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Review Article

Plants-Derived Bioactive Compounds as Functional Food Ingredients and Food Preservative

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Abstract

In past few decades, consumers are more concern toward the healthy diet to improve physical and mental well-being status. In this context, plant bioactive compounds exhibiting functional activity could be played a remarkable role to prevent chronic health disease addition to the normal nutritive function. Unlike other food items, functional food products are also prone to microbial and oxidative deterioration. Microbial contaminations of functional food product not only spoil the items but also reduce or alter the necessary nutrients required for healthy growth. Indeed, a huge number of synthetic food preservative viz., sorbic acid, benzoic acid, propionic acid, salts, butylated hydroxytoluene and butylated hydroxyanisole etc., are currently being used to prevent the microbial and oxidative deterioration. In view of green consumerism, the uses of some of the chemical preservatives are restricted/under evaluation for their continuous application. In this perspective, plants-derived compounds exhibiting strong antimicrobial and antioxidant activity could be used as an eco-friendly food preservative. This review summarizes the potential application of plant-based bioactive compounds as a novel source of functional food ingredients and food preservative. It also highlights the potential application of recent advance in science and technology to improve the functional and preservative potential of existing bioactive compounds and their large scale production.

Keywords: Antimicrobial; Antioxidant; Essential oils; Food grains; Functional food

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Introduction

In the modern era of 21st century, the lifestyle and eating habit of consumers have changed considerably. The increase in life expectancy and changes in food habits preferably high caloric and unbalanced diets adjunct to stressful environment leads to the emergence of severe diseases such as type 2 diabetes, obesity, osteoporosis and cardiovascular diseases, Alzheimer or Parkinson etc. Even since, the cure of most of the newly emerged diseases required long-term medicinal treatments which may negatively affect other physiological function of the body. Therefore, food industries, researchers, health professionals and regulatory authorities are looking towards to safer alternative to reduce the incidence of such lethal diseases especially for old-age people. In this context, functional food (food that provide health benefits beyond the essential nutrients) either as intact or in fortified form with other food could be considered as safe alternative to prevent the probability of occurrence of such disease. The concept of functional food was first introduced in 1984 in Japan to improve the consumer's health through the diet fortified with functional ingredient [1]. Thereafter, an exhaustive research studies have been performed to identify and elucidate the functional food ingredient. Food grains viz., legumes and cereals are the richest source of dietary fibre, proteins, energy, minerals, vitamins and antioxidants that have been recognised as functional food ingredient. Due to enormous beneficial potential of functional food and their direct link with health, the global demand of such product is increasing day by day. Therefore, food industries have shown a positive trend towards the development of food product fortified with functional ingredients. Indeed, a number of functional food products viz. such as dietary supplements, medical foods and food additives have already available in market [2]. Unlike other food items, functional foods products are also prone to microbial contamination during prolonged unscientific storage condition. Microbial contaminations of functional food product not only spoil the items but may also reduce or alter the necessary nutrients required for healthy growth [3]. In addition, oxidative deterioration of developed product may impose undesirable changes such as lipid peroxidation, nutritional loss, off-flavor and color impairment [4]. Hence, the cumulative effect of both microbial and oxidative deterioration could negatively influence the nutritional value and the functional activity and could decrease consumers' acceptance. To prevent the microbial and oxidative deterioration several synthetic food preservative viz., sorbic acid, benzoic acid, propionic acid, salts, BHT, BHA etc., are currently being used by the industries. However, in view of the recent consumer awareness towards green consumerism some of the commercially available synthetic preservatives are not reliable/under evaluation for their continuous application [4]. In this context, plant products exhibiting strong antimicrobial and antioxidant potential could be considered as sustainable substitute to the health hazardous synthetic preservatives [5]. This review summarizes the potential use of plant-based bioactive compounds as functional food ingredients and as food preservatives. It also highlights the potential application of recent advance in science and technology to improve the functional and preservative potential of existing products and their production on a large scale. In addition, future research direction towards the development of plant based functional food and preservatives are discussed.

Plants-derived Bioactive Compounds as Functional Food Ingredients

Since ancient time, plant products have been used in traditional practices for the treatment of chronic health diseases. According to the World Health Organization approximately 80% of the world population still relied on traditional practices for primary healthcare [6]. The plant kingdom harbour complex mixture of bioactive compounds viz. terpenes, carotenoids, limonoids, saponin, polyphenols etc., exhibiting diverse biological properties. Traditionally used food grains, millets, fruit and vegetables are the richest source of functional ingredients claiming beneficial physiological effects addition to the nutritive function [7-12]. Bioactive compound and crude extract of some of the traditional used plants viz., soy extracts (isoflavones), tomato extracts (lycopene), Spinach and collard greens (Lutein/zeaxanthin), Oat (β-Glucan) and extract of garlic oil, rosemary extracts and green tea have already been used as food supplement to boost the health [13]. Being natural in origin, the plant products are often perceived by consumers and industries as safe products. Therefore, currently the food industries are looking towards the development of plant based fortified food products with low in saturated fat, high nutritive value, enriched functional bioactive compounds to reduce the risk of chronic diseases, the so-called functional foods. Garlic (*Allium sativum*) is the richest source of physiologically active organ sulfur components (e.g., allicin, allylic sulfides) that significantly reduce the blood pressure [14,15]. Curcumin, a golden drug of diverse pharmacological application has been extracted from Curcuma sps that has been used as traditional medicine to cure disease in developing countries. The golden milk prepared with the purified extract of curcuma is commercially available in European Countries. A number of plant bioactive compounds viz., curcumin, resveratrol, quericitin, propolis and PUFAs etc., are well known for their potential to prevent the neurodegenerative disorders such Alzheimer's Disease (AD) [16]. The bioactive constituent of Green tea viz., (-)-epicatechin, (-)-epicatechin-3-gallate, (-)-epigallocatechin and (-)-epigallocatechin-3-gallate showed strong antioxidant properties [17]. Food grains and cereals such as Rice, Wheat, Maize, Sorghum Millets, Ragi and Oats are the vital source micronutrients such as vitamin E, folates, phenolic acids, zinc, iron, selenium, copper, manganese, carotenoids, betaine, choline, sulphur amino acids and dietary fibres [18]. In this regards, there is strict need of exhaustive research on exploitation of traditional used plant as a reservoir of bioactive compounds. Furthermore, before the product formulation exhaustive research and clinical trial must be performed to ensure low dose efficacy underlying the mechanism of action inside the body. Table 1 represents the bioactive compounds exhibiting strong functional activity extracted from traditionally used plant source.

Plant-Derived Bioactive Compounds as Food Preservatives

Microbial contamination is one of the major causes of food spoilage during prolong storage. According to World Health Organization nearly 2 billion people are suffering from illnesses due to food borne microbes annually [50]. Food-borne microorganism such as bacteria moulds and their associated toxins may cause significant losses in their quantity as well as quality. It has been estimated that approximately 1000 million metric tons of food is spoiled globally each year due to microbial spoilage [51]. Oxidative deterioration of bioactive compound may cause rancidity leads to decrease in the functional and nutritional quality [52]. The current available physical (aeration, cooling and thermal process) as well as chemical (ammonia, organic acid and their salts) method of food preservation may cause undesirable effect on nutritional and overall quality. The recent scientific reports confirmed the negative impact of synthetic preservatives on overall quality of food, human health and environment. Like the traditional food items, functional food are also prone to microbial and oxidative deterioration, therefore, its preservation strategies by means of natural product must be develop to maintain their bioactivity with enhanced shelf-life.

In this context, traditionally used plant products exhibiting strong antimicrobial and antioxidant activity such as essential oils, alkaloids, flavonoids, phenylpropanoids, polyphenolics, terpenoid and plant Antimicrobial Peptides (pAMPs) could be used as safer alternatives of synthetic preservative [51,53]. Among all, essential oils obtained from aromatic plant received significant attention of food industries due to its strong antimicrobial and antioxidant potential. A number of plant products such as essential oils and their bioactive compounds such as angelica, basil, citrus peels, lemongrass, thyme, ylang-ylang, carvone, cinnamaldehyde, citral, p-cymene, eugenol, limonene, menthol, linalool, etc., have been recognised as GRAS (Generally Recognised as Safe) category. A plethora of plant essential oils and its bioactive compounds exhibited strong antimicrobial (against food-borne pathogenic bacteria (*Clostridium perfringens, Escherichia coli, Listeria monocytogenes, Salmonella sp., Staphylococcus aureus, Shigella sp and Yersinia enterocolitica*), antifungal (*Aspergillus flavus*, *Fusarium* spp., *Penicillium* spp., *Alternaria* spp., Mucor etc.,) and antioxidant potential [51,54]. Bioorganic (clove oil [5%], 2-phenethyl propionate [5%], sesame oil [4%] and sodium lauryl sulphate [0.5%]), Green Match EX (lemongrass oil [50%] and a mixture of water, corn oil, glycerol esters, potassium oleate and lecithin), Matran II (clove oil [46%], wintergreen oil, butyl lactate, lecithin), Eco-Exempt (2-phenethyl proprionate [21.4%], clove oil [21.4%]), and DMC Base Natural (50% essential oils from rosemary, sage and citrus and 50% glycerol) are some of the essential oils based formulation commercially available as antimicrobial agent [55,56]. Secondary metabolite products of endophytic fungi associated with leaves of bush mango exhibited strong antimicrobial activity [57]. Table 2 and 3 represents the bioactive compounds exhibiting strong antimicrobial and antioxidant activity extracted from traditionally used plant source.

The Existing Hurdles of Plant-Derived Bioactive Compounds as Functional Food and As Preservative

Plants bioactive compounds exhibited remarkable potential as source of functional food ingredient and preservatives agents. They have certain limitation such as high dose requirement in food system, poor bioavailability, unknown mode of action, availability of raw material etc., [51,70]. In general plant bioactive compound exhibiting functional and preservative potential required much higher doses compared to the physiologically relevant in vivo dose. Further, the complex interaction between the food and fortified ingredient either

	Compounds	**Plant source**	**Application**	**Ref**
Dietary fibres				
	β-glucan	Cereals (Oat, Wheat, Barley)	Positive therapeutic effects on coronary heart disease, reductions of cholesterol and glycemic response	[7-9]
	Oligosaccharides	Cereals (Oat, Wheat, Barley)	Effective in stimulating the growth of bifidobacteria and lactobacilli in human large intestine	[10,11]
	Resistant starch	Cereals (Oat, Wheat, Barley)	Provides fermentable carbohydrates to colonic bacteria for production of desirable metabolites including short-chain fatty acids in the colon	[12]
Omega-3 fatty acid (Polyunsaturated Fatty Acids)				
	Linolenic acid	Flax, chia, walnuts, canola oil	Inhibition of mammary carcinogenesis, decrease body fat and increase bone density	[19-21]
Terpenes				
	Carotenoids	Fruits and vegetables	Biological antioxidants, protecting cells and tissues from the damaging effects of free radicals and singlet oxygen	[22,23]
	Limonoids	Peels of citrus fruits	Protection of lung tissue, clearing congestive mucus from the lungs of patients with chronic obstructive pulmonary disease, cancer and cardioprotective effects	[24,25]
	Saponins	Legumes specially soyabeans	Cholesterol lowering, antioxidant, anticancer, and immunostimulatory properties	[26,27]
	Chromanols	Palm oils and whole grain germ and/or bran	Inhibit breast cancer cell growth, cardiovascular health effects	[28]
Polyphenols				
	Phenolic acids	Fruits (blueberries, kiwis, plums, cherries, apples) and edible plants (peanuts, tomatoes, carrots, and garlic)	Antioxidant properties, lower the risk of stomach cancer by reducing the formation of carcinogenic nitrosamines	[29, 30]
	Flavonoids	onions, curly kale, leeks, broccoli, blueberries, Citrus fruits	lower incidence of heart disease, ischemic stroke, cancer, and other chronic diseases, antioxidant activity	[31-35]
	Lignans	Flaxseed, sesame seeds, cereals (triticale and wheat), leguminous plants (lentils, soybeans), fruits (pears, prunes), and certain vegetables (garlic, asparagus, and carrots)	antioxidant and (anti)estrogenic properties, reduce the risk of certain hormone-related cancers and cardiovascular diseases	[36-39]
Phytosterols and phytostanols		Cereals (corn, wheat, rye, and rice), fruits, vegetables, cotton seed, peanut, and linseed oils	Cholesterol-lowering, anti-inflammatory, antiatherogenicity, anticancer, and antioxidative activities	[40-45]
Organ sulfur compounds		Cruciferous vegetables, such as broccoli, brussels sprouts, cabbage, kale, and turnips (brassica spp.), and the onion (Allium spp.) And mustard (sinapis spp.)	Antibacterial, antiviral, antifungal, strong antioxidants, antiatherosclerotic and anticancer activities, especially for those of the gastrointestinal tract.	[46-49]

Table 1: List of some plant derived bioactive compounds and their potential application as functional food ingredients.

as functional or preservative agent is lacking that may pose risk to the consumer health. Curcumin, a polyphenolic compound derived from *Curcuma longa* exhibited strong anti-inflammatory, antioxidant, antiproliferative and antiangiogenic activities. Although, curcumin is regarded as magic bullet it exhibit deprived bioavailability due to poor absorption, rapid metabolism and rapid systemic elimination [70]. The recent advance in science and technology may overcome the existing limitations by the use of suitable adjuvants, encapsulation technique as well as synthesis of structural analogues of plant bioactive compounds. Hence, before the development of plant based functional food ingredient their interaction inside the inherent food components and effect on consumer health must be studied. In addition, consumer awareness programmes along with effective regulation and standardization procedure must be formed. Similarly, plant based food preservatives also have some technological drawbacks such as high volatility, reactivity, poor water solubility, scarcity of raw material, photochemical variation and unknown mode of action [4]. The recent advance in science and technology such as biotechnology, combinatorial chemistry, nanotechnology, active packaging have enormous potential to address these existing limitations with enhanced antimicrobial activity.

Concluding Remarks and Future Perspectives

Plants derived natural products holds promise as novel source of functional food ingredients and eco-friendly food preservative. The literature study revealed that most of the study lacking strong scientific evidence related to their effectiveness in food system. Therefore, there is a strict need for research to elucidate the interaction of fortified functional/preservative ingredients to the inherent bioactive molecule of food, and their safety to the consumer's health. The search of novel bioactive compounds from traditional source and elucidation of its metabolic pathway is also needed for the sustainable production of plant based bioactive compounds. Further, the effective combinations strategies of already exploited bioactive compounds with suitable adjuvant must be performed to reduce the effective dose with enhanced bioavailability. Therefore, a comprehensive multidisciplinary team works involving scientists with different expertise in plant science, molecular biology, agronomy, food engineering and environmental chemistry etc., are needed to address the key challenges. In addition,

Plant	Method Used	Results	Ref.
Piper betle L.	DPPH Assay	Essential oil exhibited strong antioxidant activity (IC_{50} 3.6g/ml)	[52]
Ocimum gratissimum L.	DPPH Assay	Exhibited strong DPPH scavenging activity IC_{50} =5.51 µl/ml and moderate linoleic acid oxidation inhibition 27.12%	[58]
	β-carotene/linoleic acid assay		
Zanthoxylum alatum Roxb.	DPPH Assay	IC_{50} 5.6 µl/ml for DPPH Assay, linoleic acid oxidation inhibition was 27.12%	[59]
	β-carotene/linoleic acid assay		
Origanum majorana L.,	DPPH Assay	Essential oils exhibited potent free radical scavenging activity IC_{50} value ranged between 1.30 µl/ml - 21.67 µl/ml, while linoleic acid oxidation inhibition is 8.30%-51.28%	[60]
Coriandrum sativum L, *Hedychium spicatum* Ham. ex Smith, *Commiphora myrrha* (Nees) Engl, *Cananga odorata* Hook.f. & Thomson	β-carotene/linoleic acid assay		
Cinnamomum glaucescens	DPPH Assay	Essential oils exhibited moderate free radical scavenging activity with IC_{50} 15.11 µl/ml	[61]
Boswellia carterii Birdw	DPPH Assay	IC_{50} =0.64 µl/ml for DPPH	[5]
	β-carotene/linoleic acid bleaching assay	Linoleic acid oxidation inhibition was recorded 51.68% compared to synthetic antioxidant BHT 69.60%	
Rosmarinus officinalis L.	DPPH Assay	The IC_{50} value for DPPH and percentage inhibition of linoleic acid peroxidation was 0.042 µl/ml and 71.05% respectively	[51]
	β-carotene/linoleic acid bleaching assay		
Cinnamomum zeylanicum Blume	FRAP, ABTS+ and DPPH Assay	DPPH-5.47mM trolox/mg,	[62]
		FRAP-11.99mM trolox/mg	
		ABTS-2.66mM trolox/mg	

Table 2: Plant derived bioactive compounds exhibiting strong antioxidant activity.

Plant	Major compounds	Targeted pathogen	Methods	Results	Ref
Brassica juncea	Sinapic acid, sinapoyl conjugates	*B. subtilis, E. coli, L. monocytogenes,*	Serial dilution method	*B. Juncea* extract caused complete inhibition of test microorganism at 0.1 g/l	[63]
		Pseudomonas fluorescens, and S. aureus			
Cymbopogon citratus	Ge¬ranial (citral), neral, geraniol, nerol, citronellol, 1,8-cineole (euca¬lyptol), α-terpineol, linalool, geranyl acetate	*B. cereus, B. subtilis, E. coli, Klebsiella pneumoniae, L. monocytogenes, Pseudomonas aeruginosa, P. fluorescens, Salmonel-la choleraesuis, S. aureus,*	Disc diffusion method	Exhibited broad spectrum activity against food borne pathogens	[64,65]
Mentha piperita	Menthol, menthone	*Escherichia coli*	Micro-dilution broth method	Show the moderate inhibitory effect against human pathogen	[66]
		Staphylococcus aureus Enterobacter aerogenes Klebsiella pneumoniae			
Rosmarinus officinalis	A-pinene, bornyl acetate, camphor	*Escherichia coli Salmonella typhi*	Serial dilution method	Rosemary oil show the stronger antimicrobial activity	[67]
		Staphylococcus aureus			
		Bacillus subtilis			
Lonicera japonica	Trans-nerolidol caryophyllene oxide linalool p-cymene	*Bacillus subtilis, Staphylococcus aureus, Salmonella enteritidis, Escherichia coli*	Disc diffusion method	Essential oil exhibited potent antimicrobial activity. MIC was ranged between 50-125 µg/ml	[68]
Ocimum gratissimum	Methyl cinnamate, γ-terpinene	*Aspergillus flavus, A.fumigatus, A.sydowi, A.terreus, Alternaria alternate, Penicillium italicum, Fusarium nivale, Curvularia lunata, Cladosporium spp*	Poison food technique	Essential oil caused complete inhibition of test mold sps at 0.7 µl/ml	[58]
Piper betle	Eugenol, acetyleugenol	*Aspergillus flavus, A. Niger, A.fumigatus, A. sydowi, A. candidus, A. terreus, Penicillium italicum, Fusarium oxysporum, Cladosporium cladosporoides, Curvularia lunata, Alternaria alternata, Mycelia sterlia, Nigrospora sp. Mucor sp*	Poison food technique	MIC of essential oil against test mold sps was ranged between 0.3 to 0.7 µl/ml	[52]
Zanthoxylum alatum	Linalool, methyl cinnamate	*Aspergillus flavus, A. niger, Fusarium oxysporum,F. nivale Penicillium italicum, Cladosporium cladosporioides*	Poison food technique	Essential oils exhibited broad spectrum and the MIC against the A. flavus was 1.25 µl/ml	[59]
Cinnamomum glaucescens	1,8-cineole, 2-propenoic acid	*Aspergillus flavus, A.niger, A.fumigatus, A.sydowi, A.terreus, Alternaria alternate, Penicillium italicum, Fusarium nivale, Curvularia lunata, Cladosporium spp, Mucor*	Poison food technique	Antifungal activity of essential oil ranged between 46.85% and 75.95%	[61]
				100% inhibition of AB1 at 3.5 µL mL^{-1}	

Anethum graveolens	D-carvone, d-limonene	*Aspergillus flavus*	Poison food technique	MIC of *A. graveolens* seed and leaf oil was 1.25 and 7.0 µl/ml and AFB_1 inhibition was 1.0 and 6.0 µl/ml	[60,69]
Boswellia carterii	Phenyl ethyl alcohol, benzyl acetate	*Aspergillus flavus*	Poison food technique	Essential oil inhibited the growth and aflatoxin B_1 secretion at 1.75 and 1.25 µl/ml	[5]
Cinnamomum zeylanicum	Phenol, 2- methoxy-3-(2-propenyl), caryophyllene	*Aspergillus flavus*	Poison food technique	Essential oil exhibited broad fungitoxic spectrum ranged between 0.25 to 0.6 µl/ml. In addition, oil showed moderated cholinesterase inhibition.	[62]

Table 3: Antimicrobial efficacy of plants-derived natural products.

effective regulation and guideline must be outline at international and national level to assure its safety and world-wide application. Taken as a whole, the use of functional food is one of the best approaches to reduce the chronic disease through regular balanced diet that meet the demand of both weaker and economically stable consumers. We hope that the diverse application of all available means of science and technology could address the existing challenges to the functional food to maximize its health promoting effect with reduce disease risk in the near future.

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