi:10.3390/gels11120986
34. Sarojini S, Balasubramanian B, Jayaram S, Annadurai P, Meyyazhagan A, Pappuswamy M, et al. Accentuated bioavailability of bioactive compounds

in foods by nanotechnology-based delivery approaches. Quality Assurance and Safety of Crops and Foods. 2026 Jan 1;18:1–22. doi:10.15586/QAS.V18ISP1.1607

35. Nicolescu A, Babotă M, Barros L, Rocchetti G, Lucini L, Tanase C, et al. Bioaccessibility and bioactive potential of different phytochemical classes from nutraceuticals and functional foods. Frontiers in Nutrition. Frontiers Media SA; 2023. doi:10.3389/fnut.2023.1184535

36. Fernández-Moreno P, Villegas-Aguilar M del C, Cádiz-Gurrea M de la L, Herranz-López M, Barrajón-Catalán E, Arráez-Román D, et al. Untargeted metabolomic approach to assess the acute metabolism and urinary excretion of olive leaf bioactive compounds in humans. Food Research International. 2025 Dec 1;222. doi:10.1016/j.foodres.2025.117752 PubMed PMID: 41267315.

37. Aragonès G, Danesi F, Del Rio D, Mena P. The importance of studying cell metabolism when testing the bioactivity of phenolic compounds. Trends Food Sci Technol. 2017 Nov 1;69:230–42. doi:10.1016/j.tifs.2017.02.001

38. Tarahi M, Singh M, Farahnaky A, Ghasemlou M, Dokouhaki M. Plant-based delivery systems for bioactive compounds: Mechanisms of release and functional food applications. Adv Colloid Interface Sci. 2026 Apr;103787. doi:10.1016/j.cis.2026.103787

39. Vieira IRS, Conte-Junior CA. Dietary Bioactive Compounds and Human Health: The Role of Bioavailability. Nutrients . Multidisciplinary Digital Publishing Institute (MDPI); 2025. doi:10.3390/nu17010048 PubMed PMID: 39796482.

40. He Y, Liu B, Ma X, Hu X, Yan W, Wang F. Synergistic enhancement of krill oil stability and bioavailability via whey protein isolate-chitosan dual-layer encapsulation system. LWT. 2025 Jun 1;225. doi:10.1016/j.lwt.2025.117914

41. Paula L, Ana JG, Hannu P, Carlos MJ, Eeva-Riikka V, Cristina J. Role of red beetroot in bread for reducing mycotoxin risks: Bioavailability of beetroot polyphenols and betalains with ochratoxin a, aflatoxin B1 and zearalenone in Caco-2 cells. Food Chem. 2025 Feb 15;465. doi:10.1016/j.foodchem.2024.142036 PubMed PMID: 39561602.

42. Qiu Y, Zhao P, Xu L, Zeng J, Wu D, Yang R, et al. Therapeutic mechanisms of Acorus tatarinowii and its bioactive compounds in cardiovascular diseases: A comprehensive review. Phytomedicine. 2025 Sep 1;145. doi:10.1016/j.phymed.2025.156988 PubMed PMID: 40578036.

43. García-Chacón JM, Rodríguez-Pulido FJ, Heredia FJ, González-Miret ML, Osorio C. Characterization and bioaccessibility assessment of bioactive compounds from camu-camu (Myrciaria dubia) powders and their food applications. Food Research International. 2024 Jan 1;176. doi:10.1016/j.foodres.2023.113820 PubMed PMID: 38163723.