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Original Research Article

A Review of Benefits and Prospects of Dietary Plant Polyphenols in Plant and Animal Health

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ABSRTACT

Dietary polyphenols are predominantly natural, but also synthetic or semi-synthetic, organic chemicals characterized by the occurrence of large multiples of phenol structural units. All plant phenolic compounds arise from a common intermediate, phenylalanine, or a close precursor, shikimic acid. They occur primarily in conjugated forms, with one or more sugar residues linked to hydroxyl groups. Seven classes of polyphenolic compounds: phenolic acids, flavonoids, anthocyanidins, proanthocyanidins, stilbenes, tannins and diferuloylmethanes have been detected in diverse plant species. The major dietary sources of plant dietary polyphenols include some common fruits, vegetables and beverages. Plant dietary polyphenols show a substantial structural diversity which mainly influences their actions in both plant and animal physiology. Dietary polyphenols modulate cell signaling pathways in animals and that may significantly explicate the mechanisms of actions of diets rich in polyphenols improving human health. Thus, plant polyphenols can put off degenerative diseases, particularly cancers, cardiovascular diseases and neurodegenerative sicknesses because they are powerful antimicrobial agents, antioxidants against oxidative stress and can boast body immunity. Plant polyphenols are easy and cheap to obtain than the prevalent synthetics contemporary ones used in present day formulation of cosmeceutical and pharmaceutical products. However, some polyphenols may impair body functions. For instance, some polyphenols are known as antinutrients can interfere with the absorption of essential nutrients such as iron, metal ions and other proteins. Grassroots' awareness on plant dietary polyphenols is therefore recommended for optimum therapeutic application in nutritional intervention, pharmaceutical formulations and clinical settings.

Keywords: Dietary Polyphenols, Antioxidants, Function, Therapeutic Values

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Introduction

Dietary polyphenols are a structural class of mainly natural, but also synthetic or semi-synthetic, organic chemicals characterized by the presence of large multiples of phenol structural units.[1] It is a collective term for several subgroups of phenolic compounds.[2] More than 8,000 polyphenolic compounds have been identified in various plant species. All plant phenolic compounds arise from a common intermediate, phenylalanine, or a close precursor, shikimic acid. Primarily they occur in conjugated forms, with one or more sugar residues linked to hydroxyl groups. The main dietary sources of plant dietary polyphenols include some common fruits, vegetables and beverages.[3] Macro-fungi such as mushrooms that grow on dead decaying woods are also rich in plant polyphenols.[4] Plant polyphenols can prevent degenerative diseases, particularly cancers, cardiovascular diseases and neurodegenerative diseases.[5]

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This is because polyphenols are strong antioxidants that complement and add to the functions of antioxidant vitamins and enzymes as a defense against oxidative stress caused by excess reactive oxygen species.[2] Thus, plant dietary polyphenols have been widely studied for their strong antioxidant capacities and other properties by which cell functions are regulated.[6] It is also considered to have protective effects on aging and degenerative diseases.

Most of polyphenols in plants exist as glycosides with different sugar units and acylated sugars at different positions of the polyphenol skeletons.[2] Polyphenols with hexose sugars such as galactose and mannose may improve wound healing and inhibit the inflammatory reaction since they have the ability to decrease granulation tissue formation.[7]

In recent time, plant dietary polyphenols have received tremendous attention among nutritionists, food scientists and consumers due to their roles in human health.[2] The modulation of cell signaling pathways by polyphenols may help significantly to explain the mechanisms of the actions of polyphenol-rich diets in improving health.[8] Thus, many polyphenolic extracts are therefore sold as dietary supplements, pharmaceuticals and cosmetics. Plant polyphenols are safe to the extent that nutritionists have not limited their intake. This is why the recommended dietary reference intake (RDRI) level has not been established.[9]

Polyphenols are chemically diverse and contain several subgroups of phenolic compounds which can be harnessed in many sectors. In fact, polyphenol chemistry and biochemistry have prospect for use in both biological and health sectors.[2] Therefore, this study aims to

comprehensively review the effects of dietary polyphenols found in plants and their benefits as well as potentials in the prevention and management of some plant and animal diseases through thorough literature searches.

Occurrence of Polyphenols in Nature

Naturally, condensed tannins found virtually in all the families of plants are the most abundant polyphenols. The concentrations of polyphenols are often higher in leaf tissue, epidermis, bark layers, flowers and fruits.[3] In dry green leaves, natural polyphenols occur in the range of 1-25 %.[10] Plant polyphenols can occur naturally in wooden parts of plants where they act as natural preservatives against rot.[11] It also occurs inmushrooms such as*Pleurotus pulmonarius* cultivated inconventional substrate.[12] Some members of submerged aquatic plants such as flax and Myriophyllum spicatum secrate polyphenol that are involved in allelopathic interactions whereby the growth or metabolism of other plants are inhibited.[13,14] The concentrations of polyphenols can vary widely in plant tissues depending on the types; and assay method used in polyphenel determination.[10]

In animals such as arthropods, for example insects, polyphenols are found in the epicuticle where they are responsible for the hardening or scerotization process.[15] Polyphenols such as phenolic acids can also be found in human urine[16]and this may be responsible for the therapeutic attributes of urine.

Contents of Polyphenols in Foods

Generally, many foods contain complex mixtures of polyphenols.[17] However, the most important food sources of polyphenols are those widely consumed in large quantities such as fruit and vegetables, green tea, black tea, red wine, coffee, chocolate, olives, and extra virgin olive oil. Herbs and spices, nuts and algae are also potentially significant for supplying certain polyphenols. For example, ginger (*Zingiber officinale* Roscoe), contains high level of flavonoids.[18] Some polyphenols are specific to particular food substances (flavanones in citrus fruit, isoflavones in soya bean, phloridzin in apples); whereas others, such as quercetin, are found in all plant products such as fruit, vegetables, cereals, leguminous plants, tea, and wine.[17] Capsaicinoids such as capsaicins are good examples of nitrogen-containing polyphenol known as polyphenol amides that are found mostly in peppers crops.[2]

Some polyphenols are considered ant-nutrients, compounds that interfere with the absorption of essential nutrients, especially iron, other metal ions, and also by binding to digestive enzymes and other proteins, particularly in ruminants.[19] Phenolic and carotenoid compounds with antioxidant properties in vegetables have been found to retain significantly better taste after passing through steaming than through frying.[20]

Sensory Properties of Polyphenols

Plant dietary polyphenols play a vital role in the sensory properties of foods. Polyphenols have much influence on the nutritional and sensory qualities of foods.[21] This is because polyphenols produce astringency which is a tactile sensation that results from precipitate proteins. However, while some water-soluble polyphenols with molecular weights between 500 and 3000 have been reported to precipitate protein, smaller polyphenol molecules can have astringent qualities due to the formation of unprecipitated complexes with proteins or cross-linking of proteins with simple phenols that have 1, 2-dihydroxy or 1, 2, 3-trihydroxy groups.[22]

Biosynthesis and Metabolisms of Polyphenols

The knowledge of the biosynthetic pathways of polyphenols can help the breeders develop crops rich in polyphenol content for health benefits.[23] Simple natural phenols which are building blocks for polyphenols originate from phenyl propanoid pathway in the case of phenolic acids. Biosynthensis of complex polyphenols such as flavonoids is linked to primary metabolism through plastid and mitochondrial derived intermediates, each requiring export to the cytoplasm where they are incorporated into separate parts of the molecule.[2] This is why flavonoids and caffeic acid derivatives are biosynthesized from the amino acid, phenyl alanine and malonyl-CoA. Complex gallotannins develop through the *in-vitro* oxidation of 1,2,3,4,6-pentagalloyl-glucose or dimerization processes resulting in hydrolyzable tannins. For anthocyanidins, precursors of the condensed tannin biosynthesis, dihydroflavonol reductase and leucoanthocyanidin reductase (LAR) are crucial enzymes with subsequent addition of catechin and epicatechin moieties for larger, non-hydrolyzable tannins.[24] The glycosylated form develops from glucosyltransferase activity and increases the solubility of polyphenols.[25]

Classes of Plant Polyphenols

The major classes of polyphenols found in plants are as follows:

1. Phenolic Acids
2. Flavonoids
3. Anthocyanidins
4. Proanthocyanidins
5. Stibenes
6. Tannins
7. Diferuloylmethanes

Phenolic Acids

Phenolic acids or phenolcarboxylic acids are classes of aromatic acid hydrocarbon with a phenol ring and an organic carboxylic acid functional group (C6-C1 skeleton).[26] A major class within the phenolic compounds is the hydroxycinnamic acids, which are widely distributed in plant kingdom.[3] They are found in many plant species and are mostly high in dried fruits. Good examples of natural occurring phenolic acids are 3,4-dihydroxy benzoic, p-hydroxy benzoic, vanillic, caffeic, p-coumaric, ferulic, syringic and sinapinic acids.[27] Some phenolic acids are found in plants and macro-fungi such as mushrooms and are highly medicinal.[28]

Flavonoids

Flavonoids or biflavonoids were terms formed from the Latin word *flavus*which means yellow. They are used to describe the plant secondary metabolites which have the general structure of a 15-carbon skeleton consisting of two phenyl rings and heterocyclic ring.[29] Flavonoids are the most abundant polyphenols in human diets and are mainly divided into: (a) anthocyanins- these are glycosylated derivative of anthocyanidin, present in colorful flowers and fruits; (b) anthoxanthins- these are groups of colorless compounds such flavones, flavonols, flavanols, isoflavones, and their glycosides.[3] Flavonoids are the major constituent of plant pigments for flower coloration. They can form yellow, red or blue pigmentation that attract insect pollinator in petals. They are widely distributed in plants and are of many benefits to plants and animals. For instance, a wide range of biological and pharmacological activities such as anti-inflammatory, anti-cancer and antioxidant effects of flavonoids have been documented.[30]Flavonoids have also a broad spectrum of antimicrobial action against fungal, bacterial and viral organisms.[31,32] Flavonoids can also be used as an anti-allergic drug in human therapeutics.[33] Besides, flavonoids have synergistic interaction with antibiotics[34] and are selectively toxic. Therefore, they are safe for human consumption even though the taste may be bitter as in the case of cocoa seeds

Anthocyanidins

Anthocyanins in plants mainly exist in form of glycosides which are commonly referred to as anthocyanins. They are the major constituents of the red, blue and purple pigments of the flower petals, fruits and vegetables, and some varieties of grains.[2] Cyanidin, delphinidin and pelargonidin are the most widely found anthocyanidins, along with more than two dozen other monomeric anthocyanidins.[35] Anthocyanidins are chemically stable in acidic solutions, and this could be responsible for the stable colours of some fruit juice. Plants with anthocyanidins have ant-diabetic properties, antioxidant ability and can detoxify the body organs as well as protect human hearts from many diseases.[36]

Proanthocyanidins
Proanthocyanidins were discovered in 1947 by Jacques Masquelier and are a class of polyphenols found in a variety of plants.[37] Chemically, proanthocyanidins are oligomeric flavonoids and have more complex polyphenols although they have same polymeric building block with the tannins group. They are also associated with consumer products made from cranberries, grape seeds or red wine. The outer cover of the seeds or seed coats of purple or red pigmented plants contain large amounts of oligomeric proanthocyanidins.[38]Oligomeric proanthocyanidins could be described as the product of dimer and trimer polymerization of catechins. They are often plenty in apples than wine[39]and in other darkly pigmented fruits.[11]
In nature, proanthocyanidins serve among other chemical to induce defense mechanisms against plant pathogens.[40] Some darkly pigmented fruits such as cranberries have A2-type proanthocyanidins (PACs) and the less common B-type which the ability to bind to proteins, such as the adhesions present on *E. coli* fimbriae and were thought to prevent bacterial infections, such as urinary tract infections (UTIs).[41]

Stilbenes
Stibenes are structurally characterized by the presence of 1, 2-diphenylethylene nucleus with hydroxyls substituted on the aromatic rings, and exists in the form of monomers or oligomers. The best known compound is trans-resveratrol, possessing a trihydroxysilbene skeleton. They have a good antioxidant property.[2]

Tannins
Any plant polyohenolic substance with a molecular weight greater than about 500 can be considered to be tannin.[21] In other words; tannins are a group of water-soluble polyphenols having molecular weights from 500 to 3,000. They are subdivided into condensed and hydrolysable tannins, and are commonly found complexes with alkaloids, polysaccharides and proteins. The hydrolysable tannins are readily hydrolysed into a mixture of carbohydrate and phenol while condensed tannins are complex flavonoid polymers.

Diferuloylmethanes
Diferuloylmethanes are general name for small group of phenolic compounds with two aromatic rings substituted with hydroxyls and linked by aliphatic chain containing carbonyl groups.[42] They can be found in olive fruits and olive oil.[43]

Benefits of Polyphenol in Plant Health
Both natural phenols and the larger polyphenols play important roles in the ecology of most plants. For instance, plant polyphenols play vital roles the in the decomposition of forest litter, and nutrient cycles in the forest ecology.

Physiological Functions of Polyphenols on Plants
The general effects of polyphenols in plant physiology can be divided into two categories:[44]

Hormonal effect
Most plant polyphenols are chemically stable in acidic solutions, and this could be responsible for the stable hormonal actions such as maintaining colours of some fruit juice. Plant polyphenols also help in the release and suppression of growth hormones in plants.

Protective effects
Some plant polyphenols are protective in function and can also facilitate physiological activities in plants. These functions may include:

1. Absorbing ionizing radiation from UV to accelerate some anabolic and catabolic processes using plant pigments.
2. Deterrence of herbivores from attacking the plants via their sensory properties.
3. Prevention of microbial infections through their antimicrobial activities and,
4. Signaling molecules in ripening and other growth processes.

Physiological Functions of Polyphenols on Animals
The important physiological functions of plant dietary polyphenols in animals are categorized below.

Boosting of Body Defense against Cancer
The effect of polyphenols on human cancer cell lines is most often protective because polyphenols reduce the number or growth of tumors.[45] These effects of polyphenols have been observed at different part of the body such as the mouth, stomach, duodenum, colon, liver, lung, mammary gland or skin. Many polyphenols such as quercetin, catechins, isoflavones, lignans, flavanones, ellagic acid, red wine polyphenols, resveratrol and curcumin have shown protective effects against cancer cells.[46] This is because polyphenols facilitate the excretion of cancer conjugating enzymes in metabolic waste products. Several other mechanisms by which polyphenols act include antiproliferation, induction of cell cycle arrest or apoptosis, prevention of oxidation, induction of detoxification enzymes, regulation of the host immune system and anti-inflammatory activity.[47] The intake of polyphenols also activates detoxication enzymes on their own thus, induce a general boosting of body defenses against toxic substances.[48]

Important Functions of Plant Dietary Polyphenols on blood glucose levels
Anthocyanin which is one of the common dietary polyphenols has been found to inhibit α-glucosidase activity and reduced blood glucose levels after starch-rich meals.[3] This finding has been used successfully in clinical therapy for controlling type II diabetes.[29] The glucose uptake into cells under sodium-dependent conditions was inhibited by flavonoid, glycosides and non-glycosylated polyphenols.[46] Their findings also show that under sodium-free conditions, aglycones and non-glycosylated polyphenols inhibited glucose uptake whereas glycosides and phenolic acids were ineffective. This suggests that aglycones inhibit facilitated glucose uptake whereas glycosides inhibit the active transport of glucose. The non-glycosylated dietary polyphenols appeared to exert their effects via steric hindrance.[46]

Important Functions of Plant Dietary Polyphenols on Haematological parameters
Foods rich in polyphenols such as flavanones (example soya been) and quercetin (for example vegetables and legumes) have beneficial effects on haematological parameters.[17] Haematological parameters are those parameters that are related to the blood and blood forming organs.[49,50] Changes in haematological parameters are often used to determine various status of the body and to determine stresses due to environmental, nutritional and/or pathological factors.[51]

Antioxidant Functions of Plant Dietary Polyphenols
Several research findings have proven that dietary polyphenols can neutralize oxidative activities by donating an electron or hydrogen atom to the free radicals.[52] In other words, polyphenols are reactive species toward oxidation.[53] Oxidative stress is considered to play a pivotal role in the pathogenesis of aging and several degenerative diseases, such as atherosclerosis, cardiovascular disease, type II diabetes and cancer.[2] This is why human beings develop endogenous and exogenous mechanisms to maintain redox homeostasis.[3] Although neutralization of excess free radicals in the body by antioxidant enzyme could occur under normal circumstances, intake of polyphenols results in enhanced redox cycling.

Bioavailability Functions of Plant Dietary polyphenols
Plant dietary polyphenols show a considerable structural diversity which largely influences their bioavailability.[54] Large molecular weight polyphenols such as the proanthocyanidins, and anthocyanins are the least absorbed polyphenols while the smaller molecular weight polyphenols such as isoflavones and phenolic acids are the most well absorbed.[55] Polyphenols may affect drug bioavailability and pharmacokinetics. For instance, dietary polyphenols from grapefruit juice caused up to 3-fold increase in bioavailability of benzodiazepines and terfenadine drugs.[56] In animals such as rats, polyphenols absorbed in the small intestine[57] may be bound in protein-polyphenol complexes modified by intestinal micro flora enzymes[58],

allowing derivative compounds formed by ring-fission to be better absorbed.[59,60] Besides, polyphenols improve functioning of the inner lining of blood vessels, inhibit platelet aggregation (preventing blood clots in the arteries), and positively influence blood lipids and insulin sensitivity.[61,62]

Prospects of Plants Polyphenols

At present many researchers are of the opinion that phytochemicals, particularly polyphenols can be harnessed for use in other human sectors apart from their use in enhancing physiological functions.[63] The prospects of plant polyphenols can therefore cut across many disciplines. Some of these prospects are:

Herbal therapeutics

In many parts of the world, the use of herbal products from plants in treating various infections and disorders has been well documented.[64] This is because users of such herbal products tend to believe that these botanicals are inherently safe.[65] These therapeutic ingredients from plant extract are mainly polyphenols.[2] At present, extracts from plants such as *G. latifolia* has been used in the treatment of stomach problems, dysentery, malaria, worm, cough, and high blood pressure.[66] The plant extract is also used in the treatment of diabetes mellitus[67] due to its bio-active compounds which are polyphenols. This is why the use of such extracts requires paying special attention to the extraction methods, plant-to-solvent ratios and the content of active ingredients.[68] Thus, most plant extracts used in herbal medicines are mainly plant polyphenols.

Source of Raw materials in Polymer-based Industries

Most polyphenols are used in many polymer-based industries for production of friction linings, paints, varnishes, laminating resins, rubber compounding resins, polyurethane based polymers, surfactants, epoxy resins and wood preservatives.

Tannins are good examples of common polyphenol used traditionally for leather and plastic production by polymerization process in either the presence or absence of formaldehyde.[69] The aims are generally to make use of safe plant residues. Polyphenols such as pyrogallol and pyrocatechin are among the oldest photographic developer.[53]

Production of Natural Beautifiers

The term cosmeceutical is commonly used to define cosmetic products with active ingredients promoting drugs-like benefits. Thus, natural cosmeceutical or beautifiers have many polyphenols in their composition ingredients with medicinal properties that manifest beneficial actions and provide protection against degenerative skin conditions. They improve appearance by delivering nutrients necessary for healthy skin. Thus, they possess the capacity to reduce body wrinkles and improve skin tone, texture and radiance. They are able to improve skin tone, texture and radiance while reduce wrinkles. Plants were the main source of all cosmetics before the use of synthetic substances with similar properties.[70] At present, cosmeceuticals are the fast-growing segment of the natural personal care industry.[71,72] They are becoming more prevalent in formulations, due to consumers' concerns about synthetic ingredients/chemical substances. Other benefits reported of plant extracts, used in skin care, include antioxidant and antimicrobial activities and tyrosinase inhibition effect. However, despite the known properties of plant extracts, few studies reported the development of formulations with them.[71] The use of plant polyphenol extracts from a variety of botanicals in cosmetics could accomplish two functions: care of the body and as ingredients to influence the biological functions of the skin, providing the nutrients for healthy skin.[73] Generally, plant polyphenols are rich source of antioxidants and other bioactive compounds[74] and could bring to end cases of skin cancers and infections. Besides, polyphenols are easy and cheap to obtain than the prevalent synthetics contemporary used in present day formulation of cosmeceutical. For instance, herbs, fruits, flowers and leaves which are readily available are all sources of plant polyphenols that can be used for cosmeceuticals.[75] Thus, plant polyphenols can help to ensure increased availability and cheap supply of natural raw materials used in cosmeceutical production. Besides, the use of plant polyphenol extracts in skin care products can be a solace to consumers who are increasingly concerned with buying ecologically friendly products.[76]

Production of Natural Herbicides

Most synthetic chemicals that have been commercialized as herbicides are halogenated hydrocarbons with relatively long environmental half-lives and more suspected toxicological properties.[77] Thus, they are unsafe. There is therefore a need for a novel herbicide that will be safe and environment friendly.

At present, natural compounds have increasingly become the focus of those interested in discovery of herbicides. However, no single herbicide has been developed from plants even though a good number of highly phytotoxic plant-produced compounds have been discovered.[78] For instance, bioactive compounds from *Artemisia annua* L., have been found to inhibit plant growth like cinmethylin which is a commercial herbicide.[79] Other polyphenol compounds, such as 2,4-dihydroxy-1,4-benzoxazin-3-one are also active plant growth inhibitors. Besides, plants produce many photodynamic compounds, such as hypericin that are strongly phytotoxic. Since a large number of these compounds are polyphenols, novel herbicides can be developed from such plant polyphenols.

Production of Natural Pesticides

The demand for environmentally and technologically safe pesticides that will be efficacious and selective in action is on increase.[78] This is because most commercially successful pesticides are of inorganic origin and are toxic to man and his environment. In the past, there is relatively small effort in development of plant-derived compounds as pesticides. The impact can be seen in the availability of insecticides, nematicides, rodenticides, fungicides, and molluscicides of organic origin. However, the molecular complexity, limited environmental stability, and low activity of these plant-derived biocides discouraged many researchers.

At present, the advances in biotechnology can increase the speed and ease with which man discovers and develops secondary compounds of plants as pesticides. Thus, these secondary compounds represent a large reservoir of chemical structures for pesticide production. Besides, tens of thousands of these secondary products of plants have already been identified to have pesticide actions. These compounds from plants responsible for pesticide actions are polyphenols with antimicrobial action (phytoalexins) and some have ability to deter herbivores (through their sensory properties).[80] However, this resource is largely untapped for use as pesticides. Besides, the increasing incidence of pesticide resistance is also fueling the need for new pesticides that will be environmentally safe, natural and stable. Since, plant polyphenols contain complex mixture of many chemical compounds, their use in pesticides production if harnessed appropriately, will result in a safe, cheap and stable product that can readily available to farmers unlike the synthetic products.

Sources of Drugs and therapeutic agents

The presence of valuable pharmaceutical substances made of polyphenols in both higher plants and lower ones such as mushrooms have been documented[81,82]. Quinine and penicillin drugs are good examples of the medicinal products from plant polyphenols that have been used successfully in the treatment of human infections.[84] Thus, many plants produce secondary metabolites that have medicinal properties.[85] Most secondary metabolites from plant are mainly polyphenols.[2] Some of these secondary metabolites have antimicrobial properties and can be used in the treatment of pathogens. In crops, possession of antimicrobial polyphenolsis one of the natural attributes that enable crops to escape pest or disease attacks. Such crops are able to reproduce well despite the presence of a pest or pathogen population that is equal to those which damages susceptible hosts.[86] Some plant polyphenols found in some woods have antimicrobial properties which act as natural preservatives against wood rot[11] and could be harnessed in the treatment of human infections.[80]

In traditional medicine, plants with psychoactive properties have been used in the treatment of mental illness.[87] Polyphenol extracts with such psychoactive properties can be used to produce semi-synthetic drug that could be used in the treatment of mental illness and other diseases

of man.[88]Besides, some plant polyphenols have natural polysaccharides which have health-promoting properties and a lot of beneficial therapeutic effects.[89]

Conclusion

Plant dietary polyphenols constitute the major group of phytochemicals found in plant-based foods. They are mainly secondary metabolites produced by plants to protect themselves from other organisms.[2] Plant polyphenols play a vital role in human health. For instance, high intake of fruits, vegetables, and whole grains, which are rich polyphenols, has been linked to lowered risk of many chronic diseases such as cancer, cardiovascular disease, chronic inflammation and many degenerative diseases.[5] Polyphenols therefore play vital roles in maintenance of sound physiological functions of both plants and animals.[44] Besides, there is an emerging view that polyphenols from plants can be harnessed for use in other human sectors apart from their use in enhancing physiological functions.[63]Although many polyphenols play a lot of beneficial roles in both plants and animal health, some polyphenols may have deleterious effects in animal physiology.[90] For instance; some polyphenols are known as antinutrients, compounds that interfere with the absorption of essential nutrients in the body especially iron, metal ions and other proteins. This is because polyphenols, such as tannins, characteristically possess a significant binding affinity for proteins, which can lead to the formation of insoluble protein-polyphenol complexes[91] resulting in decreased digestibility and palatability.[90] There is therefore serious need for creation of adequate awareness on plant polyphenols for optimum therapeutic use in nutritional intervention, pharmaceutical formulations and clinical settings.

Conflict of interest

The authors declare no conflict of interest

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them

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