**NANO BIOACTIVE COMPOUNDS IN FOOD DELIVERY SYSTEM**

**Dr K V Sucharitha\* and M Kalavathi\*\***

**\*Associate Professor, \*\*Ph D Scholar, Food Technology**

**Dept. of. Home Science, Sri Venkateswara University, Tirupati.**

Demand of food products with potential benefits to health had increased the scope for identification, extraction and development of products with bioactive compounds called nutraceuticals. The health benefits of these nutraceuticals are in several areas which include immune response, diabetes, cancer, aging, mental health etc. The mechanism and benefits of these compounds in health generally include anti-oxidants and anti–inflammatory activity, inhibition or detoxifying carcinogens and enzyme activity. The present science and industry are interested in designer foods which have these potential compounds with high stability. In the last decade nanotechnology field emerged into fabrication of new forms of nano-sized bioactive compounds with anticipated applications like encapsulation of bioactive compounds with higher stability and bioavailability by the customized release of compounds. Undeniably, the most thrust area of food nanoscience research is stability of bioactive compounds in developing designer foods and deliver of these compounds from food into human body when consumed. The key advantages of nano-nutraceuticals chemistry are improved bioavailability of bioactive compounds and increasing stability of these compounds in foods.

Nutraceuticals were bioactive functional compounds present in natural and processed foods which have positive health outcomes. In recent trends there was enormormous awareness in public on health and drugs. This made a shift in research from pharmaceuticals to nutraceuticals. The functional bioactive components have numerous health benefits directly and indirectly. Recently nanomaterials captured importance in different fields of research, because of its small size and important physico-chemical characteristics.

The applications of nanoparticles in the food industry encompass enhancements in the sensory attributes of foods, such as improving color, flavor, and texture. They also extend shelf life through nano preservation methods without altering the inherent characteristics of the food. Additionally, nanoparticles are employed to enhance the absorption of functional compounds present in the food or through fortification, utilizing structured and targeted delivery systems. Nano materials are high performance materials which have many opportunities for the creation of high performance target delivery systems of encapsulated bioactive systems. Many bioactive/functional food components including peptides, lipids, carbohydrates, vitamins and minerals can have better performance when encapsulated and also by appropriate delivery system.

 Nutraceuticals or pharmaceuticals intended for oral ingestion sometimes have poor bioavailability of bioactive compounds due to number of physiological and physicochemical reactions like less permeability across the cell, absorption in gastrointestinal tract, enzymatic and chemical reactions etc. Oral consumption of lipophilic nature bioactive compounds shows less bioavailability. The efficacies of these compounds depend on the diet composition through which they are consumed. Hence, the potential of these compounds can be increased through nanotechnology-based food delivery systems. Using nanotechnology, the bioactivity and functionality of bioactive compounds can be enhanced.

The present article focuses on important bioactive compounds from food and, their therapeutic benefits. These compounds can be used effectively by applying nano technology

**NANO BIO ACTIVE COMPOUNDS**

# 1. BIOACTIVE LIPIDS

# Lipids are considered as source of energy. As research processed, lipids also play certain important biological functions. Majority of dietary bioactive lipids like fatty acids, phytosterols, phospholipids, carotenoids and fat-soluble vitamins are some which exerts positive health effects. The reviews of health benefits of some of these bioactive compounds discussed.

**1.1. Carotenoids**

Carotenoids consist of approximately 600 diverse compounds responsible for imparting the yellow to red hues found in numerous food items. Carotenoids that contain oxygen atoms are commonly referred to as xanthophylls. Examples of oxygen-containing xanthophylls include lutein and zeaxanthin, while those lacking oxygen are classified as carotenes, like lycopene and β-carotene. The free radicals initiated diseases like atherosclerosis, cataract formation, age-related macular degeneration, and multiple sclerosis was inhibited by carotenoids. The sources of provitamin A are β-carotene, α-carotene, and β-kryptoxanthin. After conversion into vitamin A, these bioactive compounds support in epithelial function, normal vision, embryonic development, and immune system function. Lycopene has the potential to reduce the incidence of prostate, cervical, colon, rectal, stomach, and various other forms of cancer. Lutein and zeaxanthin, which exist in significant quantities within the human eye, have been documented to provide advantages for age-related macular degeneration and cataract prevention. They also diminish the risk factors associated with coronary heart disease, stroke, and breast cancer, and may additionally enhance skin health (Ribaya-Mercado & Blumberg 2004). The safeguarding mechanisms demonstrated by carotenoids encompass (a) antioxidative properties, (b) light-absorbing capabilities for eye health, (c) anti-inflammatory attributes, (d) transformation into active compounds during in vivo metabolism, and (e) involvement in gap junction communication (GJC).

Though carotenoids are antioxidants they do not exhibit the strong antioxidant properties when added to foods. Another functional hurdle when it comes to utilizing carotenoids as components in functional foods is their elevated melting point, causing them to become crystalline at both food storage and body temperatures. Naturally occurring carotenoids within foods typically exhibit stability. When carotenoids are employed as food additives, they tend to be relatively unstable in food systems due to their vulnerability to light, oxygen, and auto-oxidation. Furthermore, the dispersal of carotenoids into ingredient systems can lead to their swift deterioration. Carotenoids may undergo degradation through reactions that result in the loss of double bonds or the cleavage of the molecule. Furthermore, the double bonds within carotenoids have the potential to undergo isomerization, adopting the cis configuration. Isomerization reactions may indeed yield favorable effects, as it is believed that cis isomers of carotenoids, such as lycopene, exhibit enhanced bioavailability and bioactivity, as noted by Schieber and Carle in 2005. To overcome these limitations, delivery systems (nano encapsulation) is an effective technique. This technique helps in increasing the stability in processing and storage conditions and in aqueous based foods.

**1.2. Phytosterols**

The emergence of phytosterol-enriched foods has gained popularity because phytosterols have the capacity to reduce total cholesterol levels and decrease low-density lipoprotein (LDL) cholesterol by inhibiting the absorption of dietary cholesterol, as indicated by Wong in 2001 and Ostlund in 2004. Phytosterols encompass a group of phytochemicals, including compounds like stigma sterol, β-sitosterol, and campesterol. Plant stanols, which occur naturally in smaller quantities than sterols, can be produced through the hydrogenation of phytosterols. In vegetable oils, the concentrations of phytosterols typically vary between 0.1% to 1.0%. The rise in the popularity of fortified foods containing phytosterols is attributable to phytosterols capacity to impede the absorption of dietary cholesterol in humans, resulting in reductions in both total cholesterol and low-density lipoprotein cholesterol levels, as evidenced by studies conducted by Wong in 2001 and Ostlund in 2004.

The absorption of dietary phytosterols in the intestine is minimal, thus posing no adverse health effects. Phytosterols can be integrated into foods, but the challenge lies in their high melting point and propensity to form insoluble crystals. Initially, phytosterols were introduced into high-fat foods, such as margarine, where solubilization and dispersion are relatively straight forward. After consuming phytosterol esters, lipases break down the attached fatty acid, leading to the liberation of unbound phytosterols. Nano encapsulation of phytosterols can prevent oxidation when introduced into products and increase the oxidative stability. Encapsulated Phytosterols can be introduced into aqueous products.

**1.3. Polyunsaturated Fatty Acids**

Polyunsaturated Fatty Acids (PUFAs) play a vital role in maintaining overall well-being, as they cannot be naturally synthesized by the human body. Hence PUFAs should be supplied through diet only. The two main important PUFAs are Omega-3 fatty acids and Omega-6 fatty acids.

* **n-3 PUFA**

Among the dietary n-3 PUFAs, notable examples include α-linolenic acid (ALA, C18:3), eicosapentaenoic acid (EPA, C20:5), and docosahexaenoic acid (DHA, C22:6). n-3. PUFAs have undergone extensive research due to their potential to reduce cholesterol levels, as elevated LDL cholesterol is associated with the onset of cardiovascular disease (CVD). In the last trimester of pregnancy and the initial year of life, high concentrations of DHA can be found in the cell membranes of both the brain and the retina. In a study by Clandinin et al. (1980), and a review conducted by McCann & Ames (2005) on various types of research, it was determined that increases in brain DHA levels were linked to improvements in cognitive or behavioral performance. Both epidemiological observations and experimental findings have provided substantial evidence supporting the advantages of augmenting dietary n-3 PUFAs. These benefits encompass protection against various conditions such as colon, breast, prostate, and pancreatic cancers, as well as stress, anxiety, cognitive decline, mood disorders, diabetic nephropathy, inflammatory bowel disease, Alzheimer's disease, and numerous other ailments.

* **n-6 PUFA**

 The American Heart Association and numerous researchers recommend incorporating 5 to 10% of one's energy intake from n-6 PUFAs to enhance heart health, a topic explored in studies by Kris-Etherton and Harris, along with Ramsden et al. in 2010. Prominent among the dietary n-6 PUFAs are linoleic acid (LA; C18:2), its naturally occurring conjugated counterpart [conjugated LA (CLA)], and arachidonic acid (AA, C20:4). These n-6 PUFAs play a pivotal role in numerous physiological processes, with their derivatives participating in various molecular pathways. The adoption of vegetable oils as part of the diet has led to an upsurge in LA intake.

* **Arachidonic acid**

Arachidonic acid (AA) is an essential compound vital for the development of the mammalian brain and neural tissues, both in preterm and full-term human infants. From the onset of the third trimester until around the age of two years, there is a swift accumulation of arachidonic acid (AA) in the brain. Eicosanoid compounds, among which are prostaglandins, leukotrienes, and lipoxins, serve as precursor molecules to arachidonic acid (AA). These eicosanoids, originating from AA, exert influence over a broad spectrum of physiological processes. Numerous crucial elements of the immune response, including cytokine synthesis, antibody generation, cell maturation, proliferation, movement, and the display of antigens, are under the control of eicosanoids, as indicated by Harizi et al. in 2008. In healthy individuals, arachidonic acid (AA) can be produced through a series of desaturation and elongation reactions that take place within the cell's endoplasmic reticulum, starting from the conversion of linoleic acid (LA).Nevertheless, numerous investigations have documented a limited rate of conversion of AA from LA. At present, there exists no established daily recommended allowance for arachidonic acid (AA). On the other hand, infant formulas enriched with AA are accessible in numerous countries due to mounting evidence indicating the vital necessity of preformed AA in the diets of both preterm and full-term infants.

**1.4 Barriers in the Delivery of Bioactive Lipids in systems**

Important considerations in the delivery of bioactive compounds include:

The bioactive lipids should be active till they reach the site of action, because they undergo changes due to enzymes or acids in the site of their digestion that is in stomach. Another difficulty when integrating these compounds into foods is the poor water solubility of lipids, resulting in the formation of emulsions for delivery.

* The majority of bioactive lipids exhibit limited water solubility, necessitating their inclusion in a delivery system like micro emulsions or emulsions to ensure their efficient dispersion in water-based food products such as beverages, desserts, dressings, and sauces.
* In their pure state, certain bioactive lipids, such as carotenoids, exhibit a crystalline structure at room temperature. The crystalline characteristics of these lipids can pose manufacturing challenges for specific food products, potentially requiring the use of higher temperatures. Additionally, they may have the potential to adversely affect the long-term stability and sensory attributes of the final product.
* The bioactive lipid and its corresponding delivery system must be harmonious with the food matrix, ensuring that they do not detrimentally impact visual appeal, texture, shelf stability, or taste. For instance, when a product contains a bioactive lipid within an emulsion, it may appear cloudy or opaque due to light scattering caused by the droplets. Conversely, when a product incorporates a bioactive lipid within a micro emulsion, it will maintain transparency because the particles are exceptionally small, minimizing light scattering.
* The lipids need to retain their inherent bioactivity throughout the entire lifecycle of the food product, encompassing its production, storage, transportation, and consumption phases. However, certain bioactive lipids are chemically unstable and their efficacy may be compromised by factors like light exposure, oxygen, or pro-oxidants (e.g., ω-3 fatty acids, β-carotene, or lycopene).
* The lipids must retain their bioactivity within the human body until they reach their intended site of action. This may necessitate their ability to withstand the harsh conditions of the stomach, including high acidity and enzymatic activity.

**2. BIOACTIVE PROTEINS, PEPTIDES AND AMINO ACIDS**

**2.1. Bioactive Proteins**

Proteins are indispensable dietary nutrients responsible for a range of vital biological functions, including growth, immune regulation, blood pressure control, antimicrobial activities, anti-oxidative effects, and modulation of food intake. These functions are executed by proteins, peptides, and amino acids.

 Proteins derived from natural sources, including soy, dairy, fish, and meat proteins, have demonstrated bioactive properties. These bioactive effects encompass the inhibition of the angiotensin-converting enzyme (ACE), antimicrobial properties, antioxidant capabilities, anti-carcinogenic attributes, cholesterol-lowering effects, reduction in serum triglyceride levels, promotion of lean muscle mass, defense against pathogens, regulation of blood glucose levels, and satiety-inducing effects. For instance, within dairy proteins, substances like lactoferrin, lactoperoxidase, and immunoglobulins are believed to play pivotal roles in the human immune system, alongside their antibacterial, antiviral, anti-parasitic, and antifungal functions.

**Milk-Derived Bioactive Proteins**

Milk proteins have a range of biological activities. Immunoglobulins have an immunoprotective effect and lactoferrin (Lf) displays antibacterial activity. Low concentrations of growth factors and hormones, mainly present in colostrum, appear to play a significant role in post-natal development. Milk proteins are a rich source of biologically active peptides that are released during GI digestion or food processing. Bioactive peptides have been identified within the amino acid sequences of native milk proteins. Due to their versatility in terms of both physiology and physico-chemical properties, milk peptides are recognized as highly valuable components for creating health-enhancing foods. Milk proteins, specifically casein and whey proteins; provide a rich source of these bioactive peptides. In particular, alpha casein, beta casein, kappa casein, alpha lactalbumin, beta lactoglobulin, and lactoferrin play crucial roles. Numerous ACE-inhibitory peptides have been identified either through in vitro enzymatic digestion of milk proteins or the chemical synthesis of peptide analogs. These peptides offer potential benefits in controlling blood pressure. Peptides derived from alpha-s-casein exhibit a range of advantages, including the ability to scavenge free radicals and inhibit both enzymatic and non-enzymatic lipid peroxidation. Their multifunctional properties make them promising candidates for various health-promoting applications.

**Lactoferrin**

Lactoferrin (Lf), an 80 kDa glycoprotein abundantly found in milk and various body fluids, serves as a vital link between innate and adaptive immunity. Its multifaceted protective effects encompass anti-cancer, anti-inflammatory, immune modulation, and potent antimicrobial properties against diverse microorganisms. This red protein from milk was first isolated by Groves in 1960 and is not restricted to milk but found in various human and animal tissues. Initially, Lactoferrin antimicrobial function was attributed to iron sequestration from bacterial pathogens. However, subsequent research unveiled its ability to combat microorganisms independently of iron by directly interacting with bacterial cell surfaces. This iron-independent interaction extends its efficacy to strains of Haemophilus influenzae and Streptococcus mutans. Moreover, Lf showcases antiviral activity against a wide array of RNA and DNA viruses, affecting both humans and animals, including enveloped viruses like herpes simplex virus (HSV). Intriguingly, Lactoferrin exhibits a comprehensive range of antimicrobial actions, effectively targeting bacteria, fungi, viruses, and parasites through diverse mechanisms. It disrupts the cell surfaces of bacteria and certain fungi, resulting in their demise. Furthermore, Lf complements the effectiveness of antiparasitic drugs. Beyond its role in infection control, this remarkable glycoprotein has displayed promising anti-tumor properties, substantiated by laboratory research and human clinical trials, hinting at its potential significance in both cancer prevention and treatment. Lactoferrin is important in treating hepatitis-C and may help Alzheimer's patients. It safeguards against gut infections, boosts the immune system, and can stop certain harmful bacteria from growing, such as those needing lots of iron, like coliforms. It also fights against bacteria like Staphylococcus aureus, Listeria monocytogenes, and different Bacillus types.

Lactoferrin showcases impressive antiviral capabilities, particularly in relation to papillomaviruses that are linked to cervical cancer. It is also noteworthy that camel milk lactoferrin demonstrates therapeutic potential in treating hepatitis C, making it a valuable component in traditional medicine. Additionally, lactoferrin has shown promise in preventing small intestine tumors and protecting against bone damage. Furthermore, it has a significant role in the treatment and maintenance of skin infections. One study involved fortifying fermented milk with lactoferrin to address acne vulgaris, with promising results in a group of 18 subjects aged 18 to 30 who consumed 200 mg of lactoferrin daily for 12 weeks.

**Immunoglobulins**

The role of immunoglobulins found in colostrum and milk is to offer immunological defense to the calf as its own immune system develops, shielding it from environmental pathogens and toxins. Additionally, these immunoglobulins serve to safeguard the udder against infections. A crucial function of milk immunoglobulins is their ability to hinder the adhesion of pathogenic microorganisms to surfaces like epithelial cell linings or mucous membranes, which stands as a pivotal mechanism in host protection. Furthermore, immunoglobulins play a role in binding and neutralizing toxins. In many cases, bacterial toxins need to be transported via receptors inside host cells to induce cell damage, and immunoglobulin binding can thwart this internalization process.

**2.2 Bioactive Peptides**

Peptides are generated from proteins through processes such as hydrolysis, which can occur during the processing of protein-rich foods using methods like fermentation or enzymatic treatment. Alternatively, this process can also take place within the human digestive system post-food consumption, often catalyzed by acids or enzymes.

* **Soya bean**

Soy proteins offer an abundant and cost-effective source of protein with high nutritional value and exceptional functional properties. Beyond their role as dietary protein, the Soy hydrolysate and the soy-fermented foods on digestion generate oligopeptides, derived from glycinin, a soy protein. On digestion provides a peptide with ACE inhibitory activity and a peptide with, anti-thrombotic activity which resembles hirutonin. They exhibit a range of health benefits, including antihypertensive, anticholesterolemic, antioxidative, and anticancer activities. The presence of lunasin, a peptide derived from soybean cotyledon, has been associated with potential anticancer and anti-inflammatory effects. Peptides derived from soy potential in developing new drugs and functional food ingredients. Their bio functional properties make them particularly interesting for promoting gut health and modulating the absorption of nutrients in the intestine. Soybean peptides with diverse biological activities include hypo lipidemic, anti-diabetic, anti-hypertensive, anti-cancer, antioxidant, anti-inflammatory, immunostimulatory, and neuromodulator properties, as evidenced in various experimental models.

* **Meat and fish**

Peptides derived from meat and fish have demonstrated their ability to lower blood pressure and exhibit antioxidant properties in living organisms. Additionally, these peptides display various bioactivities like antimicrobial and anti-proliferative effects when tested in laboratory settings. Peptides with antihypertensive properties that act as ACE inhibitors have garnered significant interest in the prevention and treatment of hypertension. They offer a promising avenue to enhance well-being, potentially replacing synthetic drugs with novel nutraceuticals or pharmaceuticals. Proteolytic enzymes obtained from various sources, including plants, animals, and microbes, are valuable tools for breaking down marine fish products to yield bioactive peptides. Antioxidant peptides were obtained from sardinelle waste using a crude enzyme extract from sardines. Among these peptides, Leu-His-Tyr displayed the highest capacity for scavenging DPPH radicals, with the His-Tyr sequence contributing significantly to its antioxidant activity.

Oyster digestion produced a bioactive peptide with the sequence Leu-Lys-Gln-Glu-Leu-Elu-Asp-Leu-Leu-Glu-Kys-Gln-Glu, demonstrating the ability to prevent lipid peroxidation and counteract hydroxyl and superoxide radicals, suggesting that shellfish can be a source of gastrointestinal antioxidant peptides. Bioactive peptides from marine fish, particularly those acting as ACE inhibitors, hold potential as therapeutic options for preventing hypertension. Their incorporation into future pharmaceuticals is a hopeful prospect.

Bioactive peptides can be generated from meat proteins through various methods, including hydrolysis, cooking, and fermentation. These peptides can arise during food processing or be produced from precursor meat by-products, facilitated by microbial fermentation or chemical/enzymatic hydrolysis employing proteolytic enzymes derived from animals, microorganisms, or plants. Numerous bioactive peptides are identified in various meat types such as chicken, bovine, pork, duck, and mutton. These bioactive peptides are inherently embedded within the primary protein structure but can be liberated when exposed to digestive enzymes, either in vitro or in the gastrointestinal tract. On a laboratory scale, bioactive peptides can be obtained through acid, alkali, or enzymatic hydrolysis. Subsequent steps involve fractionation and purification processes to yield enriched peptide fractions. Numerous antioxidant peptides have been identified in meat and meat by-products. Notably, carnosine and anserine are well-known for their antioxidant properties, as they possess free radical scavenging and metal chelating abilities in meat.

Animal blood is a valuable source of proteins (circa 20%) and represents a promising source of bio active peptides. Serum albumin was hydrolyzed by trypsin in different concentrations and the peptide sequences in the hydrolysates has angiotensin-converting enzyme (ACE) inhibition (antihypertensive activity), DPP-IV inhibition (glucose regulation), and anti-oxidation activities.Antihypertensive activity of the novel peptides Arg-Pro-Arg from nebulin and Lys-Ala-Pro-Val-Ala and Pro-Thr-Pro-Val-Pro from titin, identified in the digest of pork meat after oral administration to spontaneously hypertensive rats (SHR). The peptide Arg-Pro-Arg showed the greatest activity in vivo. This suggest that pork meat constitute a source of bioactive compounds that could be utilized in functional foods or nutraceuticals (Escudero et al., 2012).

Marine algae, sponges, tunicates, ascidians, coelenterates, and mollusks have all been the subject of research when it comes to their chemistry and biological effects, as discussed in a study by Cheung et al. in 2015. Among these, marine algae are particularly intriguing due to their high protein content, which can reach up to 47% of their dry weight, depending on the specific species. This has piqued significant interest in these organisms as potential sources of bioactive peptides (BP). Marine algae, or macroalgae, possess intricate and unique metabolic pathways that result in the production of various bioactive organic compounds. These compounds encompass proteins, linear and cyclic peptides, depsipeptides, peptide derivatives, amino acids, and amino acid-like components. Although some bioactive peptides derived from macroalgae proteins have been identified and characterized, there remains a wealth of unexplored potential in these proteins as sources of bioactive peptides. These bioactive peptides hold promise as functional foods, offering specific health benefits and disease-preventing properties, particularly in the context of their antihypertensive effects, as highlighted by Harnedy and Fitzgerald in 2012. Bioactive peptides (BP) that have been isolated and identified from crustaceans play a crucial role in regulating a wide array of physiological functions. These functions include controlling color changes, heart activity, and the function of exoskeletal and visceral muscles, metabolic processes, development, metamorphosis, and reproduction.

The proteins obtained from these marine organisms serve as a distinctive source of raw materials for the production of bio functional peptides. Predicting the relationship between a peptide chemical structure and its activity is a complex task. A peptide activity is intricately tied to its structural features, such as the amino acid composition, the specific N and C-terminal amino acids, the length of the peptide chain, the charge characteristics of the constituent amino acids, and the hydrophobic or hydrophilic nature of the amino acid sequence, among other factors.

Peptides with higher ACE (angiotensin-converting enzyme) inhibitory activity often possess aromatic or basic amino acids at the N-terminal end and a greater proportion of hydrophobic and positively charged amino acids at the C-terminal end, ( Li and Yu in 2015). Bioactive peptides can be absorbed from the intestine and transported via the circulatory system to target sites, exerting their bioactivity. Alternatively, they can have localized effects within the digestive system.

Chicken meat contains bioactive compounds, such as carnosine and anserine, which serve essential roles in regulating intracellular pH (pH-buffering activity), inhibiting oxidation, and contributing to neurotransmitter functions. Chicken muscle is a source of various bioactive peptides, recognized for their anti-hypertensive, antioxidant, and antibacterial effects.

Glutathione, also known as γ-glutamyl-L-cysteinylglycine, is a naturally synthesized peptide found in the cytoplasm. It is widely distributed across various organs in the body, where it plays a vital role in maintaining cellular functions. Notably, glutathione serves as a potent antioxidant and contributes to detoxification processes

Sour milk has been identified as a source of bioactive peptide ACE inhibitors. Notably, the enzymatic hydrolysis of whey protein concentrate (WPC) serves as a specific example. Bioactive peptides are the result of protein breakdown by proteases found in the gastrointestinal tract. Their unique bio functions only come into play once they are liberated from their parent protein sources. Consuming fermented milk with bioactive peptides (BP) can lower blood pressure in people with hypertension. Specifically, a fermented milk product called L. helveticus LBK-16H, enriched with biologically active peptides Valyl-Prolyl-Proline (Val-Pro-Pro) and Isoleucyl-Prolyl-Proline (Ile-Pro-Pro), and has proven to reduce blood pressure in spontaneously hypertensive rats (SHR). Additionally, two other peptides (Tyr-Pro and Lys-Val-Leu-Pro-Val-Pro-Gln) from fermented milk have ACE inhibitory effects in hypertensive rats. These blood pressure-lowering properties are also found in certain whey protein-derived tetra peptides, namely α-lactorphin (Tyr-Gly-Leu-Phe) and β-lactorphin (Tyr-Leu-Leu-Phe). Moreover, two additional peptides, Tyr-Pro and Lys-Val-Leu-Pro-Val-Pro-Gln, isolated and characterized from fermented milk, demonstrate ACE inhibitory effects in SHR. Additionally, Lactorphin (Tyr-Gly-Leu-Phe) has been found to lower blood pressure in both individuals with normal blood pressure and SHR

The enzymatic breakdown of milk proteins has yielded a diverse array of biologically active peptides, including opioid peptides, immunostimulating peptides, and angiotensin I-converting enzyme (ACE) inhibitors. For instance, casein, a prominent milk protein, can generate various bioactive peptides, particularly ACE-inhibitory peptides, when acted upon by trypsin within the intestinal tract.

**Caseinophosphopeptides (CPP)**

For instance, casein phosphopeptides (CPP) represent a category of peptides known for their calcium-binding affinity. These specific peptides have exhibited diverse bioactive properties, including the protection of teeth against demineralization, as well as demonstrating antioxidant, antimicrobial, anti-cancer, and immuno-stimulatory effects. Additionally, peptides sourced from milk, plants, and fish have been scientifically validated for their ability to reduce blood pressure, as demonstrated by Muir in 2005. Antibacterial peptides from casein inhibit various bacteria, including Streptococcus mutans, Streptococcus sanguis, Porphyromonas gingivalis, Streptococcus sobrinus, Staphylococcus aureus, Escherichia coli, and Salmonella typhimurium. Casein-αs1 digestion with chymosin generates caseicin A and caseicin B, which effectively inhibit pathogens like Staphylococcus, Sarcina, Bacillus subtilis, Diplococcus pneumoniae, and Streptococcus pyogenes.

Derived from enzymatic digestion of casein, caseinophosphopeptides (CPP) have been shown to improve calcium solubility and potentially enhance intestinal calcium absorption. These peptides play a crucial role in various food products, including breakfast foods, bread, pastries, bean curds, chocolate, and caramel, juices, boiled fish, tea, and mayonnaise.

The ability to bind to calmodulin, a protein, was observed in certain peptides obtained from the digestion of bovine casein. These peptides were able to inhibit an enzyme called CaM-dependent phosphodiesterase (CaM-PDE). Some of the noteworthy peptides with calmodulin-binding properties include LKKISQRYQKFALPQY, VYQHQKAMKPWIQPKTKVIPYVRY, VYQHQKAMKPWIQPKTKVIPYVRYL, VYQHQKAMKPWIQPKTKVIPYVRY, VYQHQKAMKPWIQPKTKVIPYVRYL, AMKPWIQPKTKVIPYVRYL, and KPWIQPKTKVIPYRYL.

The production of bioactive peptides can often be a costly process, mainly due to challenges in upscaling and the necessity for expensive isolation, purification, and characterization technologies when dealing with large-scale production.

Cereal grains like wheat, barley, rice, rye, oat, millet, sorghum, and corn, which have been staples in human diets for a considerable time, are abundant sources of bioactive peptides (BP). Among these grains, wheat and oat have been found to contain ACE inhibitory peptides, dipeptidyl peptidase inhibitors, and peptides with various beneficial properties, including anti-thrombotic, antioxidant, hypotensive, and opioid activities. The stones found in fruits like plums (Prunus domestica L.) also contain substantial amounts of proteins and could serve as an economical source of bioactive peptides (BP) and have the potential to be valuable for applications in the food and pharmaceutical sectors.

Wheat, oat, barley, and rice grains have been examined for bioactive peptides, revealing a high prevalence of ACE-inhibitor peptides and peptides that inhibit dipeptidyl peptidase. These grains also exhibit properties related to anti-thrombotic, antioxidant, hypotensive, and opioid activities. Notably, wheat and rice proteins contain sequences with potential anticancer effects. Among the cereal proteins, wheat and barley stand out for their broad diversity and abundance of bioactive peptide sequences. Further investigation is needed to understand the mechanisms by which these biologically active peptide sequences are released from cereal grains

2,5-Diketopiperazines (DKPs), which are cyclic dipeptides, have garnered significant interest as bioactive substances. They can be generated from the N-terminal amino acid components of linear peptides or proteins and have been detected in a range of food products. Notably, they are found in items like roasted coffee, cocoa, roasted malt, chicken essence, as well as in fermented foods including beer, the distillation remnants of awamori, and aged sake.

It is widely recognized that eggs contain a variety of compounds that have the potential for therapeutic benefits, extending beyond their role in meeting basic nutritional needs (Zambrowicz et al., 2011). The bioactive peptide Arg-Val-Pro-Ser-Leu, derived from egg white protein, was chemically synthesized and subjected to bioassays, which demonstrated its ability to inhibit ACE and maintain stability during simulated gastrointestinal digestion.

**2.3. Amino Acids**

Amino acids have demonstrated specific biological functions. Tryptophan and tyrosine are amino acids that serve as precursors for the synthesis of neurotransmitters such as serotonin and dopamine. Both of these amino acids are associated with mood alterations, with tyrosine, in particular, being linked to diminished stress responses in humans. Additionally, the branched-chain amino acids—leucine, isoleucine, and valine—play significant roles in various essential brain functions, including those related to tryptophan and tyrosine

**2.4 Challenges**

The primary obstacles related to the delivery of bioactive proteins, peptides, and amino acids within food matrices include: When integrating bioactive compounds into food products, it is crucial to ensure that they do not compromise the sensory qualities of the food. This is particularly important since specific bioactive peptides and proteins can impart a bitter or astringent taste sensation, which may restrict their use in certain food items. The bioactivity of particular proteins can diminish throughout the food production, storage, transportation, and consumption process, as well as during extraction, purification, or thermal treatment of food. The most important step is the delivery of the bioactive proteins or peptides at the action site with the potential form.

# 3. Bioactive Carbohydrates

Dietary fibers represent the primary category of bioactive carbohydrates. The expression 'dietary fiber' encompasses a diverse group of substances, encompassing non-digestible carbohydrates and lignin. Bioactive carbohydrates play an excellent role in encapsulation of other bioactive compounds. Soluble, non-digestible polysaccharides derived from natural sources like whole grains, fruits, and vegetables can be extracted and incorporated into food items, or they can be encapsulated for targeted delivery.

**3.1. Starch**

 Starch, the primary storage polysaccharide of plant origin, is composed of glucose units connected by α-d-(1→4) and/or α-d-(1→6) linkages. This biodegradable and biocompatible polymer is composed of amylose and amylopectin. Starch-based nanoparticles have been employed to encapsulate substances like insulin, flaxseed, unsaturated fatty acids, and flavors. To improve its capacity for encapsulating hydrophobic bioactive compounds, researchers have developed hydrophobic derivatives of starch, including dialdehyde starch and propyl starch nanoparticles. Starches that have undergone alterations, such as Octenyl Succinic Anhydride (OSA) modification and acetylation, are being employed for the encapsulation of food and pharmaceutical substances, taking advantage of their enhanced hydrophobic properties and increased stability. PEGylated (Polyethylene glycol) starch acetate nanoparticles with a hydrophobic core are used for enhanced oral insulin delivery, showcasing improved encapsulation efficiency. These advancements highlight the versatility and potential of modified starch and carbohydrate-based systems. Amylose molecules can form co-crystals with a range of lipophilic compounds, including long-chain alcohols, aromatic substances, lipids, and surfactants. In this process, amylose creates helical structures that contain hydrophobic pockets, which are well-suited for encapsulating water-insoluble food bio actives with particular molecular shapes. Recent research has emphasized that the characteristics of amylose complexes, including their structure, physicochemical properties, susceptibility to amylase digestion, and release patterns, are influenced by the chemical properties of the encapsulated molecules. Notably, starch stands out for its cost-effectiveness and relatively pure composition, avoiding the complex purification processes required by some other biopolymers. However, starch's susceptibility to acid degradation and enzymatic hydrolysis, especially in the oral cavity, is a notable limitation. Nevertheless, adjustments can be made to create starch variants that are resistant to acid or enzyme degradation.

**3.2. Cellulose**

 Cellulose, a plentiful natural polysaccharide made up of glucose units connected by β-d-(1→4) bonds, can be subject to alterations to produce appropriate encapsulation structures, even though it naturally possesses limited water solubility and substantial dimensions. Nanocrystalline cellulose (NCC), obtained through acid hydrolysis, has garnered interest for its simple preparation and potential use of agricultural waste materials. Cellulose esters, divided into non-enteric and enteric categories, offer options for controlled release. Non-enteric esters such as acetate, acetate butyrate, and cellulose acetate propionate exhibit restricted water solubility, whereas enteric esters like cellulose acetate phthalate (CAP) or hydroxypropyl methyl cellulose phthalate (HPMCP) dissolve effectively in solutions with a slightly acidic to mildly alkaline pH range, making them suitable for targeted colon delivery. Enteric cellulose esters have been explored for nanocapsules to preserve bioactivity and prevent degradation of compounds like lutein. Pectin, another polysaccharide, has been utilized for nano-scale delivery systems, with pectin nanospheres produced using cross-linking agents. However, calcium pectinate carriers may have limitations in terms of entrapment efficiency and rapid release of bioactives. Techniques like high-intensity ultrasound have been proposed to enhance encapsulation efficiency.

**3.3. Guar gum**

Polysaccharide composed of mannopyranosyl units connected by 1→4 linkages and galactopyranosyl units connected by 1→6 linkages. It functions as a thickener, emulsifier, and retrogradation retardant in food. Guar gum possesses the ability to withstand enzymatic degradation until it reaches the colon, indicating its potential utility as a vehicle for drug delivery, as highlighted by studies. Modification is often Guar gum, derived from the seeds of Cyamopsis tetragonolobus, is a water-soluble needed due to native guar gum's high viscosity. De polymerization via methods like acid, enzyme, or heat hydrolysis, microwave degradation, and ultrasonication results in low molecular weight, water-soluble dietary fiber. Such depolymerized guar gum can improve flavor retention and be enhanced further by grafting with polyacrylamide to address hydration and thermal stability concerns.

**3.4. Chitosan**

Chitosan, obtained by deacetylating chitin, is a biocompatible and biodegradable polymer with a wide range of uses within the food industry. It possesses both antimicrobial and antioxidant attributes. Furthermore, it has the capacity to bind to dietary fats and prolong its presence in the digestive system, thus proving valuable for controlled release applications. Chitosan's pH-dependent solubility (acidic pH < 6.5) allows for modification through physical or chemical means. An ionic-gelling method produces chitosan-tripolyphosphate particles for controlled bioactive release. Amphiphilic chitosan derivatives encapsulate hydrophobic materials, while glycol chitosan (GCH) nanoparticles enhance water solubility and release properties, especially for acid-sensitive bioactives. These advancements enhance chitosan's potential as a versatile carrier.

**3.5. Alginate**

Alginate, sourced from marine brown algae, undergoes gelation when exposed to divalent cations, resulting in a structure reminiscent of a gel. Alginate beads cross-link through a grid-like configuration, with applications in delivering acid-sensitive bioactives. Hydrogel nanoparticles composed of alginate are generated through modified techniques. Alginate calcium particles have encapsulated lipid nanoparticles, lipase, and turmeric oil, while challenges include leaching and rapid dissolution. Combining alginate with chitosan nanoparticles addresses burst release in intestinal conditions.

**3.6. Dextran**

Dextran, a bacterial glucan polysaccharide, possesses hydroxyl groups for attaching organic functional groups. Modified dextran with adjusted degree of substitution forms self-organized nano-scale particles, offering potential for encapsulating substances with varying hydrophobicities. However, biodegradability decreases with hydrophobic group substitution, although ester links promote degradation in biological environments. While there is potential, there is a scarcity of literature on the utilization of modified dextran for nanoencapsulation of food bioactives.

**3.7 Cyclodextrins (CDs):**

Cyclodextrins (CDs) are ring-shaped oligosaccharides with hydrophilic outer surfaces and hydrophobic inner cavities, making them effective for enveloping bioactive compounds that are poorly soluble, sensitive to temperature, or prone to instability. α-, β-, and γ-CDs offer varying encapsulation capacities. These versatile compounds have found application in the encapsulation of antimicrobial agents, antioxidants, essential oils, and flavor compounds. Modifications such as hydroxypropyl β-cyclodextrin (HP-β-CD) have been developed to enhance water solubility and biocompatibility. Additionally, novel polysaccharides sourced from unconventional origins, such as Balangu and wild sage seeds, exhibit potential for encapsulation. These polysaccharides possess a combination of hydrophobic and hydrophilic properties, making them suitable for encapsulating a wide range of food-related bioactive compounds. However, further investigation is necessary to fully comprehend their structural characteristics and explore their potential in tailored delivery systems.

The functional benefits of bioactive compounds are presented in the above section. The challenges of utilization or bioavailability of these compounds depends on the food matrix along which they are consumed. The research says most of these substances are not effective due to inhibit activities of other nutrients. The Nano technology emerged as an effective mechanism for these substances as Nano sized and as controlled delivery systems through Nano encapsulation. The next section of this chapter concentrates on the review of different Nano delivery systems of bioactive compounds for therapeutic applications.

**4. NANO DELIVERY SYSTEMS**

Nanodelivery systems are categorized into liquid and solid forms. The liquid systems include nano emulsions, nanoliposomes, and nano polymersomes and Solid systems include lipid nanoparticles, polymeric nanoparticles, and nanocrystals. Nanoemulsions consist of immiscible liquids stabilized by surfactants, while liposomes are lipid structures suited for hydrophilic and hydrophobic molecules. Polymersomes, similar to liposomes, use polymers for encapsulation. Nanocrystals boost solubility and interaction with cells. Solid Lipid Nanoparticles (SLNs) and Nanostructured Lipid Carriers (NLCs) provide controlled release and stability, while polymeric nanoparticles include nanospheres and nanocapsules, serving as protective carriers. These systems find applications in food and medicine, enhancing stability, solubility, and controlled release of bioactives.

**4.1. Nanostructured Approaches for Encapsulating Bioactive Lipids**

Nanotechnology offers a remedy for enhancing the management, durability, and efficiency of bioactive lipids via miniature delivery systems on the nanoscale. These nanoscale systems excel in some situations over traditional methods because of their small size and larger surface area. Numerous nanoscale delivery systems based on lipids have been created, each featuring distinctive designs aimed at protecting and conveying bioactive lipids. These systems vary in terms of their composition, structure, and functionality. Factors like size, shape, charge, composition, and how they group together can be customized for specific tasks. This context delivers into several commonly employed nanoscale delivery systems for bioactive lipids.

**4.2. Nanoemulsions**

Oil-in-water nanoemulsions comprise small oil droplets (typically under 200 nm in size) coated with emulsifying agents, dispersed within an aqueous solution. These droplets can entrap bioactive lipids either prior to or after the formation of the nanoemulsion. They are produced using food-grade oil, water, and emulsifiers through either low- or high-energy techniques. Low-energy processes result in the formation of small droplets as conditions are altered, whereas high-energy methods involve the use of devices such as homogenizers to disintegrate oil and water into tiny droplets. Various food-grade emulsifiers like proteins, polysaccharides, and biosurfactants prevent droplet merging. Nanoemulsions are resistant to separation, though they can enlarge through Ostwald ripening, especially with soluble oils. Careful design with ripening inhibitors is needed to counter this. Nanoemulsions and microemulsions share traits but differ in stability and preparation. Microemulsions are more stable but often rely on synthetic surfactants, which isn't ideal for food uses.

**4.3. Nanostructured Solid Lipid Particles and Lipid Carriers**

Lipid-based Nanoparticles are minuscule lipid particles enveloped by emulsifiers, giving rise to crystalline structures capable of safeguarding and managing the release of bioactive lipids. However, there's a risk of migration to the surface during crystallization, affecting stability. Also, shape changes can cause aggregation. Nanostructured lipid carriers (NLCs) overcome this challenge by employing a combination of solid and liquid lipids, enhancing the solubility and structural integrity of bioactive lipids. Careful lipid and emulsifier choice is crucial for optimal performance.

 **4.4. Nanoliposomes**

Nanoliposomes are tiny lipid nanoparticles (below 200 nm) with concentric lipid bilayers formed by phospholipids in water. The polar heads face outwards, and the non-polar tails create hydrophobic areas that can hold bioactive lipids. Techniques such as coating-solvent evaporation and "homogenization" are employed to produce nanoliposomes, with the latter being more suitable for large-scale commercial production.

**4.5. Nanostructured Biopolymer Gels and Fibers**

Nanostructured biopolymer gels and fibers are created for the encapsulation of bioactive lipids. Nanogels refer to tiny particles rich in biopolymers dispersed in water. They form a network that captures water because of hydration and capillary forces. Bioactive lipids can be either directly enclosed or loaded into lipophilic nanocarriers within this interconnected structure. Nanofibers are thin crosslinked biopolymer fibers made through electrospinning, where bioactive lipids are incorporated in the biopolymer solution. These advancements improve the stability and delivery of bioactive lipids, finding applications in the fields of food processing and packaging.

**4.6. Emulsions Stabilized by Nanoparticles in the Pickering Style**

Pickering Emulsions of the Oil-in-Water Type comprise tiny oil droplets encased within food-grade nanoparticles, making them efficient carriers for bioactive lipids. Appropriate nanoparticles encompass nanocellulose, nanochitin, nano-starch, protein-based nanoparticles, and SLNs. Bioactive lipids can be encapsulated within either the oil droplets or the stabilizing nanoparticles themselves. The creation of nanoscale delivery systems involves high- or low-energy techniques like homogenization, sonication, spontaneous emulsification, and phase inversion. Common systems like nanoemulsions, SLNs and NLCs can be produced using methods involving both high and low energy. Nanoliposomes can be formed through a variety of processes, while alternative methods like nano-spray drying and freeze drying produce powders loaded with nanoparticles. Each of these systems comes with its own advantages and disadvantages that need to be taken into account for specific food applications.

**4.7. Nano-Delivery Systems Utilizing Protein from Food Sources**

Proteins derived from food sources, such as caseins and whey proteins, exhibit valuable functional attributes like emulsification, gelation, and foaming, rendering them excellent choices for developing nano carriers for the safe delivery of drugs or nutraceuticals. These protein-based nanocarriers offer benefits like biodegradability, lack of antigenicity, and binding capabilities for various compounds. Caseins, forming micelles with unique structures, have been explored for encapsulating hydrophobic compounds, while whey proteins like β-lactoglobulin have shown potential for binding hydrophobic molecules. These proteins can be harnessed for oral delivery systems, exploiting their stability against digestion enzymes. Gelatin, derived from collagen, offers versatility and has been used to create nanoparticles for drug delivery. Overall, protein-based nanocarriers present promising options for delivering bioactive substances in food and pharmaceuticals.

**4.8. Nano-Delivery Systems Utilizing Polysaccharides**

Polysaccharides, which are essential constituents in various foods, provide a wide array of advantages owing to their flexible structures and the potential for digestion at specific sites. These characteristics render them suitable as carriers for precise and controlled delivery of drugs or nutraceuticals within the gastrointestinal system. Their attributes include biocompatibility, stability, and bioadhesion on mucosal surfaces, allowing specific delivery and extended retention. Polysaccharides like chitosan, derived from de acetylated chitin, stand out as effective carriers. Chitosan's cationic nature and biodegradability enable improved absorption of active compounds, making it valuable for applications in food, cosmetics, and pharmaceuticals. Chitosan nanoparticles have shown promise in efficient drug delivery, utilizing interactions with anions like tripolyphosphate to form microgel particles. Controlled release of bioactives like tea catechins and curcumin has been achieved using chitosan-based nanoparticles. Composite nanoparticles incorporating chitosan, alginate, and pluronic polymers have demonstrated cytotoxicity against cancer cells. Additionally, chitosan-based amphiphiles have been developed, presenting a structured network for potential applications. Overall, polysaccharide-based nanocarriers, particularly chitosan, offer a promising avenue for enhancing drug and nutraceutical delivery with potential implications across various fields.

**4.9 Nanodelivery Systems Involving Complexes of Polysaccharides and Proteins (Peptides)**

Proteins sourced from food, including casein, gelatin, whey proteins (particularly β-lactoglobulin), and casein phosphopeptides (CPP), have the potential to serve as candidates for nanocarriers due to their biodegradability, absence of antigenicity, nutritional value, and drug-binding attributes. Nevertheless, their susceptibility to enzymatic breakdown within the digestive tract presents a hurdle when considering oral administration. On the other hand, non-starch polysaccharides such as alginate, pectin, dextran, and chitosan possess advantageous qualities for oral delivery, including resilience to gastric conditions, resistance to enzymatic degradation, and the ability to adhere to mucosal surfaces. Biopolymer nanoparticles can be created by orchestrating controlled self-assembly, primarily guided by the electrostatic attractions between protein and polysaccharide components with opposite charges. pH variations influence the complexation and phase separation of these biopolymer systems, offering the potential for controlled drug delivery. Strategies involving β-lg and chitosan or pectin have demonstrated the formation of hydrogel particles with varying sizes and behaviors in response to different pH conditions. These approaches show promise for delivering water-insoluble and sensitive bioactive compounds within transparent liquid systems. Combining chitosan with proteins like α-lactalbumin or β-lg has also been explored as a means to create potential carriers for bioactive substances.

**4.10 Nanoparticles Combining Polysaccharides and Peptides**

Utilizing proteins for nano-complexes may raise allergy concerns, prompting the use of bioactive peptides as a safer alternative. An innovative nano-complex was developed from casein phosphopeptide (CPP), sourced from milk casein protein, and chitosan. CPP, resistant to digestion and possessing various benefits, formed hierarchical nanocomplexes with chitosan based on electrostatic interactions and hydrophobic bonding. These nanocomplexes offer potential as secure drug and functional food ingredient carriers. Additionally, CPP was employed to crosslink chitosan and bind with Epigallocatechin gallate (EGCG), resulting in well-dispersed nanoparticles that efficiently entrapped EGCG. This method demonstrated improved encapsulation efficiency and controlled release of EGCG compared to previous approaches. Protein-based nanoparticles are gaining traction for drug and bioactive delivery in the food industry, enhancing solubility, stability, and bioavailability of encapsulated compounds. These nanoparticles can extend residence time in the gastrointestinal tract and enable targeted delivery. Soy protein based nano particles, owing to their natural composition and compatibility with bio actives offer advantages such as ease of fabrication, controlled release, and cost- effectiveness making them a promising choice for a variety of applications.

Nanoparticles derived from soy protein, created using different methods, hold potential as vehicles to improve the solubility, stability, and bioavailability of bioactive compounds with low solubility, such as curcumin, phytosterols, coenzyme Q10, resveratrol, and vitamin D3. Nanostructured emulsions using soy proteins as stabilizers offer effective transport for lipophilic bioactives, displaying resistance to lipid oxidation. Protein-polysaccharide complexes have gained attention for their ability to protect and stabilize lipophilic ingredients, enhance bioavailability, and provide sustained release. Nanoemulsions enhance the bioavailability of encapsulated lipophilic compounds due to improved solubility and bioaccessibility, offering benefits for compounds like vitamin E, vitamin D, resveratrol, and beta-carotene. Carbohydrates, particularly polysaccharides, hold potential as building blocks for delivery systems, originating from various sources like plants, animals, algae, and microbes, and can be tailored for specific applications.

**5. Effective Carbohydrate Combinations**

To improve the functional attributes, carbohydrate pairings are frequently employed. Combinations of alginate and chitosan harness chitosan's mucoadhesive characteristics and utilize alginate's resistance to acidity, as evidenced in prior research studies. Researchers investigated the layer-by-layer encapsulation of probiotic Lactobacillus acidophilus using chitosan and carboxymethyl cellulose as a strategy to enhance viability within the gastrointestinal environment. Carbohydrates serve as coatings for nanocarrier systems, as seen with chitosan-coated nanostructured lipid carriers for hesperetin encapsulation. Coated liposomes with cationic chitosan and anionic pectin were used to enhance protection and stability of polyphenolic grape seed extract.

Nano sized bioactive compounds and Nano delivery systems are emerging fields of Nano food science research. The chapter describes the effect of different bioactive compounds on different diseases. The challenge is how these compounds are delivered effectively to the target area without losing the efficacy of the functions of the bioactive compounds. The Nano structured delivery systems like Nano emulsions, Nano structured lipid, protein, carbohydrate carriers and combination of these carriers, and Nano encapsulations are proved to be the better ways of delivering these compounds.

**References:**

1. Araujo, D. M. R., Santos, G. F. da S., & Nardi, A. E. (2010). Binge eating disorder and depression: A systematic review. The World Journal of Biological Psychiatry, 11(2-2), 199–207.
2. Banderet, L. E. and Lieberman, H. R. (1989). Treatment with tyrosine, a neurotransmitter precursor, reduces environmental-stress in humans. Brain Research Bulletin, 22(4): 759–762.
3. Bing Hua and Qing-rong Huangb (2013) Biopolymer based nano-delivery systems for enhancing bioavailability of nutraceuticals Chinese Journal of Polymer Science Vol. 31, No. 9, (2013), 1190−1203
4. Borel T, Sabliov CM. (2014). Nanodelivery of bioactive components for food applications: types of delivery systems, properties, and their effect on adme profiles and toxicity of nanoparticles. Ann Rev Food Sci Technol 5(5):197–213
5. Britton, G., Liaaen-Jensen, S., Pfander, H., (2009). Carotenoids, Volume 5: Nutrition and Health. Birkhäuser, Basel
6. Chaiyasit, W., Elias, R. J., McClements, D. J., & Decker, E. A. (2007). Role of Physical Structures in Bulk Oils on Lipid Oxidation. Critical Reviews in Food Science and Nutrition, 47(3), 299–317.
7. Charles B Stephensen (2001) Vitamin A, Infection, and Immune Function\* Annual Review of Nutrition Vol. 21:167-192
8. Chatterjee, C., Gleddie, S., & Xiao, C. (2018). Soybean Bioactive Peptides and Their Functional Properties
9. Chatterton, D. E. W., Smithers, G., Roupas, P. and Brodkorb, A. (2006). Bioactivity of beta-lactoglobulin and alpha-lactalbumin – Technological.
10. Chen, B., McClements, D. J., & Decker, E. A. (2013). Design of Foods with Bioactive Lipids for Improved Health. Annual Review of Food Science and Technology.
11. Cho, M. J., Unklesbay, N., Hsieh, F. H. and Clarke, A. D. (2004). Hydrophobicity of bitter peptides from soy protein hydrolysates. Journal of Agricultural and Food Chemistry, 52(19): 5895–5901
12. Chinevere, T. D., Sawyer, R. D., Creer, A. R., Conlee, R. K. and Parcell, A. C. (2002). Effects of L-tyrosine and carbohydrate ingestion on endurance exercise performance. Journal of Applied Physiology, 93(5): 1590–1597
13. Clandinin MT, Chappell JE, Leong S, Heim T, Swyer PR, Chance GW (1980) Intrauterine fatty acid accretion rates in human brain- Implications for fatty acid requirements. Early Human Development 4, 121-129Clandinin MT, Chappell JE, Leong S, Heim T, Swyer PR, Chance GW (1980) Intrauterine fatty acid accretion rates in human brain- Implications for fatty acid requirements. Early Human Development 4, 121-129
14. Crittenden, R. G., Martinez, N. R., & Playne, M. J. (2003). Synthesis and utilisation of folate by yoghurt starter cultures and probiotic bacteria. International Journal of Food Microbiology, 80(3), 217–222
15. David Julian McClements, Hang XiaO (2014) Excipient foods: designing food matrices that improve the oral bioavailability of pharmaceuticals and nutraceuticals
16. Dikeman, C. L. and Fahey, G. C. (2006). Viscosity as related to dietary fiber: A review. Critical Reviews in Food Science and Nutrition, 46(8): 649–663
17. Duran, A., & Kahve, H. I. (2017). The Use of Lactoferrin in Food Industry. Aksaray University, Turkey
18. During, M. J., Acworth, I. N. and Wurtman, R. J. (1988). Effects of systemic L-tyrosine on dopamine release from rat corpus striatum and nucleus accumbens. Brain Research, 452(1–2): 378–380
19. Edward Giovannucci (1999) Tomatoes, Tomato-Based Products, Lycopene, and Cancer: Review of the Epidemiologic Literature JNCI: Journal of the National Cancer Institute, Volume 91, Issue 4, 17 February 1999, Pages 317–331,
20. Fernstrom, J. D. (2005). Branched-chain amino acids and brain function. Journal of Nutrition, 135(6): 1539S–1546S
21. Fathi, M., Martín, Á, & McClements, D. J. (2014). Nanoencapsulation of food ingredients using carbohydrate based delivery systems. Trends in Food Science & Technology, 39(1), 18–39.
22. García-Montoya, I. A., Siqueiros Cendón, T., Arévalo-Gallegos, S., & Rascón-Cruz, Q. (2011). Lactoferrin: A Multiple Bioactive Protein - An Overview. Laboratorio de Biotecnología, Facultad de Ciencias Químicas, Universidad Autónoma de Chihuahua, Circuito 1, Nuevo Campus Universitario, CP 31125, Chihuahua, Mexico
23. Harizi, H., Corcuff, J.-B., & Gualde, N. (2008). Arachidonic-acid-derived eicosanoids: roles in biology and immunopathology. Trends in Molecular Medicine, 14(10), 461–469.
24. Harris, W. S., Mozaffarian, D., Rimm, E., Kris-Etherton, P., Rudel, L. L., Appel, L. J. Sacks, F. (2009). Omega-6 Fatty Acids and Risk for Cardiovascular Disease: A Science Advisory from the American Heart Association Nutrition Subcommittee of the Council on Nutrition, Physical Activity, and Metabolism; Council on Cardiovascular Nursing; and Council on Epidemiology and Prevention. Circulation, 119(6), 902–907.
25. Harris, R. A., Joshi, M., Jeoung, N. H. and Obayashi, M. (2005). Overview of the molecular and biochemical basis of branched-chain amino acid catabolism. Journal of Nutrition, 135(6): 1527S–1530S
26. Howard Sprecher, Devanand L. Luthria, B. S. Mohammed, and Svetla P. Baykousheva (1995) Reevaluation of the pathways for the biosynthesis of polyunsaturated fatty acids. Department of Medical Biochemistry, The Ohio State University, Columbus, OH 43210
27. Hu, B., & Huang, Q.-r. (2013). Biopolymer-based nano-delivery systems for enhancing bioavailability of nutraceuticals. Chinese Journal of Polymer Science.
28. Huang, Q., Yu, H., & Ru, Q. (2010). Bioavailability and Delivery of Nutraceuticals Using Nanotechnology. Journal of Food Science, 75(1), R50–R57.
29. Ishak, K. A., Mohamad Annuar, M. S., & Ahmad, N. (2017). Nano-Delivery Systems for Nutraceutical Application. Elsevier BV.
30. Katiyar, V., & Ghosh, T. (2021). Edible Food Packaging: An Introduction - Nanotechnology in Edible Food Packaging - Food Preservation Practices for a Sustainable Future. Springer Singapore.
31. Kim, S. K. and Mendis, E. (2006). Bioactive compounds from marine processing byproducts - A review. Food Research International, 39(4): 383–393
32. Kim, S.-K., Ngo, D.-H., & Vo, T.-S. (2012). Marine Fish-Derived Bioactive Peptides as Potential Antihypertensive Agents
33. Kitts, D., & Weiler, K. (2003). Bioactive Proteins and Peptides from Food Sources: Applications of Bioprocesses used in Isolation and Recovery. Current Pharmaceutical Design, 9(16), 1309–1323
34. Korhonen, H., Marnila, P. and Gill, H. S. (2000). Milk immunoglobulins and complement factors. British Journal of Nutrition, 84: S75–S80
35. Lafarga, T., & Hayes, M. (2014). Bioactive peptides from meat muscle and by-products: generation, functionality, and application as functional ingredients. Meat Science.
36. Liu, X., Bi, J., Xiao, H., & McClements, D. J. (2015). Increasing Carotenoid Bioaccessibility from Yellow Peppers Using Excipient Emulsions: Impact of Lipid Type and Thermal Processing. Journal of Agricultural and Food Chemistry.
37. Marina Heinonen, Katri Haila, Anna-Maija Lampi & Vieno Piironen. (1997) Inhibition of oxidation in 10% oil-in-water emulsions by β-carotene with α- and γ-tocopherols. J Amer Oil Chem Soc 74, 1047–1052
38. McClements, D. J., & Xiao, H. (2014). Excipient Foods: Designing Food Matrices That Improve the Oral Bioavailability of Pharmaceuticals and Nutraceuticals. Food Function.
39. McClements, D. J., Decker, E. A., Park, Y., & Weiss, J. (2009). Structural Design Principles for Delivery of Bioactive Components in Nutraceuticals and Functional Foods. Critical Reviews in Food Science and Nutrition.
40. McClements, D. J., Li, F., & Xiao, H. (2015). The Nutraceutical Bioavailability Classification Scheme: Classifying Nutraceuticals According to Factors Limiting their Oral Bioavailability. Annual Review of Food Science and Technology
41. McClements, D., & Öztürk, B. (2021). Utilization of Nanotechnology to Improve the Handling, Storage and Biocompatibility of Bioactive Lipids in Food Applications. Foods, 10(2), 365.
42. Meisel, H. (1997). Biochemical properties of bioactive peptides derived from milk proteins: Potential nutraceuticals for food and pharmaceutical applications. Livestock Production Science, 50(1–2): 125–138
43. Minioti, K. S., Sakellariou, C. F., & Thomaidis, N. S. (2007). Determination of 13 synthetic food colorants in water-soluble foods by reversed-phase high-performance liquid chromatography coupled with diode-array detector. Analytica Chimica Acta, 583(1), 103–110.
44. Muir, A. D. (2005). Natural peptides in blood pressure control. A review. Agro Food Industry Hi-Tech, 16(5): 15–17
45. Nelson, G. J., Kelly, D. S., Emken, E. A., Phinney, S. D., Kyle, D., & Ferretti, A. (1997). A human dietary arachidonic acid supplementation study conducted in a metabolic research unit: Radionale and design. Lipids, 32(4), 415–420.
46. Niaz, B., Saeed, F., Ahmed, A., Imran, M., Aslam, A., Maan, M. K. I. Khan, T., Tufail, T., Anjum, F. M., Hussain, S., & Suleria, H. A. R. (2019). Lactoferrin (LF): A Natural Antimicrobial Protein.
47. Ostlund, Richard E Jr (2004) Phytosterols and cholesterol metabolism
48. Park, Y. W., & Nam, M. S. Bioactive Peptides in Milk and Dairy Products: A Review.
49. Pastrana, L., González, R., Estévez, N., Pereira, L., et al. (2017). Functional Foods. Elsevier BV.
50. Pedrosa, M., Pascual, C. Y., Larco, J. I. and Esteban, M. M. (2006). Palatability of hydrolysates and other substitution formulas for cow's milk-allergic children: A comparative study of taste, smell, and texture evaluated by healthy volunteers. Journal of Investigational Allergology and Clinical Immunology, 16(6): 351–356.
51. Piorkowski, D. T., & McClements, D. J. (2014). Beverage Emulsions: Recent Developments in Formulation, Production, and Applications. Food Hydrocolloids
52. Playne, M. J., Bennett, L. E. and Smithers, G. W. (2003). Functional dairy foods and ingredients. Australian Journal of Dairy Technology, 58(3): 242–264
53. Rapola, J. M., Virtamo, J., Ripatti, S., Huttunen, J. K., Albanes, D., Taylor, P. R., & Heinonen, O. P. (1997). Randomised trial of α-tocopherol and β-carotene supplements on incidence of major coronary events in men with previous myocardial infarction. The Lancet, 349(9067), 1715–1720
54. Redgwell, R. J. and Fischer, M. (2005). Dietary fiber as a versatile food component: An industrial perspective. Molecular Nutrition & Food Research, 49(6): 521–535.
55. Ribaya-Mercado, J. D., & Blumberg, J. B. (2004). Lutein and Zeaxanthin and Their Potential Roles in Disease Prevention. Journal of the American College of Nutrition, 23(sup6), 567S–587S
56. Riediger, N. D., Othman, R. A., Suh, M., & Moghadasian, M. H. (2009). A Systemic Review of the Roles of n-3 Fatty Acids in Health and Disease. Journal of the American Dietetic Association, 109(4), 668–679
57. Russo, S., Kema, I. P., Fokkema, R., Boon, J. C., Willemse, P. H. B., de Vries, E. G. E., den Boer, J. A. and Korf, J. (2003). Tryptophan as a link between psychopathology and somatic states. Psychosomatic Medicine, 65(4): 665–671
58. Ryan, J. T., Ross, R. P., Bolton, D., Fitzgerald, G. F., & Stanton, C. (2011). Bioactive Peptides from Muscle Sources: Meat and Fish
59. Salvia-Trujillo, L., Martín-Belloso, O., & McClements, D. (2016). Excipient Nanoemulsions for Improving Oral Bioavailability of Bioactives. Nanomaterials.
60. Sánchez, A., & Vázquez, A. (2017). Bioactive peptides: A review. Food Quality and Safety, 1(1), 29-46.
61. Schieber, A., & Carle, R. (2005). Occurrence of carotenoid cis-isomers in food: Technological, analytical, and nutritional implications. Trends in Food Science & Technology, 16(9), 416–422
62. Severin, S. and Xia, W. S. (2005). Milk biologically active components as nutraceuticals: Review. *Critical Reviews in Food Science and Nutrition*, 45(7–8): 645–656.
63. Seyler, J. E., Wildman, R. E. C. and Layman, D. K. (2007). “Protein as a functional food ingredient for weight loss and maintaining body composition”. In Handbook of Nutraceuticals and Functional Foods, , 2nd Edition, Edited by: Wildman, R. E. C. 391–407. Boco Raton, FL: CRC Press
64. Silva, E., Oliveira, J., Silva, Y., Urbano, S., Sales, D., Moraes, E., Rangel, A., & Anaya, K. (2020). Lactoperoxidase System in the Dairy Industry: Challenges and Opportunities. Czech Journal of Food Sciences, 38(6), 337–346.
65. Singha, B. P., Vij, S., & Hati, S. (2014). Functional Significance of Bioactive Peptides Derived from Soybean
66. Tripathi, A. K. and Misra, A. K. (2005). Soybean - a consummate functional food: A review. Journal of Food Science and Technology-Mysore, 42(2): 111–119
67. Tsuda, H., Sekine, K., Ushida, Y., Kuhara, T., Takasuka, N., Iigo, M., Han, B. S. and Moore, M. A. (2000). Milk and dairy products in cancer prevention: focus on bovine lactoferrin. Mutation Research, 462: 227–233
68. Wang, W. Y. and De Mejia, E. G. (2005). A new frontier in soy bioactive peptides that may prevent age-related chronic diseases. Comprehensive Reviews in Food Science and Food Safety, 4(4): 63–78
69. Ward, R. E., & German, J. B. (2004). Understanding Milk’s Bioactive Components: A Goal for the Genomics Toolbox. The Journal of Nutrition, 134(4), 962S–967S.
70. Xianquan, S., Shi, J., Kakuda, Y., & Yueming, J. (2005). Stability of Lycopene during Food Processing and Storage. Journal of Medicinal Food, 8(4), 413–422.
71. Xing, L., Li, G., Toldrá, F., & Zhang, W. (2021). The physiological activity of bioactive peptides obtained from meat and meat by-products. Advances in Food and Nutrition Research, 147–185
72. Zimecki, M., Wlaszczyk, A., Cheneau, P., Brunel, A.-S., Mazurier, J., Spik, G. and Kubler, A. (1998). Immunoregulatory effects of a nutritional preparation containing bovine lactoferrin taken orally by healthy individuals. Archivum Immunologiae et Therapiae Experimentalis, 46: 231–240