

Bioactive Lipids: Chemistry & Health Benefits

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Abstract: The dietary requirement depends upon various factors such as age, occupation, location, and health condition. With an ever-changing lifestyle and increasing food safety issues, coronary heart diseases, diabetes, obesity, hypertension, and several other health conditions are increasing. However, as observed by doctors and nutritionists, the consumption of certain food items is associated with the prevention of disorders. Bioactive components are the extra nutritional components present in minute quantities in food. They are intensively studied to evaluate their effects on human health. These bioactive compounds differ widely in their chemical structure and function and thus are categorized accordingly. Bioactive lipids can play a crucial role in prevention against the onset of certain disorders. The present paper reviews the different dietary bioactive lipids, the effect of their consumption on health, and challenges in the incorporation of such components into food systems.

Keywords: Fats, biolipids, nutrition, bioactive compounds, health, food.

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1. Introduction

Food is a basic necessity for sustaining life. Our dietary requirement depends upon various factors like age, occupation, location as well as health conditions. With an ever-changing lifestyle and increasing food safety issues, coronary heart diseases, diabetes, obesity, hypertension, and several other health conditions are increasing. Obesity is also linked with diabetes, heart diseases etc. [1]. However, as observed by doctors and nutritionists, consumption of a balanced diet having certain components on a regular basis is helpful in reducing the risk of lifestyle disorders. Besides, it can also help in shaping gut microbiota, resulting in better digestibility and reduced chances of colon cancer [2,3]. Functional foods and nutraceuticals are the two terms often used in this context. Functional foods are products that show positive effects on one or more bodily functions apart from nutrition, leading to improved health and/or reduced risk of disease [4]. There is a rise in the development of functional foods via fortification of some bioactive components [5-13]. The positive effects of consuming functional foods in the diet are due to the presence of certain components in them, often coined as bioactive components. *Encyclopedia of Food & Culture* defines food bioactive components as non-essential biomolecules present in foods that can modulate one or more metabolic processes, resulting in better health [14]. Another definition states that bioactive substances are food components that have an impact on body function through an effect on biological processes. Thus, a dietary component should impart measurable biological effect when consumed within a realistic level, to be considered as bioactive. Secondly, bioactivity measured must be in terms of potential to impact health beneficially only.

Lipids are one of the major classes of biological molecules that are predominantly hydrophobic, show low solubility in water and high solubility in nonpolar solvents.

Structurally, lipids are primarily made up of hydrocarbons with the presence of other associated functional groups at times and exhibit either hydrophobic or amphipathic nature; thus, it can be said of possessing polar as well as nonpolar groups. Hydrophobicity of lipids results in them possessing effective barrier property towards polar molecules. This unique selectivity of lipids helps in ensuring the high functionality of cell membranes [15]. Lipid consumption, just like nearly every other food component, can have both positive and negative impacts on human health. Thus, the careful selection and a balanced amount of lipids are required for good health. Certain lipids and associated groups show preventive effects against the onset of diseases, while some other help in combating problems associated with an imbalanced diet. Such lipids exhibit functional properties through the expression of these positive functions, thus referred to as bioactive lipids [16-17].

Several lipid groups are capable of showing bioactivity and provide health benefits and, thus, are referred to as bioactive lipids. Consumption of certain bioactive lipids and related components, such as phytosterols, polyunsaturated fatty acids, fat-soluble vitamins, carotenoid, etc. are beneficial for health. Bioactive lipids can be included in the diet in a variety of forms. Most of the time, they are naturally present within complex food ingredients. Oilseeds, nuts, eggs, and dairy products are among the significant sources of bioactive lipids, among others. If not present, they can be added as functional ingredients through various means [17].

The basic structural unit of lipid, fatty acid, is made up of hydrocarbon chains associated with the carboxyl group at the end. Fatty acids are present in a significant amount in natural biological systems in the bound state, although rarely in free form. Mostly, these are present, esterified to glycerol or other related groups in saturated or unsaturated form. Unsaturation in structure enables fatty acids to orient in flexible aggregates in comparison to saturated chains that form rigid arrays, resulting in enhanced functionality. Essential fatty acids serve as a precursor for various metabolic and synthesis processes in the body (e.g., synthesis of prostaglandins) [15].

Our present diet includes fats in varying fatty acid compositions. The risk of developing cardiovascular diseases is found to be directly related to the consumption of high saturated fatty acids in the diet. It has been found that the incorporation of unsaturated fatty acids such as linoleic acid in the diet through the use of corn oil and similar oils may reduce the chances of developing lifestyle diseases, heart attacks, and obesity. Vegetable oils contain a higher amount of unsaturated fatty acids than oils obtained from animal origin. Bioactive lipids induce health benefits through compositional changes in tissue fatty acids or certain metabolic pathways linked with cell signaling. Solid lipid nanoparticles possess some therapeutic properties [18]. The present review paper covers the major bioactive lipids and their potential health benefits.

2. Dietary Bioactive Lipids and Health Benefits

2.1. Butyric acid.

Milk lipid is one of the significant sources of butyric acid. It is one of the major fiber fermentation by-products in the colon as well. Butyric acid has been associated with several beneficial health benefits. Despite being stimulant of the usual proliferation of cells, butyric acid is also the inhibitor of colon cancer cell lines growth [19]. It acts as a nutrient for the growth of cells of large intestine and regeneration. Butyric acid consumption prevents colon cancer through mutant colonic cells apoptosis. Besides these, it is related to increased energy expenditure through thermogenesis, thereby contributing to a loss in body weight.

2.2. Medium-Chain fatty acids.

Medium-Chain Fatty Acids (ex. caprylic acid (C8:0), capric (C10:0) acid) are metabolized differently compared to long-chain fatty acids, as evident from some studies [19]. Carnitine palmitoyltransferase is an enzyme that controls the rate of the β - oxidation process and thus, transportation of fatty acids. However, medium-chain fatty acids do not require the presence of this enzyme for transportation in mitochondria. Upon direct intake through food, these fatty acids directly enter the blood circulatory system, ultimately reaching the liver where they are oxidized to the ketone, which is evident from decreased triglyceride level in blood upon ingestion of Medium Chain Triglycerides (MCTs) during intervention trials on the human body. Because of this difference in metabolizing dietary MCTs, thermogenesis is induced in the body upon the consumption of these fatty acids. Hence, the problem of weight gain does not arise as no deposition occurs in the adipose tissues [19]. Diet rich in medium-chain fatty acids also contribute to reduced LDL and LDL-cholesterol levels in the blood as compared to the traditional edible oils containing saturated, long-chain triglycerides. Thus, medium-chain fatty acids can be used for the prevention and treatment of obesity. Medium-chain fatty acids up-regulate lipoprotein lipase expression and activate lipase, resulting in an enhanced rate of lipolysis and, thus, reduction in fat accumulation, as evident from reported studies [20].

Despite beneficial effects, there are certain limitations of using medium-chain fatty acids as cooking oils due to their lower smoke point as compared to oils containing long-chain fatty acids. Therefore, value addition for developing oils containing MCFAs and long-chain fatty acids esterified to the glycerol backbone along with triglycerides is carried out.

2.3. Long-Chain fatty acids.

Fatty acids having 14 or more carbon atoms linearly arranged are named long-chain fatty acids. These can be present in a saturated or unsaturated form in natural products although, mostly found as triglycerides.

2.3.1. Monounsaturated fatty acids (MUFAs).

Oleic acid-rich diet intake results in up to 17% reduction in cholesterol concentration of plasma compared to intake, predominantly rich in saturated fatty acids. The substitution of saturated fatty acids with monounsaturated fatty acids is reported to show a 28% decline in Apolipoprotein B (ApoB) levels as well as a low concentration of LDL in the plasma. Consumption of oleic acid is associated with the prevention of brain-related disorders such as dementia and Alzheimer's disease [21]. Detailed in vivo studies are essential to examine the exact phenomenon. However, preliminary work in the direction is indicative of the beneficial effects of oleic-acid rich diets on brain functions. Oleic acid also has a potential role in controlling colorectal cancer through inhibition of the stress-operated calcium ion entry process, which is involved in numerous physiological and cellular processes [22]. The blockage of calcium ion entry in cells in the presence of oleic acid channelizes through carboxylate-mediated metal chelation.

Fatty acid structural conformation is one of the contributing effects of inhibitory properties. For example, calcium ion entry blockage through binding to molecules at the outer side of the membrane is evident in the case of oleic acid but not in stearic acid despite having the same carbon length. Our body can synthesize MUFAs. Dietary MUFAs are an essential class of bioactive lipids that have been associated with various health benefits. MUFAs

consumption is shown to lower blood glucose in people with type II diabetes, as exhibited in various studies [17].

Paniagua and group observed that breakfast based on virgin olive oil decrease postprandial glucose and insulin concentrations in the offspring of obese and type 2 diabetes patients [23]. Decreased susceptibility of low-density lipoprotein (LDL) to oxidative modification is also associated with dietary intake of MUFAs. As a result, MUFAs show a preventive effect against atherosclerosis [24]. Other studies attribute this effect to the higher content of α -tocopherol in dietary fats [25].

2.3.2. Polyunsaturated fatty acids (PUFAs).

The human body cannot generate PUFAs, and hence, these must be consumed in the diet. Therefore, PUFAs fall under the class of essential fatty acids. PUFAs are highly beneficial bioactive lipids. These exist naturally in seed oils and play a crucial role in the biosynthesis of cellular hormones (eicosanoids). Apart from this, PUFAs act as a substrate for the synthesis of certain other health modulating compounds. PUFAs have the *cis* orientation as their predominant form, imparting nonlinear, rigid structure, enhancing the fluidity of cell membranes, resulting in enhanced intra-cell communication and maintenance of homeostasis [19].

Epidemiological studies show that the consumption of PUFAs is likely to result in a low incidence of lifestyle diseases. Diet having high levels of linoleic and linolenic acids is proven to show better cholesterol-reducing effects compared to a diet rich in saturated fat. The central marker of cholesterol in the blood circulation system and thus of increased cardiovascular damage risk and atherosclerosis, ApoB (low-density lipoprotein), can be decreased by polyunsaturated-rich diet through the combination of reduced production and increased catabolism. This can serve as a preventive measure and protect against certain diseases of cardiovascular origin associated with excess vascular cholesterol levels. Besides, it also helps through decreased blood levels of mediators of insulin resistance, increased sensitivity, and enhanced leptin levels.

Consumption of high levels of fish is associated with improved immunity, reduced asthma-and related risks symptoms besides addition to decreased proinflammatory compound levels such as interleukin-6 and prostaglandins. Long-chain PUFAs have antihypertensive effects and decrease the risk of adverse cardiovascular problems. Antihypertensive effects associated with PUFAs are due to endothelial nitric oxide production upregulation. PUFAs can also potentially inhibit kidney damage and excessive proliferation of muscle cells [19].

2.4. Omega-3 & omega-6 fatty acids.

PUFAs are majorly divided into two major groups on the basis of structure. The location of the last double bond concerning terminal methyl end of fatty acid (FAs) serves as the differential criteria between the two groups, i.e., n-3 and the n-6 FAs. Linoleic acid (C18:2) is the simplest omega-6 fatty acid, while linolenic acid (C18:3) is the simplest omega-3 fatty acid found in food materials.

These fatty acids have a protective effect against inflammatory and cardiovascular diseases (lupus, diabetes, psoriasis, obesity, Crohn's, rheumatoid arthritis, cystic fibrosis, Alzheimer's, and multiple sclerosis, etc.). These fatty acids reduce the pathogenesis of brain diseases by reducing the in vitro activity of PEP enzymes. Animal experiments indicate that the ratio of omega-3 (n-3) to omega-6 (n-6) is a crucial determinant of health benefits. A high

ratio (more n-3 and less n-6) in the dietary intake is desirable for human health in terms of reduced weight, adipocyte size, and heartbeat normalization [26]. These effects are because of the conversion of n-3 PUFAs to anti-inflammatory eicosanoids and n-6 PUFAs to proinflammatory eicosanoids.

2.4.1. n-3 PUFA.

Dietary n-3 PUFAs enhance the body's ability to fight against inflammatory conditions, which are responsible for the initiation and growth of diseases like cancer, kidney malfunction, diabetes, and cardiovascular disorders. A study shows that human interventional trial consumption of 1 g omega-3 fatty acid daily led to a significant reduction in the cumulative rate of all-cause death [27]. α -linolenic acid, docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) are the major fatty acids of the group. n-3 PUFAs show preventive action against the onset of cardiovascular diseases, as indicated by studies [28]. Omega-3 fatty acids increase postprandial satiety, thereby reducing food and calorie intake. Animal studies show the ability of omega-3 fatty acids to affect metabolic pathways by promoting protein synthesis and maintenance of lean muscles.

Combinations of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) with linolenic acid are found to possess the power of lowering heart disease in aged people. Docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) can reduce blood pressure and viscosity through the enhanced formation of PGI₃ (a platelet anti-aggregator) and inhibition of thromboxane A₂ (potent platelet aggregator and vasoconstrictor) [19].

Consumption of n-3 PUFA helps in sustaining infant visual and brain development. The brain undergoes rapid growth during the last 3 months of pregnancy. During this time, cell membranes within the brain and retina have DHA at high levels. It accumulates rapidly at that time and during the first year of life [29]. n-3 PUFA also supports cardiovascular health. Experimental evidence shows that increasing dietary intake of n-3 PUFAs benefits against various types of cancer (colon, prostate, and pancreatic cancers amid others) [30], anxiety, mood disorders, stress, cognitive impairment, diabetic nephropathy, inflammatory bowel disease and Alzheimer's disease [31].

High omega 3: omega 6 ratio is present in fish oil, which is shown to decrease serum triglyceride and cholesterol levels. Fish oil consumption also lowers down the blood pressure in hypertensive patients. The presence of omega-3 PUFA, EPA, and DHA in fish oil are major contributing factors behind its nutrient profile. Flaxseed, green leafy vegetables, rapeseed, and walnuts contain α -Linolenic acid (ALA), which upon elongation within body yield EPA, docosapentaenoic acid (DPA), and DHA. Thus, ALA can be used as EPA and DPA dietary precursor for people that do not consume fish oil products.

DHA is another major bioactive lipid that is recommended for maintaining sound physiological health [32]. DHA contributes to the upregulation of intracellular antioxidants like glutathione, leading to oxidative stress reduction. Besides this, DHA is also reported to exhibit anti-inflammatory effects upon oxidization to molecules like resolvins and protectins [19]. Antioxidant activity of these compounds can be determined using DPPH assay [33-40]. These antioxidants reduce oxidative stress in the human body and provide various health benefits [41-43]. Neuroprotection, among these, play a role in nerve regeneration and leukocyte reduction during inflammation. These are linked with homeostasis maintenance during the aging process. Some other benefits of omega-3 PUFAs include an anti-arrhythmic effect (arrhythmia is a condition of abnormal heartbeat), decrease in LDL and total cholesterol level, anti-

inflammatory nature- reduces platelet aggregation and reduced potential for atherogenesis, protects against the development of prostate cancer through competitive inhibition of Omega-6 PUFAs conversion to proinflammatory eicosanoids. However, when consumed at higher levels, i.e., >20g/day, bleeding can increase. High dosage of omega-3 fatty acids also increase plasma LDL concentration and may induce gastrointestinal discomfort and nausea.

2.4.2. n-6 PUFA.

Linoleic acid, conjugated linoleic acid (CLA), and arachidonic acid are the major fatty acids of this group. n-6 PUFAs play a crucial role in many physiological functions and molecular pathways. American Heart Association (AHA) and many scientists across the globe advice to consume at least 5% to 10% of energy as n-6 PUFA for improving heart health [44]. Linoleic acid is found to be an activator of prostaglandins- PG 1 and PG 2 synthesis. It prevents the rise of blood pressure.

2.4.2.1. Conjugated Linoleic Acid (CLA).

CLA is a group of linoleic acid derivative isomers [45]. Dairy products and ruminant meat are good sources of CLA. Dietary CLA in animal studies is associated with protection against regaining fat mass following weight loss [46]. Ruminant fats (tallow, milk fat, etc.) contain a small amount of CLA naturally. CLA content of milk fat is in the range of 5–7 mg/g. It can be synthesized from linoleic acid as well. Vegetable oils such as corn, canola, safflower, sunflower, soybean, etc. contain a large amount of linoleic acid and hence can be used for the synthesis of CLA. Major bioactive lipid form of CLA is *cis(c)* -9, *trans(t)* -11 isomer. It is present in milk & other dairy products, meat, and related processed products of ruminant origin at 73–94% of total CLA content. Other bioactive lipid isomers of CLA have been identified and studied as well. Structurally, CLA has two double bonds, separated by one single bond. CLA falls under the category of essential fatty acid; thus, these have to be taken in diet. Important dietary sources of CLA are animal products such as milk and ruminant meat. Ruminants have specific bacteria in the stomach to convert linoleic acid to CLA that is absorbed into the tissues. However, this particular bacteria is not present in the non-ruminant body. Hence, they do not produce CLA. The dietary intake of CLA has been found to suppress atherosclerosis and possess anti-carcinogenic effects. It also reduces insulin resistance that can be preventive against the onset of diabetes in adults. CLA intake also enhances immunity and inhibits the growth of tumors. Regular consumption of CLA in the diet protects the tissues and membranes against destructive oxidative stress. It also contributes to direct free radical scavenging, lipid peroxidation inhibition, and upregulation of vitamin E level. Potential preventive action of CLA isomers against chronic kidney disease has received considerable attention [47]. Studies on male rats with kidney disease indicated that diet with 1% CLA mixture resulted in significant decreases in oxidative damage (30%), proliferating cells (28%), inflammation (42%), and fibrosis (28%) [19].

2.4.2.2. Arachidonic acid (ARA).

Arachidonic acid is obtained from animal food sources such as meat, fish eggs, seafood, and poultry [48]. At the same time, plants and vegetables do not produce it. AA plays a crucial role in the growth of mammalian brain and neural tissues in infants and thus has a significant pharmacological and physiological effect on their health [49]. Accumulation of ARA in the

brain begins rapidly in the last 3 months of pregnancy and continues until two years of age. ARA is among significant eicosanoid precursors signal molecules that impact a wide range of physiological processes such as cytokine production, antibody formation, cell proliferation, migration, etc. [50]. Arachidonic acid, along with DHA constitutes about 20% weight (dry basis) of the human brain. It is mainly concentrated in the outer membranes of neurons and the myelin sheath [51]. Further, ARA comprises of up to 15-17% of total fatty acids. Therefore its intake in the diet affects the functioning of muscles, resolves inflammation, increases lean body mass, muscle strength in individuals [52].

2.5. Carotenoids.

Two major classes of carotenoids that exhibit bioactivity are carotenes and xanthophylls. Carotenes refer to hydrocarbon carotenoids, while xanthophylls are carotenoids that have oxygen attached in hydroxyl, methoxyl, carboxyl, keto, or epoxy groups. Lycopene, a red color pigment, present in watermelon and tomatoes in great quantity, is one major example of carotene. Lutein, present abundantly in green leafy vegetables, is a type of xanthophyll. Carotenoids are associated with inhibition of free-radical-initiated diseases such as atherosclerosis, age-related muscular degeneration, and multiple sclerosis [53].

Besides, β -carotene, α -carotene, and β -cryptoxanthin are sources of provitamin A and upon conversion, help in the maintenance of normal eye health, epithelial function, embryonic development, and immune system function [54]. The anticancer effect of lycopene has been extensively studied [55]. Lutein and zeaxanthin have found to be beneficial against age-related macular degeneration and cataracts [56]. Besides this, they are also known to exhibit preventive effects against coronary heart disease and breast cancer.

2.6. Phytosterols.

Phytosterols can be incorporated into the diet through vegetables and vegetable oils. Stigmasterol, β -sitosterol, and campesterol are among the major phytosterols exhibiting bioactivity. Vegetable oils contain phytosterol concentration in range from 0.1% to 1.0% [57]. The production of phytosterol-fortified foods has become popular because of the ability of phytosterols in reducing total and LDL cholesterol by reducing the absorption of dietary cholesterol and reducing the occurrence of cardiovascular disease. Further, phytosterols also possess other health-promoting effects such as anti-carcinogenic effect (protects against several cancers-colon, prostate and breast cancer), anti-inflammatory effect, anti-oxidative effect, and immunomodulatory effects [58]. Studies have revealed that saturated phytosterols, i.e., stanols, are more efficient in lowering the blood cholesterol levels than the sterols [59].

3. Challenges in the incorporation of Bioactive Lipids in Food Products

For optimum benefit from bioactive dietary components, it is essential to maintain their quantity and activity significant within the product till consumption and release in the body. Besides that, in the case of fortification or incorporation of bioactive in food, they must not adversely affect the desirable attributes of the food in terms of appearance, flavor, texture, etc. Bioactive components are often light, oxygen, and temperature-sensitive as well. Thus, to design food products with bioactive components, the following challenges must be met.

3.1. Oxidation.

Bioactive lipids are susceptible to oxidation when in the presence of food matrices. Oxidation can occur during processing as well. The process can further be accelerated by factors such as light, heat, enzymes, metals, and microorganisms. As a result, complex reactions of autoxidation, thermal oxidation, photo-oxidation, or enzymatic oxidation can take place, resulting in loss of bioactivity and onset of off-flavor in the products [60]. The formation of toxic compounds is another significant risk. EPA and DHA are most vulnerable to oxidation reactions, with the development of off-flavors.

3.2. Bioavailability.

Bioavailability refers to the quantity of an ingested compound that is absorbed by our body. Factors affecting the overall bioavailability of bioactive components include the bioaccessibility coefficient (FB), transport coefficient (FT), and non-metabolized coefficient (FM) [61].

3.3. Water Solubility.

Bioactive lipids can be categorized into three classes based on water solubility:

- (a) insoluble, nonpolar lipids
- (b) insoluble, swelling amphiphiles
- (c) weakly soluble neutral lipids

The majority of foods have water as their most dominant, continuous phase. Thus, lipids with limited or no solubility in water cannot be incorporated as such in these products.

3.4. Structural Properties and Physical State.

Certain bioactive compounds show their functional properties as a function of structural conformation. The molecular weight, morphology, hydrophobicity, and polarity of carotenoids influence their bioactivity to a great extent [62]. Thus, before going for any system design for incorporating bioactive components, a complete understanding and quantification of the relationship between bioactive lipid/peptide dietary intake and resulting health benefits should be studied so that accurate information could be disseminated to the consumer about its benefits.

4. Bioactive Delivery Systems

Bioactive lipids can be directly incorporated in a fat-rich matrix such as shortening, butter, margarine, and spreads without any problem. Incorporating bioactive lipids into aqueous-based foods, such as beverages, sauces, dressings, soups, and desserts, is, however, challenging. Different methods can be used to incorporate bioactive components in food.

4.1. Emulsification.

Emulsification is one of the major processes used for creating bioactive delivery systems based on oil-in-water emulsions [63, 64]. Emulsion refers to a combination of immiscible liquids with one of the liquids being dispersed as small spherical droplets in the other [61]. For encapsulation through the emulsion, bioactive lipids can be used directly or along with carrier oils. This method can be used for the enrichment of milk, yogurt, salad dressing, fitness bars, ice cream, and meat patties with omega-3, AA, and CLA FAs, lycopene,

and other bioactive lipids [17]. Nanoemulsions and microemulsions are often used to deliver bioactive lipids into food beverages.

4.2. Spray drying.

Spray drying is the most common encapsulation technique, widely used in the industry for conversion of bioactive to a solid powder form that can be readily used as a dry food ingredient [65, 66]. Spray drying involves the emulsification of core material, which is then dried in the presence of suitable wall material (often proteins and/or carbohydrates). Several biopolymers and modified biopolymers are used in drug delivery [67]. Various structure associated emulsion-based delivery systems like solid lipid nanoparticles, nanoemulsions, multiple emulsions, multilayer emulsions, and filled hydrogel particles have been worked upon for encapsulating bioactive lipids [68-72].

5. Conclusion

Bioactive lipids are highly beneficial against lifestyle diseases. However, the intake amount needs to be carefully decided to prevent adverse effects upon overconsumption. Balanced and well-planned diet plays a big role, not only in keeping us energetic for day to day activities but also against the future onset of various disorders. There are certain challenges in designing systems for the production and incorporation of bioactive components in the diet. The most popular methods at present for bioactive production and processing are emulsification, spray drying, and membrane-based separation processes.

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Conflicts of Interest

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References

1. Stanislav, A.A.; Vassu-Dimov, T.; Iacob, M.M.; Botezatu, A.; Arsene, C.; Burlibasa, L.; Bodron, P.; Sarghie, L.; Cucu, N.; Alexandrescu, L. Investigation of fat mass and obesity associated (FTO) gene polymorphism in Romanian population. *Biointerface Research in Applied Chemistry* **2018**, *8*, 3710-3718.
2. De Almeida, C.V.; de Camargo, M.R.; Russo, E.; Amedei, A. Role of diet and gut microbiota on colorectal cancer immunomodulation. *World Journal of Gastroenterology* **2019**, *25*, 151-162.
3. Seidel, D.V.; Azcarate-Peril, M.A.; Chapkin, R.S.; Turner, N.D. Shaping functional gut microbiota using dietary bioactives to reduce colon cancer risk. In *Seminars in cancer biology*. Volume 46. Academic Press: USA 2017; pp. 191-204, <https://doi.org/10.1016/j.semcancer.2017.06.009>.
4. Abdel-Salam, A.M. Functional foods: Hopefulness to good health. *American Journal of Food Technology* **2010**, *5*, 86-99, <https://doi.org/10.3923/ajft.2010.86.99>.
5. Mudgil, D.; Barak, S.; Khatkar, B.S. Process optimization of partially hydrolyzed guar gum using response surface methodology. *Agro Food Industry Hi Tech* **2012**, *23*, 13-15.
6. Mudgil, D.; Barak, S. Development of functional buttermilk by soluble fibre fortification. *Agro Food Industry Hi Tech* **2016**, *27*, 44-47.
7. Mudgil, D. The Interaction Between Insoluble and Soluble Fiber. In: *Dietary Fiber for the Prevention of Cardiovascular Disease*. Elsevier: U.S.A 2017; pp. 35-59, <https://doi.org/10.1016/B978-0-12-805130-6.00003-3>.

8. Mudgil, D.; Barak, S.; Khatkar, B.S. Development and characterization of soluble fiber enriched noodles via fortification with partially hydrolyzed guar gum. *Journal of Food Measurement and Characterization* **2018**, *12*, 156-163, <https://doi.org/10.1007/s11694-017-9626-y>.
9. Mudgil, D. Partially Hydrolyzed Guar Gum: Preparation and Properties. In: *Polymers for Food Applications*. Springer: Cham. 2018; pp. 529-549, https://doi.org/10.1007/978-3-319-94625-2_20.
10. Mudgil, D. Influence of Partially Hydrolyzed Guar Gum as Soluble Fiber on Physicochemical, Textural and Sensory Characteristics of Yoghurt. *Journal of Microbiology, Biotechnology and Food Sciences* **2019**, *8*, 794-797.
11. Mudgil, D.; Barak, S. Classification, Technological Properties, and Sustainable Sources. In: *Dietary Fiber: Properties, Recovery, and Applications*. Elsevier Academic Press: USA, 2019; pp. 27-58, <https://doi.org/10.1016/B978-0-12-816495-2.00002-2>.
12. Mudgil, D.; Barak, S.; Khatkar, B.S. Cookie texture, spread ratio and sensory acceptability of cookies as a function of soluble dietary fiber, baking time and different water levels. *LWT- Food Science and Technology* **2017**, *80*, 537-542, <https://doi.org/10.1016/j.lwt.2017.03.009>.
13. Mudgil, D.; Barak, S.; Khatkar, B.S. Soluble fibre and cookie quality. *Agro Food Industry Hi Tech* **2012**, *23*, 15-17.
14. Solomon, H.K.; William, W.W. Bioactive Food Components, Encyclopedia of Food & Culture. *Acceptance to Food Politics, B Letter, Charles Scribner's Sons* **2003**, *1*, 201-202.
15. Garrett, R.H.; Grisham, C.M. Lipids. In: *Biochemistry*. Saunders College Publishing: Orlando, 2016; pp. 245-270.
16. Chiurchiù, V.; Leuti, A.; Maccarrone, M. Bioactive lipids and chronic inflammation: managing the fire within. *Frontiers in immunology* **2018**, *9*, 1-11, <https://doi.org/10.3389/fimmu.2018.00038>.
17. Chen, B.; McClements, D.J.; Decker, E.A. Design of foods with bioactive lipids for improved health. *Annual Review of Food Science and Technology* **2013**, *4*, 35-56, <https://doi.org/10.1146/annurev-food-032112-135808>.
18. Gaur, P.K.; Pal, H.; Puri, D.; Kumar, N.; Shanmugam, S.K. Formulation and development of hesperidin loaded solid lipid nanoparticles for diabetes. *Biointerface Research in Applied Chemistry* **2020**, *10*, 4728-4733, <https://doi.org/10.33263/BRIAC101.728733>.
19. Aluko, R. Bioactive lipids. In: *Functional foods and nutraceuticals*. Springer: New York 2012; pp. 23-36, <https://doi.org/10.1007/978-1-4614-3480-1>.
20. Liu, Y.; Xue, C.; Zhang, Y.; Xu, Q.; Yu, X.; Zhang, X.; Wang, J.; Zhang, R.; Gong, X.; Guo, C. Triglyceride with medium-chain fatty acids increases the activity and expression of hormone-sensitive lipase in white adipose tissue of C57BL/6J mice. *Bioscience, Biotechnology, and Biochemistry* **2011**, *75*, 1939-1944, <https://doi.org/10.1271/bbb.110321>.
21. Chackalamannil, S.; Rotella, D.; Ward, S. *Comprehensive Medicinal Chemistry III*. Elsevier: USA 2017.
22. Berger, E.; Nassra, M.; Atgié, C.; Plaisancié, P.; Géloën, A. Oleic acid uptake reveals the rescued enterocyte phenotype of colon cancer Caco-2 by HT29-MTX cells in co-culture mode. *International Journal of Molecular Sciences* **2017**, *18*, <https://doi.org/10.3390/ijms18071573>.
23. Paniagua, J.A.; de la Sacristana, A.G.; Sánchez, E.; Romero, I.; Vidal-Puig, A.; Berral, F.J.; Escribano, A.; Moyano, M.J.; Pérez-Martínez, P.; López-Miranda, J.; Pérez-Jiménez, F. A MUFA-rich diet improves postprandial glucose, lipid and GLP-1 responses in insulin-resistant subjects. *Journal of the American College of Nutrition* **2007**, *26*, 434-444, <https://doi.org/10.1080/07315724.2007.10719633>.
24. Joris, P.J.; Mensink, R.P. Role of cis-monounsaturated fatty acids in the prevention of coronary heart disease. *Current Atherosclerosis Reports* **2016**, *18*, 38, <https://doi.org/10.1007/s11883-016-0597-y>.
25. Castro, A.V.B.; Kolka, C.M.; Kim, S.P.; Bergman, R.N. Obesity, insulin resistance and comorbidities? Mechanisms of association. *Arquivos Brasileiros de Endocrinologia & Metabologia* **2014**, *58*, 600-609, <http://dx.doi.org/10.1590/0004-2730000003223>.
26. Juárez-Hernández, E.; Chávez-Tapia, N.C.; Uribe, M.; Barbero-Becerra, V.J. Role of bioactive fatty acids in nonalcoholic fatty liver disease. *Nutrition journal* **2015**, *15*, <https://doi.org/10.1186/s12937-016-0191-8>.
27. Manson, J.E.; Cook, N.R.; Lee, I.M.; Christen, W.; Bassuk, S.S.; Mora, S.; Gibson, H.; Albert, C.M.; Gordon, D.; Copeland, T.; D'Agostino, D.; Friedenberg, G.; Ridge, C.; Bubes, V.; Giovannucci, E.L.; Willett, W.C.; Buring, J.E. Marine n-3 fatty acids and prevention of cardiovascular disease and cancer. *New England Journal of Medicine* **2019**, *380*, 23-32, <https://doi.org/10.1056/NEJMoa1811403>.
28. Yagi, S.; Fukuda, D.; Aihara, K.I.; Akaike, M.; Shimabukuro, M.; Sata, M. N-3 polyunsaturated fatty acids: Promising nutrients for preventing cardiovascular disease. *Journal of Atherosclerosis and Thrombosis* **2017**, *24*, 999-1010, <https://doi.org/10.5551/jat.RV17013>.
29. Lauritzen, L.; Brambilla, P.; Mazzocchi, A.; Harsløf, L.; Ciappolino, V.; Agostoni, C. DHA effects in brain development and function. *Nutrients* **2016**, *8*, <https://doi.org/10.3390/nu8010006>.
30. Riediger, N.D.; Othman, R.A.; Suh, M.; Moghadasian, M.H.; A systemic review of the roles of n-3 fatty acids in health and disease. *Journal of the American Dietetic Association* **2009**, *109*, 668-679, <https://doi.org/10.1016/j.jada.2008.12.022>.

31. Turner, D.; Shah, P.S.; Steinhart, A.H.; Zlotkin, S.; Griffiths, A.M. Maintenance of remission in inflammatory bowel disease using omega-3 fatty acids (fish oil): A systematic review and meta-analyses. *Inflammatory Bowel Diseases* **2011**, *17*, 336-345, <https://doi.org/10.1002/ibd.21374>.
32. Bahramian, G.; Golestan, L.; Khosravi-Darani, K. Antimicrobial and antioxidant effect of nanoliposomes containing zataria multiflora boiss essential oil on the rainbow trout fillets during refrigeration. *Biointerface Research in Applied Chemistry* **2018**, *8*, 3505-3513.
33. Kanatt, S.R.; Siddiqui, A.; Chawla, S.P. Antioxidant/antimicrobial potential of *Emblca officinalis* Gaertn and its application as a natural additive for shelf life extension of minced chicken meat. *Biointerface Research in Applied Chemistry*, **2018**, *8*, 3344-3350.
34. Kanwal, Z.; Rahman, T.U.; Zeb, M.A.; Sajid, M. Antioxidant, alpha-amylase inhibitory and antiglycation activity of *Berberis royleana* roots. *Biointerface Research in Applied Chemistry* **2018**, *8*, 3725-3728.
35. Hassan A.; Ullah, H.; Israr, M. The antioxidant activity and phytochemical analysis of medicinal plant *Veronica biloba*. *Letters in Applied NanoBioScience* **2019**, *8*, 732-738, <https://doi.org/10.33263/LIANBS84.732738>.
36. Ammaji, S., Sunddep, C., Sandeep, K., Ashok, K., Praveen, K., Murali, B.S. In silico toxicity prediction, synthesis, characterization, antimicrobial and antioxidant activity of different di substituted chalcones. *Letters in Applied NanoBioScience* **2020**, *9*, 908-913, <https://doi.org/10.33263/LIANBS91.908913>.
37. Riane, K.; Sifour, M.; Ouled-Haddar, H.; Idoui, T.; Bounar, S.; Boussebt, S. Probiotic properties and antioxidant efficiency of *Lactobacillus plantarum* 15 isolated from milk. *Journal of Microbiology, Biotechnology and Food Sciences* **2019**, *9*, 516-520..
38. Duda A; Jeżowski, P.; Radzikowska, D.; Kowalczewski P.L. Partial wheat flour replacement with gluten-free flours in bread - quality, texture and antioxidant activity. *Journal of Microbiology, Biotechnology and Food Sciences* **2019**, *9*, 505-509.
39. Benmaghnia, S.; Meddah, B.; Tir-Touil, A.; Hernández, J.A.G. Phytochemical analysis, antioxidant and antimicrobial activities of three samples of dried figs (*Ficus carica* L.) from the region of mascara. *Journal of Microbiology, Biotechnology and Food Sciences* **2019**, *9*, 208-215, <https://doi.org/10.15414/jmbfs.2019.9.2.208-215>.
40. Dimcheva, V.; Karsheva, M. Optimization and comparison of different techniques for extraction of flavonoids of bulgarian mavrud grape by-products. *Journal of Microbiology, Biotechnology and Food Sciences* **2019**, *9*, 510-515.
41. Duman, A.; Mogulkoc, R.; Baltaci, A.K.; Sivrikaya, A. The effect of 3',4'-dihydroxyflavonol on plasma oxidant and antioxidant systems in testis ischemia-reperfusion injury in rats. *Biointerface Research in Applied Chemistry* **2018**, *8*, 3441-3445.
42. Sandig, G.; Seifert, M.; Herrling, T.; Jung, K. Selection of antioxidant mixtures for different categories of finished products. *Agro Food Industry Hi Tech* **2018**, *29*, 14-17.
43. Cazzola, R.; Garziano, M.; Porta, M.D.; Loreggian, L.; Cestaro, B. First insights of macadamia nut oil as dietary fat Potential health benefits. *Agro Food Industry Hi Tech* **2018**, *29*, 18-20.
44. Maki, K.C.; Eren, F.; Cassens, M.E.; Dicklin, M.R.; Davidson, M.H. ω -6 polyunsaturated fatty acids and cardiometabolic health: current evidence, controversies, and research gaps. *Advances in Nutrition* **2018**, *9*, 688-700, <https://doi.org/10.1093/advances/nmy038>.
45. Gangidi, R.R.; Lokesh, B.R. Conjugated linoleic acid (CLA) formation in edible oils by photoisomerization: a review. *Journal of Food Science* **2014**, *79*, R781-R785, <https://doi.org/10.1111/1750-3841.12449>.
46. den Hartigh, L.J. Conjugated linoleic acid effects on cancer, obesity, and atherosclerosis: A review of pre-clinical and human trials with current perspectives. *Nutrients* **2019**, *11*, <https://doi.org/10.3390/nu11020370>.
47. Mooney, D.; McCarthy, C.; Belton, O. Effects of conjugated linoleic acid isomers on monocyte, macrophage and foam cell phenotype in atherosclerosis. *Prostaglandins & Other Lipid Mediators* **2012**, *98*, 56-62, <https://doi.org/10.1016/j.prostaglandins.2011.12.006>.
48. Abedi, E.; Sahari, M.A. Long-chain polyunsaturated fatty acid sources and evaluation of their nutritional and functional properties. *Food Science & Nutrition* **2014**, *2*, 443-463, <https://doi.org/10.1002/fsn3.121>.
49. Elinder, F.; Liin, S.I. Actions and mechanisms of polyunsaturated fatty acids on voltage-gated ion channels. *Frontiers in physiology* **2017**, *8*, <https://doi.org/10.3389/fphys.2017.00043>.
50. Yui, K.; Imataka, G.; Nakamura, H.; Ohara, N.; Naito, Y. Eicosanoids derived from arachidonic acid and their family prostaglandins and cyclooxygenase in psychiatric disorders. *Current Neuropharmacology* **2015**, *13*, 776-785, <https://doi.org/10.2174/1570159x13666151102103305>.
51. Tallima, H.; El Ridi, R. Arachidonic acid: physiological roles and potential health benefits—a review. *Journal of Advanced Research* **2018**, *11*, 33-41, <https://doi.org/10.1016/j.jare.2017.11.004>.
52. Salem, N.M.; Lin, Y.H.; Moriguchi, T.; Lim, S.Y.; Salem Jr, N.; Hibbeln, J.R. Distribution of omega-6 and omega-3 polyunsaturated fatty acids in the whole rat body and 25 compartments. *Prostaglandins, Leukotrienes and Essential Fatty Acids* **2015**, *100*, 13-20, <https://doi.org/10.1016/j.plefa.2015.06.002>.
53. Milani, A.; Basirnejad, M.; Shahbazi, S.; Bolhassani, A. Carotenoids: biochemistry, pharmacology and treatment. *British Journal of Pharmacology* **2017**, *174*, 1290-1324, <https://doi.org/10.1111/bph.13625>.
54. Green, A.S.; Fascetti, A.J. Meeting the vitamin A requirement: the efficacy and importance of β -carotene in animal species. *The Scientific World Journal* **2016**, 1-22, <https://doi.org/10.1155/2016/7393620>.

55. Ono, M.; Takeshima, M.; Nakano, S. Mechanism of the anticancer effect of lycopene (tetraterpenoids). In: *The Enzymes*. Volume 37. Academic Press: USA 2015; pp. 139-166, <https://doi.org/10.1016/bs.enz.2015.06.002>.
56. Buscemi, S.; Corleo, D.; Di Pace, F.; Petroni, M.L.; Satriano, A.; Marchesini, G. The effect of lutein on eye and extra-eye health. *Nutrients* **2018**, *10*, <https://doi.org/10.3390/nu10091321>.
57. Verleyen, T.; Forcades, M.; Verhé, R.; Dewettinck, K.; Huyghebaert, A.; De Greyt, W. Analysis of free and esterified sterols in vegetable oils. *Journal of the American Oil Chemists' Society* **2002**, *79*, 117-122, <https://doi.org/10.1007/s11746-002-0444-3>.
58. Wadikar, D.; Lakshmi, I.; Patki, P. Phytosterols: An Appraisal of Present Scenario. *Acta Scientific Nutritional Health* **2017**, *1*, 26-27.
59. Ogbe, R.J.; Ochalefu, D.O.; Mafulul, S.G.; Olaniru, O.B. A review on dietary phytosterols: Their occurrence, metabolism and health benefits. *Asian Journal of Plant Science and Research* **2015**, *5*, 10-21.
60. Decker, E.A.; Elias, R.J.; McClements, D.J. *Oxidation in foods and beverages and antioxidant applications: management in different industry sectors*. Elsevier: USA 2010.
61. McClements, D.J. Design of nano-laminated coatings to control bioavailability of lipophilic food components. *Journal of Food Science* **2010**, *75*, R30-R42, <https://doi.org/10.1111/j.1750-3841.2009.01452.x>.
62. Clinton, S.K. Lycopene: chemistry, biology, and implications for human health and disease. *Nutrition Reviews* **1998**, *56*, 35-51, <https://doi.org/10.1111/j.1753-4887.1998.tb01691.x>.
63. Barak, S.; Mudgil, D.; Taneja, S. Exudate gums: chemistry, properties, and food applications – a review. *Journal of the Science of Food and Agriculture* **2020**, *100*, 2828-2835, <https://doi.org/10.1002/jsfa.10302>
64. Mudgil, D.; Barak, S. Mesquite gum (Prosopis gum): Structure, properties & applications-A review. *International Journal of Biological Macromolecules* **2020**, <https://doi.org/10.1016/j.ijbiomac.2020.05.153>
65. Drosou, C.G.; Krokida, M.K.; Biliaderis, C.G. Encapsulation of bioactive compounds through electrospinning/electrospraying and spray drying: A comparative assessment of food-related applications. *Drying Technology* **2017**, *35*, 139-162, <https://doi.org/10.1080/07373937.2016.1162797>.
66. Eun, J.B.; Maruf, A.; Das, P.R.; Nam, S.H. A review of encapsulation of carotenoids using spray drying and freeze drying. *Critical Reviews in Food Science and Nutrition* **2019**, 1-26, <https://doi.org/10.1080/10408398.2019.1698511>.
67. Munir, H.; Shahid, M.; Anjum, F.; Mudgil, D. Structural, thermal and rheological characterization of modified Dalbergia sissoo gum—A medicinal gum. *International Journal of Biological Macromolecules*, **2016**, *84*, 236-245, <https://doi.org/10.1016/j.ijbiomac.2015.12.001>
68. McClements, D.J.; Decker, E.A.; Park, Y. Controlling lipid bioavailability through physicochemical and structural approaches. *Critical Reviews in Food Science and Nutrition* **2008**, *49*, 48-67, <https://doi.org/10.1080/10408390701764245>.
69. Bush, L.; Stevenson, L.; Lane, K.E. The oxidative stability of omega-3 oil-in-water nanoemulsion systems suitable for functional food enrichment: A systematic review of the literature. *Critical reviews in food science and nutrition* **2019**, *59*, 1154-1168, <https://doi.org/10.1080/10408398.2017.1394268>.
70. Mahato, N.; Sharma, K.; Koteswararao, R.; Sinha, M.; Baral, E.; Cho, M.H. Citrus essential oils: Extraction, authentication and application in food preservation. *Critical reviews in food science and nutrition* **2019**, *59*, 611-625, <https://doi.org/10.1080/10408398.2017.1384716>.
71. Assadpour, E.; Jafari, S.M. A systematic review on nanoencapsulation of food bioactive ingredients and nutraceuticals by various nanocarriers. *Critical reviews in food science and nutrition* **2019**, *59*, 3129-3151, <https://doi.org/10.1080/10408398.2018.1484687>.
72. Sivapratha, S.; Sarkar, P. Multiple layers and conjugate materials for food emulsion stabilization. *Critical reviews in food science and nutrition* **2018**, *58*, 877-892, <https://doi.org/10.1080/10408398.2016.1227765>.