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Comprehensive review on nutraceutical significance of phytochemicals as functional food ingredients for human health management

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Abstract

Plants have been claimed to possess potential therapeutic properties in the traditional medicine system and were used for treating a large number of diseases especially by tribal people. Furthermore, potential of plant derived medicines has not only contributed towards health and wellbeing of human but also has inspired the scientific community for novel drug development. Phytochemicals are plant components having discrete bio-activities with a variety of health benefits and are sometimes referred to as functional ingredients/ nutraceutical compounds and are identified as carotenoids, vitamins, minerals, fibers, fatty acids, peptides, proteins and secondary plant metabolites. Whereas, phenolics, terpenoids, glucosinolates, polyacetylene, phytosterols & phytostanols and non-digestible carbohydrates and are present in a good amount in fruits, vegetables, nuts, cereals and legumes. Various epidemiologic studies over decades have indicated that a continuous consumption of fruits and vegetables in regular diet is often correlated with decreased risk of cancer, cardiovascular diseases and age-related macular degeneration. However, identification, quantification, standardization of extraction techniques for different compounds and their incorporation in food products with higher stability are major focus areas for research personals and for commercial establishments to put them in direct use as food. Most of studies carried out presently primarily focuses on establishment of scientific rationale to support the use of phytochemicals as potential nutraceutical ingredients. Hence, a broad outline of different phytochemicals and their health concerns is essential as many of these phytochemicals have been reported to illicit both positive as well as negative biological effects.

Keywords: Phytochemicals, nutraceuticals, functional foods, food applications, disease management

Introduction

Presently, transition in lifestyle, changes in food consumption pattern combined with a high level of mental stress has resulted increased incidences of lifestyle related problems like heart disease, obesity, diabetes, cancer and hypertension [1, 2]. All these factors have contributed towards increased interest of consumers in specific food or food components which can maintain and improve health over a specific consumption period [3]. As a result, researchers has shifted their focus from identifying nutrients and amounts needed to prevent deficiency diseases, towards improving health and quality of life by incorporating and stabilizing such components in food products. The plant based bioactive compounds or 'phytochemicals' are non-nutritive compounds associated with protection against chronic degenerative diseases and have been used in traditional medicine system since humans have looked to nature to provide cures for various ailments and diseases [4]. In recent times, applications of phytochemicals have extended into other areas especially nutraceutical and functional foods [5]. The term nutraceutical is derived from two words "nutrition" and "pharmaceutical" and Stephen De Felice, the founder and chairman of Foundation for Innovation in Medicine (FIM), Cranford in 1989 has referred it to as "any substance that is a food or a part of a food which provides medical or health benefits including the prevention and treatment of disease" [6]. Nutraceutical is a product isolated or purified from foods that is generally sold in medicinal forms not usually associated with foods. There is an extremely wide range of functional ingredients which have been consumed knowingly or unknowingly over the time either in one or the other forms of food [2, 4, 7, 8]. Some functional ingredients/ bioactive or nutraceutical compounds identified by various researchers have been summarized in Table 1. Hence, keeping in view the potential of these compounds in health care system, the present article has been compiled to provide a comprehensive review of different types of phytochemicals along with their health-promoting activities and potential use as functional food ingredient or food supplements. This review focuses on health benefits of specific phytochemicals, however toxic nature of these phytochemicals is not discussed in this document.

Phytochemicals

Phytochemicals (derived from Greek word *phyto*, meaning "plant") are bio chemicals produced in plants by primary or secondary metabolic processes and possess biological activity and are important in plant growth or defence against pathogens or predators. Phytochemicals are generally not considered as essential diet components and are not required for sustaining normal life, but have been reported to possess some pharmacological properties [4, 9]. Numerous epidemiological studies suggested that diets rich in phytochemicals not only protect against chronic diseases [10, 11] but also helps to protect cellular systems from oxidative damage [12, 13, 14].

Classes of phytochemicals and their nutraceutical significance

In nature more than 4,000 phytochemicals have been catalogued till day and are mostly classified on the basis of their biological activity, physical characteristics and chemical characteristics [4, 15]. There has been a tremendous increase in the total number of identified phytochemicals in last decade with addition of some new secondary plant metabolites. The main classes of phytochemicals based on their particular distinctions and characters have been shown in Fig. 1 and are discussed below:

A) Phenolics

Phenolics constitute the largest category of phytochemicals in plant kingdom. Flavonoids, phenolic acids and stilbenes (sometimes also known as tannins) are most important phenolics which occur from less than 1mg/kg to up to 3000mg/kg in various foods [16]. They are general hydroxyl ion (-OH) containing group of chemical compounds in which hydroxyl group (-OH) is directly attached to an aromatic hydrocarbon group (C₆H₅OH). Phenolics exhibit several beneficial effects with their antioxidant properties as most important because of their role in suppressing free radical-mediated disease processes.

Phenolic acids

These compounds are very strong antioxidants and have been studied historically for their potential against oxidative damages which otherwise leads to various degenerative diseases. The most important phenolic in nature is chlorogenic acid. Some investigations have revealed that phenolic acids effectively inhibited mouse pre-adipocytes with enhanced apoptosis as well [17]. Role of dietary phenolics in suppression of weight gain and inhibition of fatty acid biosynthesis has been reported by many researches [18, 19, 20, 21]. Ferulic acid, one of the most important phenolic compounds found in rice bran oil has been exploited for its antioxidant activities [22, 23]. The presence of ferulic acid has been recorded in some other cereals (wheat and oats), coffee beans, apples, artichoke, peanuts, oranges and pineapples with varying proportions [24]. Hypolipidemic properties of ferulic acid are helpful in lowering obesity linked to high fat diet [25] and can also reduce serum cholesterol, protects liver injury and most importantly it is a potent tumor inhibitor [23, 26].

Stilbenes

Stilbenes are small molecular weight phenolics (approximately 200-300 g/mol), naturally present as plant monomers and oligomers. The most commercial use includes their application in aroma therapy products and dietary supplements. They are commonly known as tannins and can

be categorized into two classes i.e. hydrolyzable tannins and condensed tannins. They are produced in plants as a result of environmental stress, infection and exposure to excessive ultraviolet light and also minimize the inflicted damage [27]. Stilbenes are sometime compared with phytoestrogen as they have a close structural similarity to estrogens and they are also able to react with estrogen receptors [28]. Dietary stilbenes are gaining interest for their potential health benefits however, their bioavailability is very limited due to rapid metabolism and their excretion in partially digested forms which limits their use as potential nutraceuticals [29]. However, resveratrol is an important stilbene found in grape skin which has anti-inflammatory, anti-cancer and anti-oxidant activities [30, 31, 32, 33]. Chemo preventive activity of resveratrol is well documented. A daily dose of 40 mg resveratrol per kg body weight has been reported to increase mice survival with subcutaneous neuroblastomas from 0 to about 70 per cent [34]. A good amount of resveratrol is accumulated in wine during grape processing and regular consumption of red wine in appropriate amount is often cited as explanation for popular proverb 'French Paradox' [35] a term that describes the fact of a low risk of cardiovascular diseases especially in French people despite their food habits of consuming diet high in saturated fat [36]. Red wine has been reported to contain a higher amount of resveratrol which can effectively promote vasorelaxation, decrease platelet aggregation, reduce lipid peroxidation, suppress atherosclerosis and improve serum cholesterol and triglyceride concentrations [37, 38, 39, 40].

Flavonoids

Flavonoids constitute one of the largest groups under phenols and they are the compounds with low molecular weight and a wide spectrum occurrence [41]. Their antioxidant properties have been studied most widely however, recently much attention has been paid to their potential as inhibitory substances for various stages of tumour development. Flavonoids are further grouped into two different categories viz. anthocyanins and anthoxanthins. Anthocyanins are responsible for a wide range of colors (red, blue and purple) in fruits and vegetables and are also reported to have significant anti-inflammatory and anti-obese properties [42, 43]. Whereas, anthoxanthins are usually colorless or white to yellow molecules which are further classified into five sub classes including flavonols, flavanone, flavones, flavanols and isoflavones. Out of them, flavonols and flavones are most widely distributed anthoxanthins in fruits and vegetables. Quercetin, kaempferol and myricetin are the 3 most important flavonols. Quercetin and flavonoid content of some important fruits is shown in Fig. 2. Flavonols and flavones are generally distinguished from one another by the presence of a hydroxyl group at C₃ in flavonols. They are the heat sensitive compounds and losses during food preparation depends upon the type of cooking method and are present in highest concentrations in immature fruits [44, 45].

There has been a strong inverse association between occurrence of coronary heart diseases and flavonol and flavones intake. The anticarcinogenic, antiobesity and antiproliferative effects of flavonoids and quercetin are now well explained and they have been reported to inhibit adipogenesis and induce apoptosis [46, 47, 48, 49]. Genistein and daidzein are two major isoflavones having many pharmacological benefits and are gaining interest for their potential functional properties. Limited information is available on recommended dietary intake of individual polyphenols in literature, however Hertog *et al.* [45] found that

intake of 23 mg/day flavonol and flavones in Dutch diet effectively inflicted the nutraceutical action. On the other hand Justesen *et al.* [50] reported 28mg/day combined intake of flavones, flavonols, and flavanones. Whereas, dietary intake of polyphenols in general has been suggested at about 1g/day by Scalbert and Williamson [51] which is relatively very high compared with other known dietary antioxidants i.e. 10 times higher the intake of vitamin C and 100 times the intake of vitamin E and carotenoids. Fruits like grape, apple, cherry, pear and various berries contain good quantities of different polyphenols and the major health benefits associated to polyphenols intake has been listed in Table 2.

B) Terpenoids

Terpenoids are plant metabolites essential for normal growth, development and metabolism in different plants [4, 14, 52]. Terpenoids have a wide range of biological functions and have been used in preparation of functional foods, flavorings, bio-colorants pharmaceuticals, cosmetics, disinfectants and agrichemicals. The most commercial properties of these terpenoids includes their use as insect attractants and repellents, anti-feedants, toxins or antibiotic agents [53], whereas in food preparations, they are used as flavouring agents in non-alcoholic beverages (31ppm), ice creams (68ppm), candy (49ppm), baked foods (120ppm), gelatines and puddings (48-400ppm), and chewing gum (2300ppm) [54, 55]. Terpenoids are also well recognized for their role in stress response or defence mechanisms [56]. Several terpenoids have been studied and used as pharmacological agents to benefit human health. For example, artemisinin is such a terpenoids which is potentially used as an antimalarial drug [57]. Tocopherol, α -d-tocopherol (vitamin E) has been extensively reviewed for its antioxidant potential and is also reported effective apoptotic inducers for human breast cancer cells [58, 59].

Carotenoids, another important class of terpenoids are also colored (yellow, orange and red pigmented) compounds and are present in various fruits and vegetables with a very rich antioxidant profile [60]. Carotenes (γ -carotene, lycopene and lutein), a type of Carotenoids have a tissue specific biological activity and have been reported to protect against uterine, prostate, breast, colorectal and lung cancers [61, 62]. Whereas, the xanthophylls, another type of carotenoids acts symbiotically with other antioxidants and protect them from oxidation while, may exhibit tissue specific protection at the same time. Zeaxanthin, cryptoxanthin and astaxanthin are important forms of xanthophyll which are used as functional food ingredients in various preparations [63]. Whereas, D-Limonene, is the most common monocyclic monoterpene, which occur in highest amounts in orange peel oil and has been found to inhibit pancreatic carcinogenesis [63] induced in the hamster by *N*-nitrosobis (2-oxopropyl) amine and gastric carcinogenesis induced in wistar rats by *N*-methyl-*N*-nitro-*N*-nitrosoguanidine [64]. Limonoids have also been reported to provide protection to lung tissues against many ailments [65].

C) Glucosinolates

Glucosinolates (GLS) are sulphur-containing glucosides in cell vacuoles of cruciferous vegetables, especially the *Brassica spp.* (e.g. cabbage, broccoli) and also in some oilseeds such as rapeseed and in condiments such as mustard seed [66]. Glucosinolate (GLS) contents of major cruciferous vegetables are depicted in Fig 3. High glucosinolate content of brassica (kale, radish and broccoli) is often contributed to its anticarcinogenic properties [68, 69]. A large number of

naturally occurring isothiocyanates have been successfully isolated and used to prevent cancer in animals [70] though more attention has been given particularly to isothiocyanate from broccoli, known as sulforaphane which are principal inducers of a Phase II enzyme (quinone reductasem) which have a strong anti-cancerous activity. Fahey *et al.*, [71] demonstrated that 3 day old broccoli sprouts contained glucoraphanin (glucosinolate of sulforaphane) which were 10-100 times higher compared with corresponding mature plants.

D) Polyacetylenes

Polyacetylenes are chemically reactive natural metabolites isolated from different flora. Their occurrence is highest in *Apiaceae* (carrot, celery and fennel), *Araliaceae* (ginseng, *hedra spp.*) and *Asteraceae* (lettuce, chicory, sunflower and artichoke) families. Three such compounds *viz.* faltarinol, faltarindiol, and faltarindiol-3-acetate are natural pesticides released in carrots as natural defence against pest attack and have strong functional profile which have recently gained significant scientific attention as functional ingredient [72]. Faltarinol and faltarindiol are two most important but less abundant bioactive compounds among all [73] and preservative action of these compounds results from their antifungal properties [74]. Faltarinol is bioavailable in humans [75] with biological activities such as anti-inflammatory [76], stimulator of immune system [77], anti-platelet- aggregatory [78] and cytotoxicity [79]. However, faltarinol is allergic in nature while, faltarindiol and faltarinone are not allergenic [77]. Further, the beneficial effects of these compounds occur at relatively non-toxic concentrations and thus represent pharmacologically useful properties [73].

E) Phytosterols and Phytostenols

Plants contain a large variety of sterols, which are collectively known as '*phytosterols*'. This term is derived from Greek word '*phyton*' means plant and '*stereos*' means solid and till date more than 250 phytosterols have been identified and successfully isolated from various plants [80]. Phytosterols are largely derived from vegetable oils, cereals and fruits, while phytostanols are abundant and are present in good amount in corn, wheat, rye and rice. Phytosterols occur in five common forms *viz.* (i) free alcohol (FS), (ii) fatty-acid esters (SE), (iii) steryl glycosides (SG), (iv) acylated steryl glycosides (ASG) and (v) phytosteryl hydroxycinnamic-acid esters (HSE) [81] with all of them having a similar function as that of cholesterol in our body. Phytosterols and phytostanols are essentially derived from dietary sources and their content is especially high in oils (corn oil, rapeseed oil, soybean oil, and sunflower oil), nuts, seeds, and cereals [82]. Some of the most abundant phytosterols and phytostanols in our diet are sitosterol, sitostanol, campesterol and campestanol. Phytosterols and phytostanols are non-energetic but are reported to lower cholesterol [80], cancer protection [83], immuno-modulation and skin protection [84]. Some of the sources of important phytosterols along with their total phytosterols content are given in Table 3.

F) Non-Digestible Carbohydrates

Non-digestible carbohydrates (NDC) are complex, heterogeneous dietary substances derived principally from plants. There are 3 main types of NDC namely (i) non-starch polysaccharides (NSP), (ii) resistant starch (RS) and (iii) nondigestible oligosaccharides (NDOs). Non-digestible carbohydrates are essential diet constituents and inadequate intake may sometimes lead to gastrointestinal disorders

(constipation, diverticular disease, irritable bowel syndrome) and colorectal cancer^[89]. Dietary fibres are the analogous carbohydrates, which fall into two categories according to their solubility i.e. water-soluble fibre (non-starchy polysaccharides, mainly β -glucan) and water-insoluble fibre (lignin, cellulose, hemicelluloses and arabinoxylan). The structural complexity and almost similar nomenclature makes it difficult to classify non-starch polysaccharides (NSP). They however, are can be classified into three different groups based on their distinct mode of action, namely cellulose, non-cellulosic polymers and pectic polysaccharides. Cereal grains are main source of dietary fibres and a comparative view of total dietary fiber content in some commonly consumed grains is presented in Fig. 4. Nutritionally one of most important dietary fibre is β -glucan which have been recognised to be present in various forms with distinctly important positive therapeutic properties with protection against coronary heart disease and reduction of cholesterol and glycemic response^[93]. Oat bran is the most common and popular source of dietary fibre and is a good source of β -glucan (3-12%) which supports the growth of *Lactobacilli* and *Bifidobacteria*. Resistant starch (RS) forms another important class of non-digestible carbohydrate which surpasses digestion as it passes the gastrointestinal tract^[94] as it is cannot be hydrolyzed to D-glucose after consumption; however, it is sometimes fermented in colon. Four different classes of resistant starch RS-1, RS-2, RS-3 and RS-4 occur in

nature with each class having a specific role to play (Table 4). The resistance of each class to digestion is generally affected by milling, chewing and processing conditions. According to Southgate^[96], the most common food sources of RS includes whole or partly milled grains and seeds, potatoes, green bananas, some legumes, high-amylose starches. Foods on the basis of RS content can be categorized as low (1-2.5% e.g. cereals, biscuits, bread, pasta and boiled rice), medium (2.5-5% e.g. corn flakes, crispies and fried potatoes), high (5-15% e.g. lentil, peas, potatoes and cooked starch foods) and very high RS content (>15% e.g. potatoes, raw legumes, retrograded amylose and banana etc.). The RS content of different foods is generally affected by processing conditions such as pH, heating temperature and time, cooling cycles, freezing and drying. It has been reported that incorporation of modified resistant starch in food improve the functional properties of food i.e. crispness and expansion of products, mouthfeel, color and flavor^[100]. Fructans form an important group of non-digestible oligosaccharides (NDOs) naturally present in a good amount in onion, artichoke, chicory, garlic, banana, rye and barley and may be generated during processing. In food industry, simple oligosaccharides are used as bifidogenic substances or prebiotics and in some infant products with a vision to provide benefits similar to oligosaccharides present in human milk. These compounds have well documented functional properties some of which have been shown in Table 5.

Table 1: Important bioactive/nutraceutical compound along with their source and potential health benefits

Class	Source (s)	Potential health benefits
1. Fatty acids		
Conj. Linoleic Acid	Cheese, milk and meat products	Improved body composition, reduce different types of cancers
n-3 FA (DHA, EPA)	Mmustard, rapeseed, linseed and tree nuts	Reduce the risk of CVD, improve mental and visual health
2. Polyphenols		
Catechins	Tea, mustard cake, rape seed	Antioxidant, anti-carcinogenic
Flavones and Flavonone	Citrus fruits and soybean	Antioxidant, anti-carcinogenic
Phenolic acid A. Hydroxycinnamic B. Hydroxybenzoic acids	Coffee, wine, artichokes, basil, kale, mentha, rose, rosemary, rice, strawberries	Analgesic, anti-inflammatory, and prevention of arrhythmia, cancer, Antioxidant, support weight loss and prevention of cancer, reducing low-density lipoprotein (LDL) cholesterol
Stilbenes (Resveratrol)	Grapevine, berries and peanuts	protection against chronic diseases like cancer, cardiovascular and neurodegenerative pathologies
Flavonoids		
A. Anthocyanidine (Delphinidin, Malvidin, Pelargonidin, Cyanidin etc.)	Apple, black olive, blueberry, peach, cherry	Neutralizes free radicals, anti-carcinogenic
B. Flavan-3-ols (Proanthocyanidins)	Apples with skin, chocolate, dark, tea, green, brewed, wine, red, shiraz	Beneficial for metabolic and cardiovascular health
C. Flavonols (Isorhamnetin, Kaempferol, Myricetin, Quercetin)	Blueberries, Broccoli, Chili peppers, Kale, Spinach, Cowpea	Anti-inflammatory, antimicrobial, anticancer, cardioprotective, neuroprotective, antidiabetic
D. Flavanones (Hesperetin, Eriodictyol, Naringenin)	Citrus fruits (oranges, grapefruits, lemons)	It acts as a strong antioxidant, have very high free radical scavenging activity, its antioxidant activity owes to its ability to increase superoxide dismutase (SOD) and catalase activities
E. Flavones (Apigenin, Luteolin)	Celery hearts (green), celery, parsley, peppermint, Thyme	Neuro-protective, anti-inflammatory, prevention of neuro inflammation, enhanced cognitive and monastic functions
F. Isoflavones (Diadzein, Glycitein, Genistein)	Soybeans and soy foods, legumes Soy based fermented foods	Lowering of low-density lipoproteins, lower breast cancer, decrease risk of endometrial cancer, can reduce hot flushes in menopausal symptoms
3. Terpenoids		
(Salvinorin, cannabinoids, ginkgolide, curcuminoids)	Citral, menthol, camphor, <i>Salviadinorum</i> , cannabis, ginkgo biloba, turmeric and mustard seed.	Anti-feedants in plants, important as signal transducers and growth regulators, antimalarial, anti-ulcer, hepaticidal, antimicrobial and anti-diuretic
4. Glucosinolates (Isothiocyanates, sulforaphane gluconasturtiin, glucoraphanin, glucomoringin)		
	Cauliflower, cabbage, broccoli, bok choy, turnip, kohlrabi, rapeseed, radish	Antibacterial and antifungal activities of isothiocyanates Detoxification of undesirable compounds and improve antioxidant defense system
5. Pollyacetylene		
Falcarinol Falcarindiol	Parsley, bishop's weed, celery, coriander, asafoetida, ajowan	Anti-platelet-aggregatory, anti-inflammator and antibacterial; Neurotoxicity; Allergenicity

6. Phytosterols and Phytotanol	Mostly in oils (corn, rapeseed, soybean and sunflower) nuts, seeds and cereals	They are used as food supplements in form of non-pharmacologic serum and low density lipoprotein
7. Non Digestible carbohydrates	Legumes, bananas, potatoes, and foods prepared from modified starches (e.g. bread and nutrition bars)	Increases stools bulk, acts as prebiotic food, reduces LDL cholesterol levels, hypoglycemic effect, reduced CHD risk factors, some cancer
8. Saponins	Soybeans, chickpea, haricot bean, alfalfa, quinoa	Lower cholesterol, anticancer, accelerated cholesterol degradation, antioxidant, antibiotic and fungicidal properties
9. Phytoestrogen		
Isoflavones- Daidzein and genistein	Soybean, flax seeds, lentil seed, maize	Influences menopause symptoms, improve bone and brain health
Lignans	Flax seeds, rye and some vegetables	Anticancer reduces occurrence of heart diseases
10. Carotenoids		
β - carotene	Carrots, vegetables, mango, papaya etc.	Neutralizes free radicals
Luteine, Zeaxanthine	Vegetables, marigold, eggs, citrus	Improve healthy vision
Lycopene	Tomato & tomato products	Reduce occurrence prostate cancer
11. Dietary fiber		
Insoluble dietary fiber	Wheat bran, rice bran, raw fruits	Reduce chances of breast cancer, healthy digestive system
Whole grain, β -glucan	Cereal grains, Oats	Reduce the risk of CVDs

Source: [3, 4, 5, 6, 7, 11, 14, 24, 36, 101].

Table 2: Major health benefits of polyphenols intake

Reduce the risk of high blood cholesterol and myocardial infarction concentrations and anti-carcinogenic
Protect against inflammation and neurotoxic drugs
Inhibit platelet aggregation and non-heme iron absorption
Improve endothelial dysfunction
Induce apoptosis of human oral tumour cell lines
Reduce plasma lipid peroxidation
Prevention Neuro-degenerative diseases
Inhibit each stage of multistage carcinogenesis
Inhibit oxidation of LDL
Treatment to prevent osteoporosis and diabetes
Prevent dental caries and colon carcinogenesis
Induce tumour cell death

Source: Adapted from Thakur and Sharma [4].

Table 3: Total phytosterols contents of selected foods

Phytosterol food sources	Total phytosterols content (mg/100g)	Phytosterol food sources	Total phytosterols content (mg/100g)
Rice bran	1055	Beet root	25
Corn	952	Brussels sprout	24
Wheat germ	553	Cauliflower	18
Flax seed	338	Onion	15
Cottonseed	327	Carrot	12
Soybean	221	Cabbage	11
Peanut	206	Yam	10
Olive	176	Cashew	158
Coconut	91	Almond	143
Palm	49	Pecan	108
Orange	24	Pistachio	108
Banana	16	Walnut	108
Apple	12	Pea	135
Cherry	12	Kidney bean	127
Peach	10	Broad bean	124
Pear	8		

Source: [26, 85, 86, 87, 88].

Table 4: Different types of resistant starch (RS) their potential health benefits

Type of RS	Property	Food sources
RS-1 Physically inaccessible starch	It is physically inaccessible or digested very slowly and incompletely as is entrapped inside the milled grains, heat soluble	Whole grains, milled grains, some legumes
RS-2 Native starch granules	It is native, uncooked granules of starch, high amylose starch, crystalline structure is retained during processing and makes it poorly susceptible to hydrolysis	high-amylose maize starch, potatoes
RS-3	non-granular starch-derived retrograded starch, formed during processing and	Potatoes, bread and mostly

Retrograded starch	storage at low temperature, higher water holding capacity, resistant to digestion by pancreatic amylases	formed during processing of food
RS-4 Chemically modified starch	It is chemically modified starch which is resistant to digestion. Formed due to crosslinking etherisation or esterification with chemicals so as to decrease their digestibility.	Drinks, breads and cakes

Sources: [94, 95, 96, 97, 98, 99].

Table 5: Physiological and functional effects of non-digestible oligosaccharides (NDOs)

Major health benefit
Non-carcinogenic
Anti-diabetic
Hypoglycaemic effect
Stimulates growth of beneficial bacteria in colon
Hypocholesterolemic effects
lowers risk of infections and diarrhoea
Improves and enhances the response of immune system
Increases the bioavailability of minerals (calcium, phosphorus, iron, and zinc)
Inhibition of fat accumulation
Reduction of gall stone formation

Source: [93, 94, 97, 101, 102, 103].

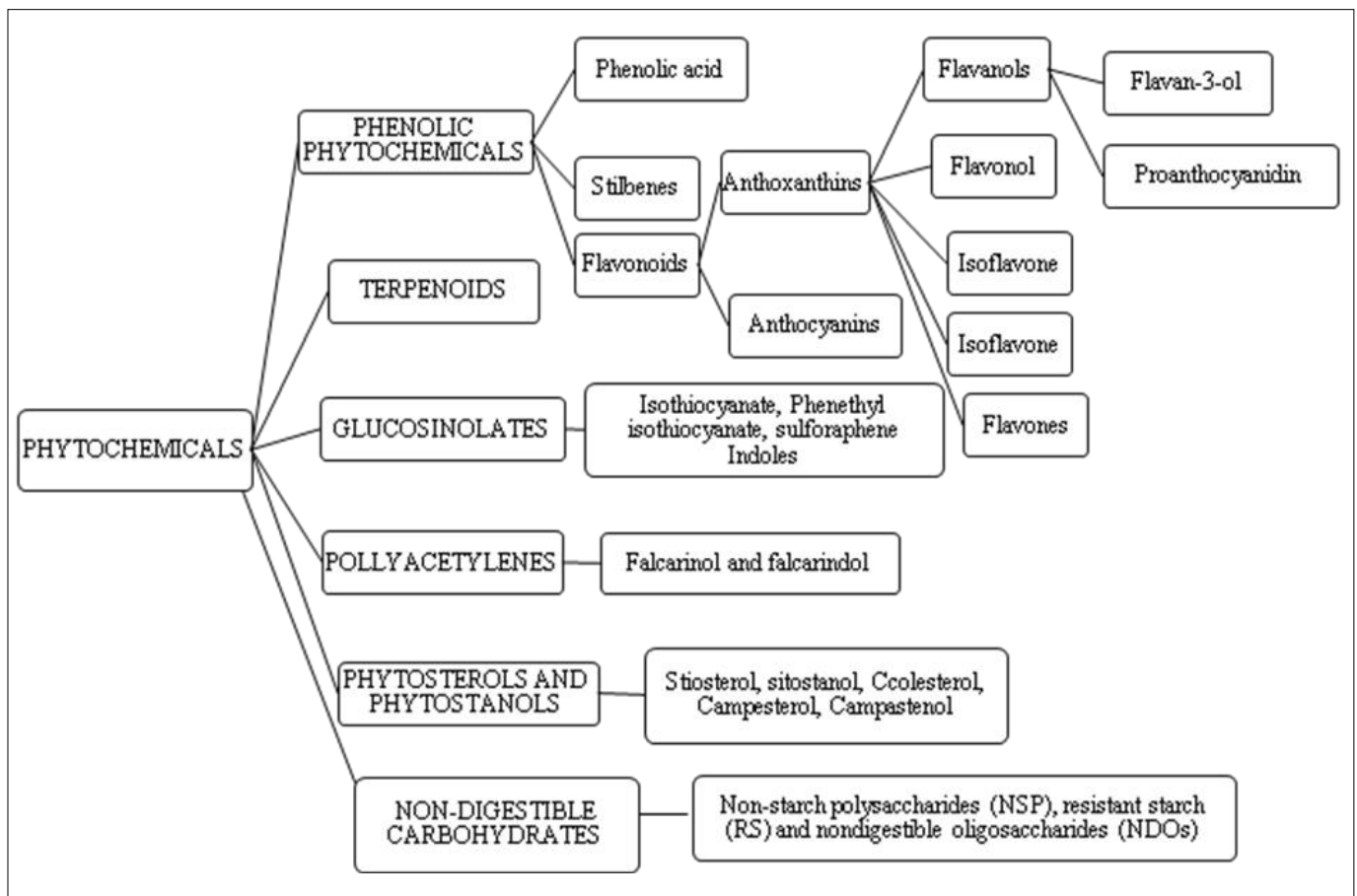


Fig 1: Different classes of phytochemicals [4, 9, 15, 95].

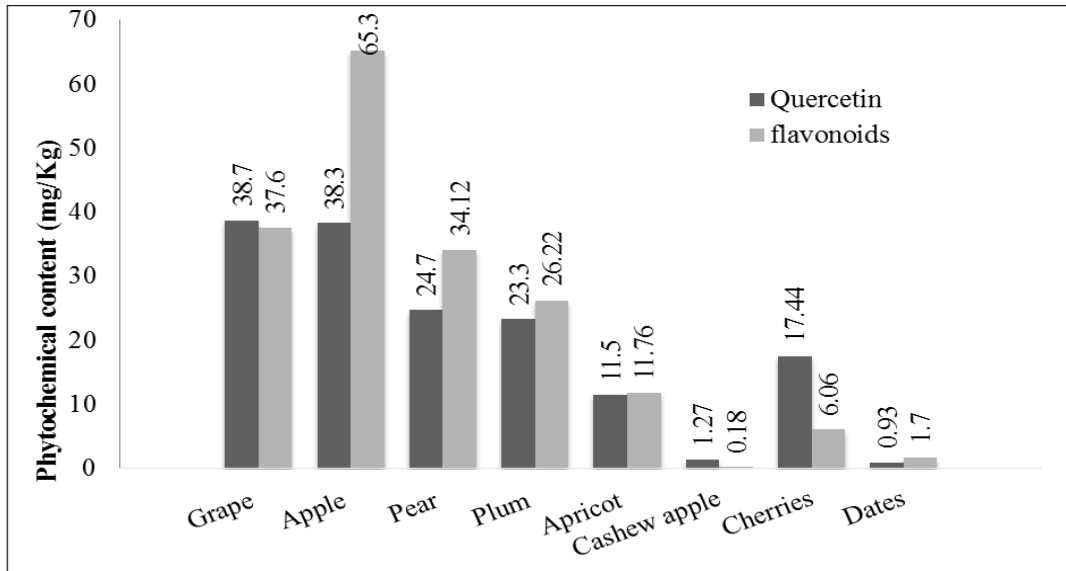


Fig 2: Quercetin and flavonoid content of some important fruits [4, 66, 67].

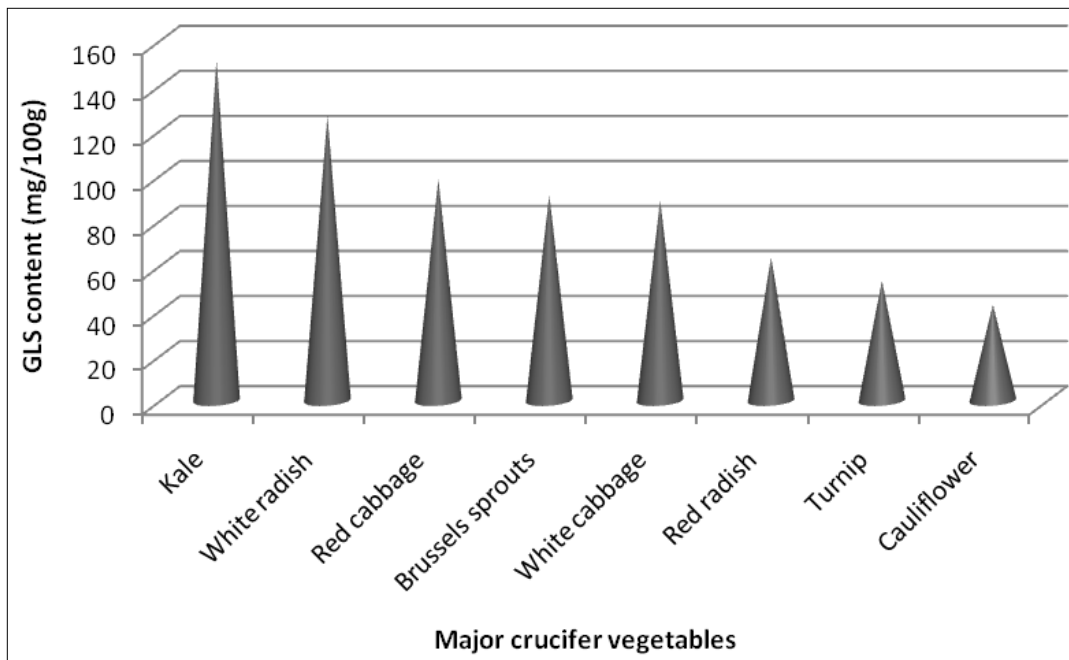


Fig 3: Glucosinolates (GLS) content of different cruciferous vegetables [4, 66, 67].

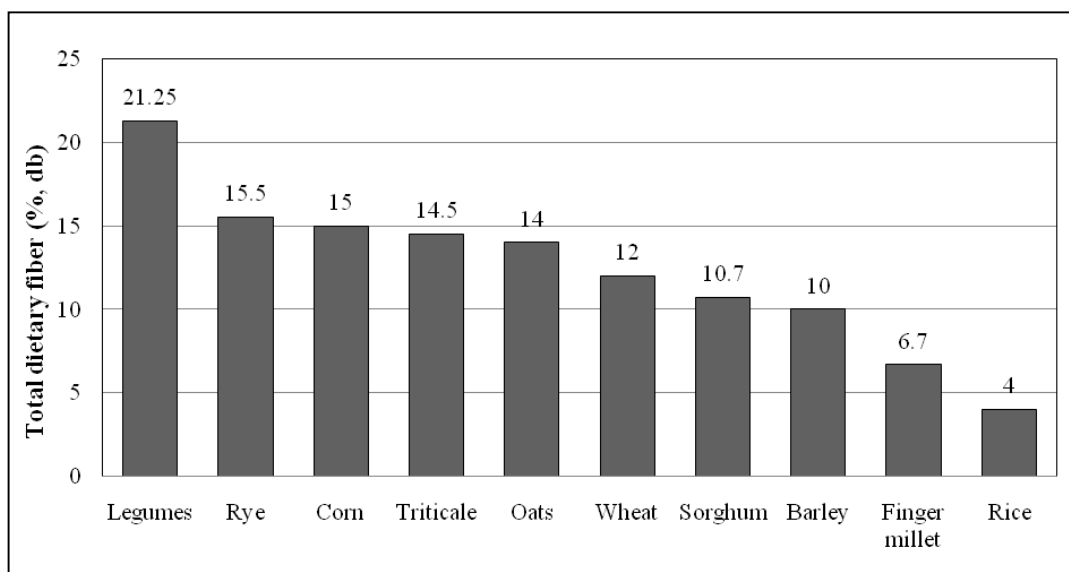


Fig 4: Total dietary fibre (%) content in different cereal grains [90, 91, 92].

Conclusion and future prospective

Nature is a unique and vast source of phytochemicals, many of which possess interesting biological activities and medicinal properties. It is difficult to establish a clear functional and structural similarity or difference among different phytochemicals especially their relationship regarding effects on biological systems. This is due to their wide spectrum occurrence, structural similarity and complexity of physiological reactions. Further, with a large number of phytochemicals which have been isolated so far from different flora, nature might still have many more in store. Foods containing a minimum concentration of these substances has a potential to maintain or improve health with specific diseases prevention potential. There are vast research opportunities in food and nutrition science to explore the complex behaviour and relationship between different food components. Advanced synthetic methodology and sophisticated isolation and analytical techniques of present era represents a vast vacuum in knowledge available about these dietary substances as many of such phytochemicals may be expected to be identified in future and could be used in functional food formulations. Also awareness about the health benefits of foods rich in phytochemicals to consumers is equally important so that consumers can make healthy food choices among foods they eat and enjoy.

Further, the claimed health benefits of the functional foods ingredient and their stability of during food preparation and storage must be studied to establish sound scientific rationales for their potential. Most of the data presently available pertaining to health benefits of various phytochemicals have been generated from *in vitro* studies and need to be verified through *in vivo* studies. Thus, more efforts are required to put these phytochemicals in direct use as functional food/nutraceutical with high retention in order to achieve specific functional health benefits associated with them. Keeping in mind abundance of these dietary substances in nature, there are exciting opportunities for people in food industries to formulate novel food products and provide the consumers with comparatively healthy food choices as presently there is a huge gap in market demand and supply of such food products.

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