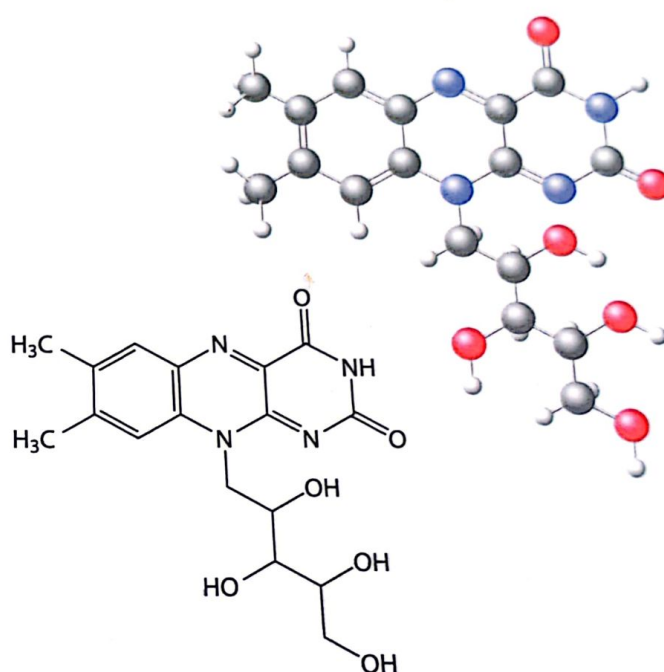


NUTRITION AND DIET IN HEALTH

Principles and Applications



Vitamins: Riboflavin (B_2)



Edited by Adenike Temidayo Oladiji,
Johnson Olaleye Oladele, and Ebenezer I. O. Ajayi

Nutrition and Diet in Health

Nutrition and diet play a crucial role in sustaining good health throughout human lives. Food provides us with essential nutrients involved in many physiological activities and biological processes in the body, including growth and development, metabolism, immune function, and overall well-being. *Nutrition and Diet in Health: Principles and Applications* reviews and discusses the issues related to the roles of nutrition and diet in human health and diseases.

The book contains two sections: one section features principles; the other covers applications. Part I provides information on sustainable use of nutrition and diets in health and diseases; advanced biotechnological approaches to improve nutritional content of food; trace elements in nutrition; drug and nutrient interactions; functional foods and nutraceuticals in health maintenance; and biomarkers of functional foods and nutraceuticals in health maintenance. Part II discusses the significance of nutrition in selected human diseases, including cardiovascular diseases, cancer, infection, neurodegenerative diseases, and metabolic co-morbidities. It also discusses optimal nutrition for wellness, fitness, pregnancy, mental health, aging, and longevity.

FEATURES

- Molecular and cellular-based research findings on the principles and applications of nutrition and diets in health.
- Roles of nutritional agents in the pathogenesis of human diseases.
- Underlying mechanisms that govern activities and strategies to prevent pathological conditions using nutritional agents.

Nutrition and Diet in Health: Principles and Applications is suitable for academia and scientists, and it enhances knowledge of students in healthcare and areas of biological sciences.

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Adenike Temidayo Oladiji,
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10 Role of Dietary Fibre and Phytonutrients in Human Health and Nutrition

*Rukayat A. Oyegoke, Johnson Olaleye Oladele,
Oluwaseun Titilope Oladele, and Adenike Temidayo Oladiji*

10.1 INTRODUCTION

There are very important constituents of food that are very beneficial for the maintenance of human health and that need to be researched. Some of these include dietary fibre, vitamins and minerals. Research has shown that they have numerous health benefits that are yet to be explored. Therefore, the understanding of their constituents, how these constituents interact with each other and other biomolecules and how they elicit their health benefits requires to be understood.

10.2 DIETARY FIBRES

The adoption of the term “dietary fibre” was originally stated by Hipsley in the year 1953 to illustrate the cell wall composition of plants used in food (Gray, 2006). According to Codex 2005, dietary fibre is described as a carbohydrate polymer with several monomeric units ranging from ten and above and is mainly not hydrolyzed (non-digestible and non-absorbable) by the endogenous enzymes in the human small intestine; likewise, it undergoes incomplete and sometimes complete fermentation in the duodenum and is classified under the following categories:

- a. Unrefined carbohydrate polymers present naturally in the food consumed.
- b. Refined carbohydrate polymers gotten from food raw material either by physical, enzymatic or chemical means; have been shown to exhibit a physiological effect and of great benefit to health, as stated by major scientific literatures and findings.
- c. Carbohydrate polymers synthetically produced; these types of carbohydrate polymers are known to have some physiological importance that is profitable to human health, as confirmed by most scientific bodies of competent authority.

The foregoing definition encompasses both natural and synthetic carbohydrate polymers, but the major pointers are that they are found only in plant foods, non-digestible/absorbable in the small intestine, incomplete or sometimes complete fermentation in the duodenum and they are profitable to human health. Because of everyday advances in research on dietary fibre, especially on its classification and constituents, which incorporates many additions constantly, it is now defined as consisting of “intrinsic” plant cell wall polysaccharides.

10.2.1 TYPES OF FIBRES AND DIETARY SOURCES

10.2.1.1 Classification/Types of Fibres

There is no rigid classification of fibres, as there are many properties that can be used to classify them, but the boundaries of these properties are not absolutely defined. In fact, the mode of

classification is abundant; these include their functions in plants, type of polysaccharides they possess, solubility in their gastrointestinal tract, site and products of digestion, etc. (Tungland and Meyer, 2002). However, the classification that has gained the highest acceptance is the one that classifies dietary fibre on the basis of two things, which are:

- Its solubility potential in buffer at a specified pH.
- Its ability to ferment in vitro using an aqueous enzyme solution as a model for the human alimentary system.

The foregoing means of classification therefore leads to the two major classifications, which are:

- Soluble and well-fermented fibres.
- Insoluble and less-fermented fibres.

10.2.1.2 Sources of Fibres

The major food sources of dietary fibre include but are not limited to cereal grains and brans, woody plants, legumes, fruits, vegetables and nuts (Clifford *et al.*, 2015). They are widely spread in different species of the previously mentioned sources, although their composition varies from one food to another.

10.2.1.2.1 Soluble and Well-Fermented Fibres

This group includes pectin, gums and mucilages.

- Pectin:** This is a complex polysaccharide in which D-galacturonic acid is the principal component – i.e., the polysaccharide is comprised mostly of esterified D-galacturonic acid in α – (1–4) linkage (Kay, 1982). This is the reason they are chemically called polygalacturonic acid. The acid-side chain units are esterified with that of the methoxy groups in the natural product. The side chains linked to pectin include arabinose, galactose, xylose, rhamnose and glucose (Figure 10.1).

This group of fibre serves as the structural components of cell walls and intracellular tissues of plants. They are of high water-solubility (most widely soluble dietary fibre) and form gels easily (Gray, 2006). Natural sources of pectin include fruits, vegetables, legumes, nuts, sugar beets and potatoes.

- GUM:** Gum is comprised of a Dmannopyranosyl backbone and it is linked by a β -(1→4) linkage; also, there is a A-D-galactose side chain linked (1→6) to the mannose backbone (galactose, glucuronic acid-mannose and galacturonic acid-rhamnose) with xylose, fructose and galactose as side chains (Figure 10.2). It consists of a broad mixture of gelatinous

PECTIN

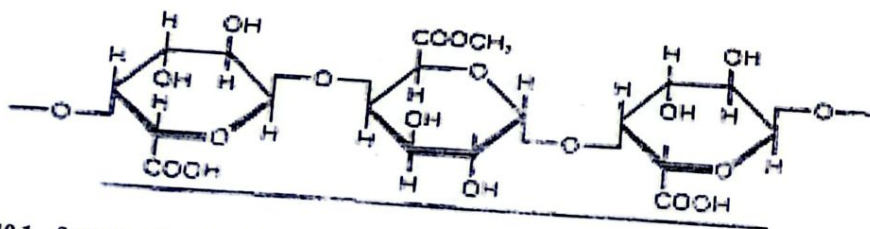


FIGURE 10.1 Structure of pectin. (Major component is D-galacturonic acid.)

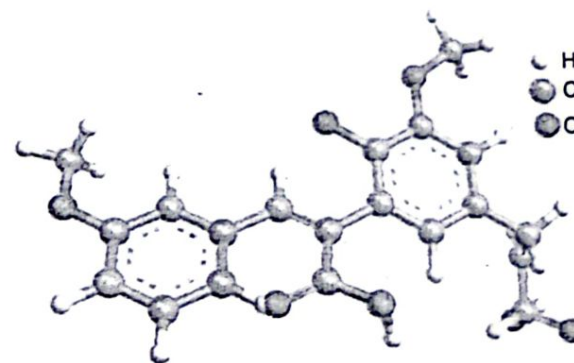


FIGURE 10.2 Structure of gum.

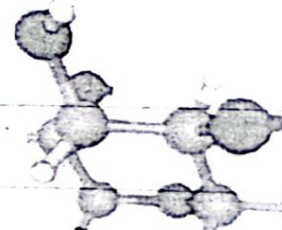


FIGURE 10.3 Structure of mucilage.

polysaccharides and is formed from specialized secretory cells of plant origin, mostly at the site of injury or trauma (Devinder *et al.*, 2012). The degree and pattern of galactosyl determines its physical characteristics. They are mainly two constituents: leguminous seed gum and gum Arabic; another, less common, one is locust bean gum. Guar gum and locust bean gum are gums from leguminous seed plants hauled out from *Cyamopsis tetragonolobus* and *Ceratonia siliqua* seeds, respectively, while Arabic gum is extracted from the acacia tree (Devinder *et al.*, 2012). The sources of gum include oatmeal, dried beans, legumes, fruits, vegetable, seawort, microbial gum, etc. They are mainly for food and pharmaceutical uses.

- Mucilages:** The main chain of this fibre consists of several disaccharide units, notable among which are a linkage between galactose and mannose, glucose and mannose, arabinose and xylose, galacturonic acid-rhamnose with galactose at its side chain (Kay, 1982) (Figure 10.3). These clear, colorless, gel-like fibres are synthesized by plants with the sole aim of protecting the seeds from extreme dehydration. Mucilages are produced in large concentration from psyllium (plantain) and are utilized in minute quantity as gel/thickener, stabilizers and emulsifying agents. Examples include the gum acacia, gum karaya, gum tragacanth, ispaghula, etc.

10.2.1.2.2 Insoluble and Less-Fermented Fibres

These include cellulose, hemicellulose and lignin (Devinder *et al.*, 2012).

10.2.1.2.2.1 Cellulose Cellulose is a polysaccharide whose monomers are joined by a β -(1 $\rightarrow$ 4) glycosidic linkages; this is differentiated from most polysaccharides whose linkages are α -(1 $\rightarrow$ 4), as in amylase (Figure 10.4). It is a major component of the plant cell wall and has an un-branched polymer of glucose comprised of long, straight chains which are linked by β -(1 $\rightarrow$ 4) glycosidic linkages (Devinder *et al.*, 2012). This linkage gives it the rigid nature that is due to the presence of multiple hydrogen bonds. Humans cannot digest cellulose because they lack the enzyme cellulase in their digestive system; hence, it is of no nutritional value to them. However, ruminant animals make good use of it due to the presence of some microorganisms in their system that are capable of breaking it down into smaller molecules. Studies have shown that the presence of dietary fibre from cellulose origin has been implicated in the management or treatment of most frontline diseases such as cardiovascular diseases, diabetes, colon cancer, etc. It is present in unrefined cereals, vegetables, sugar beets, various brans, fruits. The majority of the fibre found in cereal and fruits is mainly cellulose, whereas one-third of it is found in vegetables and nuts (Gray, 2006).

10.2.1.2.2.2 Hemicellulose Hemicellulose is also a part of the cell wall component of most plants; it differs from cellulose in that it contains a backbone of β -(1,4)-linked pyranoside sugars such as xylose, mannose, galactose and glucose and a branched chain of mainly arabinose, galactose and glucuronic acid (Figure 10.5). They are of two types – xylans and galactans – and are mainly found in grains, although they might also be available in fruits, vegetables, nuts and legumes in small amounts (Gray, 2006).

10.2.1.2.2.3 Lignin Lignin is comprised of several polymers, cross linked to each other with different chemical bonds (Figure 10.6), which are mainly of phenylpropane units. It is not a polysaccharide; however, due to its reactions with hemicelluloses in the cell wall of plants, it is most times allied with plant cell-wall polysaccharides (Gray, 2006), though realistically, it is the only non-polysaccharide fibre that occurs as a result of pairing of three primary precursors (monolignols) *p*-coumaryl, coniferyl and sinapyl alcohols (Kay, 1982). The side chain is a three-dimensional structure. Lignin is very inert due to the strong intramolecular bonding. It is insoluble in 72% sulfuric acid. Its variations lie in its molecular weight and the methoxyl content. It resists bacterial degradation. It is a major component of foods with "woody" composition – for instance, celery – and in the outer layers of cereal grains, rice and legume hulls (Gray, 2006).

CELLULOSE

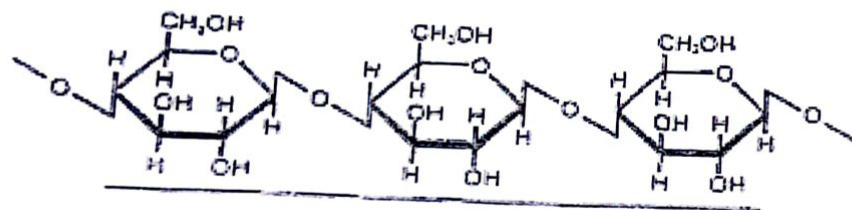
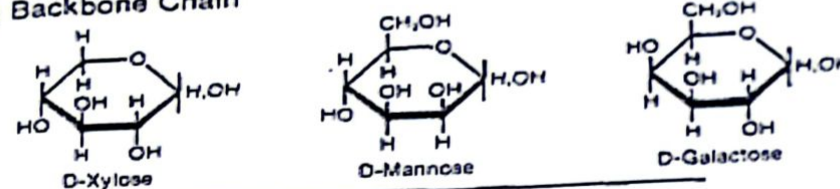


FIGURE 10.4 Structure of cellulose.

HEMICELLULOSE (major component sugars)

a) Backbone Chain



b) Side Chains

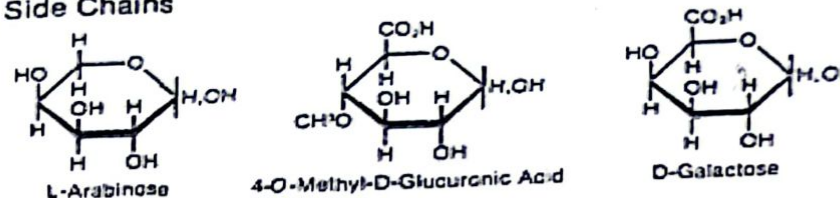


FIGURE 10.5 Structure of hemicellulose.

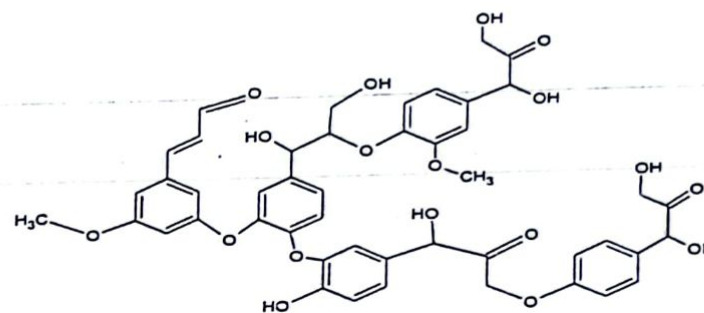


FIGURE 10.6 Structure of lignin.

10.2.2 HEALTH BENEFITS OF DIETARY FIBRES AND MECHANISMS OF ACTIONS

Most dietary fibre that possesses profitable physiological potential and is useful to human health is tagged to be functional fibre (Clifford *et al.*, 2015). Findings from several studies have indicated that free radical production in the human system either during stress, exercise or even digestion contributes greatly to most disease conditions. Thus, it is of crucial importance to look at the anti-inflammatory and antioxidant properties of these fibres to unveil the secret behind its curative actions on most of these pathological disease conditions.

10.2.2.1 Anti-Inflammatory Effects of Dietary Fibre

The human metabolic system works in conjunction with its immune system (Lotterberg *et al.*, 2010), and inflammation can be triggered by several factors as a result of interactions within the human system; notable substances responsible for such actions are: hormones, cytokines, signaling proteins, transcription factors and bioactive lipids. All these substances act in way that fatty tissue

generates pro-inflammatory substances, which formerly are taught to be connected only with the immune system – for example, interleukin 6 (IL-6), tumor necrosis factor alpha (TNF- α) (Bullo *et al.*, 2007), C-reactive protein (CRP) and plasma plasminogen activator inhibitor (PAI) (Xu *et al.*, 2003). This pro-inflammatory activity of fat tissue, generated in the course of immune response or metabolic processes, denotes a likeable risk toward the progression of some acute or chronic disease and its complications (Wellen and Hotamisligil, 2005).

Evidence from several scientific researches shows that consumption of fibres reduces inflammation that occurs due to some chronic disorder; for instance, a diet containing a good amount of fibre can potentially lower inflammation by altering both the pH and the permeability of the gut. The resultant reduction in inflammatory compounds may also adjust the neurotransmitter concentrations to reduce symptoms of depression.

10.2.2.2 Antioxidant Effects of Dietary Fibre

Antioxidants are known to mop up free radicals generated in the human system that occur either during metabolic processes or exercise (Velioglu *et al.*, 1998). Phytochemical studies have shown that most dietary fibre contains compounds capable of mopping up reactive oxygen species generated in most diseases. For instance, most polyphenol compounds that are attached to diverse polysaccharide complexes are detached in the cause of metabolic processes in the gut, thereby exhibiting their antioxidant potentials.

10.2.2.3 Biological Activities/Effects of Dietary Fibre

10.2.2.3.1 Irritable Bowel Disease

This is a general term for many gastrointestinal disorders, and this include diarrhea, constipation, ulcerative colitis, etc. Laxation is a biological process that is often underrated or taken for granted until it is abused, resulting in the constipation process (AACC, 2001). Constipation is a physiological effect that brings unease to the body system, and it has been defined as a condition in which there is need to strain on defecation, resulting in abdominal pain and bloating (AACC, 2001). Constipation is related to stool weight and consistency as well regularity of bowel movement (Gray, 2006). There is no gainsaying in understating the discomfort in constipation as well as the risk it potentiates in development of other diseases such as diverticular diseases and hemorrhoids. High dietary fibre nutrition has been scientifically proven to boost the laxation and thereby relief of constipation through different mechanisms exhibited by various types of fibres. Fibres have been confirmed to have an established effect on bulk and consistency of stool as well as the lowering of intestinal mobility (Heredia *et al.*, 2002). This might be due but not limited to hydration aptitude of the existing residues, generation of osmotically active metabolites but also the initiation of bacterial output and growth as well as species distribution due to the increase in low colonic pH and thereby improving/increasing the frequency, regularity of defecation as well as reduction of transit time. Diverticula are purses on the intestinal wall that can become inflamed and painful. This inflammatory condition, which arises due to bacterial infection, is called diverticulitis, which is mainly due to reduced fecal bulk. Studies have shown that this effect can be ameliorated by the regular intake of dietary fibre through the previously mentioned mechanisms. Cellulose is of high effectiveness in this respect, as it has a high bran content, and this protective effect may involve increase in stool weight and decrease in transit time and intracolonic pressure (Gray, 2006).

10.2.2.3.2 Cancer

Consumption of dietary fibre has been scientifically confirmed to be effective in the management of various types of cancer – most especially breast and colon cancer. Several mechanisms of action of these fibres have been proposed particularly for colon cancer and is mainly attributed to the antioxidant component present in them, as in their ability to mop up reactive oxygen species in the cells.

This finding is based on the awareness that insoluble fibre increases the time at which wastes are evacuated from the body. Therefore, the body has less exposure to toxic substances produced during

digestion. Phenolic compounds present in lignin are also well known to assist in the mopping of reactive oxygen species. Dietary fibre also regulates the colonic pH, thus moderating the metabolic end-products of human intestinal flora, thus helping reduce the risk of cancer. Similarly, butyric acid, a volatile fatty acid, is a metabolic by-product produced after fermentation of most dietary fibre by the microflora in the colon stimulates apoptosis of cancerous colon cells in vitro and even provides the mechanism for inhibiting multiplication of cancerous cells.

10.2.2.3.3 Diabetes

It is widely accepted that inclusion of dietary fibre in the diet minimizes the risk of being diabetic to a great extent, and likewise, helps regulate the blood sugar level. Several successes have been recorded in the management of diabetics when dietary fibre is introduced to foods, which, in turn, leads to the reduction of the administration of insulin in the situation of a type 1 condition and also in sulfonylurea drugs for the type 2 (Rivellese *et al.*, 1980). Higher intake of fibre, especially that in whole grains when compared to refined, has been shown to modestly lessen the glycemic index and enhance insulin sensitivity, which, in turn, results in a decreased risk for developing type 2 diabetes. Also, fibre exhibits its action by delaying the uptake of glucose from the small intestine, thus causing the rise in blood glucose, and in so doing, putting it at a minimal level, which, in turn, attenuates the insulin response, resulting in a slower decline in blood glucose level. Other possible mechanisms of fibre action include delayed gastric emptying, lessening the release of gastric inhibitory polypeptide, improved glucose tolerance, reduced insulin requirements and increased peripheral tissue insulin sensitivity (AACC, 2001).

10.2.2.3.4 Obesity, Satiety and Weight Loss

The rate at which obesity is becoming pronounced is alarming, both in the Western world and in developing countries. Consumption of fibres are known to caused fullness due to its bulky nature and low energy-density; likewise, its water-absorbing ability (AACC, 2001).

Therefore, due to its promotion of satiety, it's performed a crucial function in the control of energy balance and body weight. It has also been reported that foods with a low glycemic index are more satiating than the ones with a high glycemic index. Dietary fibres delay gastric emptying, and more importantly, by forming gels, slow down the absorption of carbohydrates from the small intestine in such a way that it is less accessible to digestive enzymes, thereby reducing the contact with the intestinal mucosa (Gray, 2006).

10.2.2.3.5 Coronary Heart Diseases and Related Disorders

High cholesterol level in the system has been a culprit in most heart-related disease and disorder. The consumption of fibres that are water soluble tends to bind to bile acids, thereby increasing the excretion of cholesterol from the system (Clifford *et al.*, 2015). A variety of foods loaded with dietary fibre have been verified to reduce the atherogenicity of semi-synthetic diets with or without added fat and sterol. It has also been ascertained that the hypolipidic effect in humans lowers both serum cholesterol and triglycerides (Takahashi *et al.*, 1993). It should also be noted that dietary fibre may reduce total body cholesterol, even when a significant reduction in serum cholesterol does not occur (Oda *et al.*, 1993).

10.3 MICRONUTRIENTS AND HEALTH BENEFITS

Micronutrients are vital elements necessary for growth and healthy living for both humans and other organisms. It is required to coordinate a series of physiological functions for health maintenance (Awuchi *et al.*, 2020). The essential micronutrients required by humans are vitamins and minerals, and they are required in amounts less than 100 mg daily (Ormsbee *et al.*, 2014). They are referred to as essential nutrients since they are either synthesized in minute amount in the body or not synthesized at all and therefore must be taken in from our diet.

10.3.1 VITAMINS AND HEALTH BENEFITS

Vitamins play a key role in the prevention of most frontline diseases that are nutritionally related; they are required to prevent the nutritional deficiency disease "beriberi" because of its vital need (Naik, 2012). Vitamins are grouped into two based on their solubility (Figure 10.7). These are:

- Fat-soluble vitamins (vitamins A, D, E and K).
- Water-soluble vitamins (vitamins B_{complex} and C).

10.3.1.1 Fat-Soluble Vitamins

Fat-soluble vitamins are vitamins that can easily be dissolved in fat. They are, to a great extent, stored in the body, and so, do not require frequent intake (Naik, 2012). Examples are: vitamins A, D, E and K.

10.3.1.1.1 Vitamin A (Retinol)

This vitamin contains a single 6-membered ring to which is attached an 11-carbon side-chain (Figure 10.8) (Naik, 2012). Vitamin A can exist in three different active forms (retinol, retinal and retinoic acid) all of which are derived from the plant precursor molecule, β -carotene.

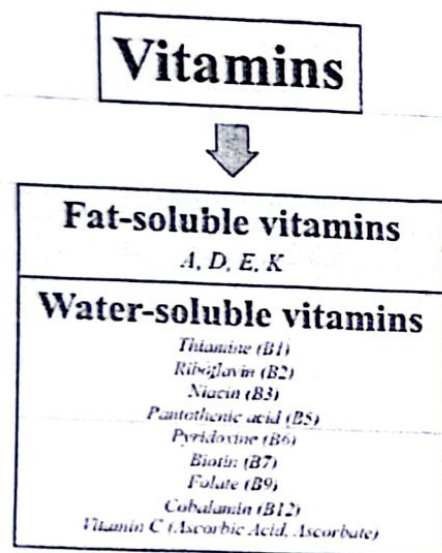


FIGURE 10.7 Classification of vitamins.

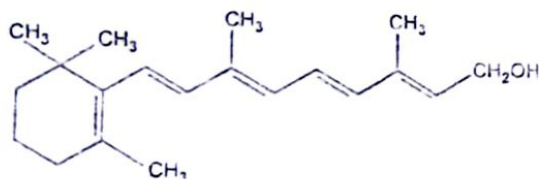


FIGURE 10.8 Structure of vitamin A.

Vitamin A supports bone growth and immune function. It is involved in cellular differentiation and physiological function of epithelial glands. It also supports the skin and partakes in the uptake of visual sharpness (Muhammad *et al.*, 2020). Deficiency of it leads to lack of rhodopsin in the retinol rod cells, visual impairment, xerophthalmia, keratomalacia, respiratory and intestinal infections. Excess of it can result into vomiting, nausea and anorexia. Important sources of vitamin A include leafy vegetables, meat, fish, green mango, egg, spinach, cabbage, cod liver oil, etc.

10.3.1.1.2 Vitamin D (Cholecalciferol)

Vitamin D could exist in several kinds (Figure 10.9). Four crystalline D vitamins are isolated, and at least ten pro-vitamins D are known (Muhammad *et al.*, 2020). However, there are primarily two prominent ones naturally produced cholecalciferol (D₃), which is gotten from animal sources in the diet, like from ultraviolet light from sunlight on 7-dehydrocholesterol (Naik, 2012). The second type is the one that is artificially produced form D₂ or ergocalciferol and it is made in the laboratory by irradiation of plant sterol, ergosterol.

The absorption and deposition of phosphorus and calcium in the intestine and bones, respectively, is greatly enhanced by vitamin D. Another crucial role of vitamin D is the modulation of transcription of cell cycle proteins that decreases and increases the cell proliferation and differentiation of a number of specialized cells in the body, which include keratinocytes, osteoclastic precursors, enterocytes, etc. Studies have shown that vitamin D also possesses antioxidant and immunomodulatory properties (Christakos *et al.*, 2015). Deficiency of vitamin D can affect development of the bone in both children and adults (Kennel *et al.*, 2010). It causes rickets in children, while, in adults, it causes osteomalacia (Nair and Maseeh, 2012). The main source of vitamin D is sunlight-induced synthesis; likewise, cod liver oil, fish oil, liver and egg yolk are very good sources (Naik, 2012).

10.3.1.1.3 Vitamin E (Tocopherol)

Vitamin E is a natural antioxidant and also an anti-sterility factor that consists of eight naturally occurring tocopherols, of which α -tocopherol is the most active form (Figure 10.10) (Naik, 2012).

As earlier stated, this vitamin is a natural antioxidant that scavenges free radicals and molecular oxygen. Some of the other numerous important properties of vitamin K are that it prevents peroxidation of polyunsaturated fatty acids in cell membranes and also partakes in wound healing and immunity (Schmölz *et al.*, 2018). Deficiency of this vitamin leads to hemolytic anemia and retrolental fibroplasia (RLF), while excessive intake of it can lead to interference with the utilization of vitamins A and K, intestinal irritability, prolonged prothrombin time, etc. (Gomez-Pomar *et al.*, 2018; Moisa *et al.*, 2018). Sources of vitamin K include fat and oils – i.e. germ oil, corn oil, fish oil, eggs and lettuce (Naik, 2012).

10.3.1.1.4 Vitamin K

Vitamin K is known as an anti-hemorrhagic factor because its deficiency leads to uncontrolled hemorrhages due to a defect in blood coagulation (Figure 10.11) (Naik, 2012). There are mainly

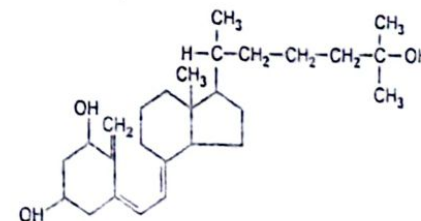


FIGURE 10.9 Structure of vitamin D

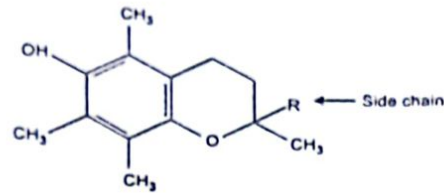


FIGURE 10.10 Structure of A-tocopherol (vitamin E).

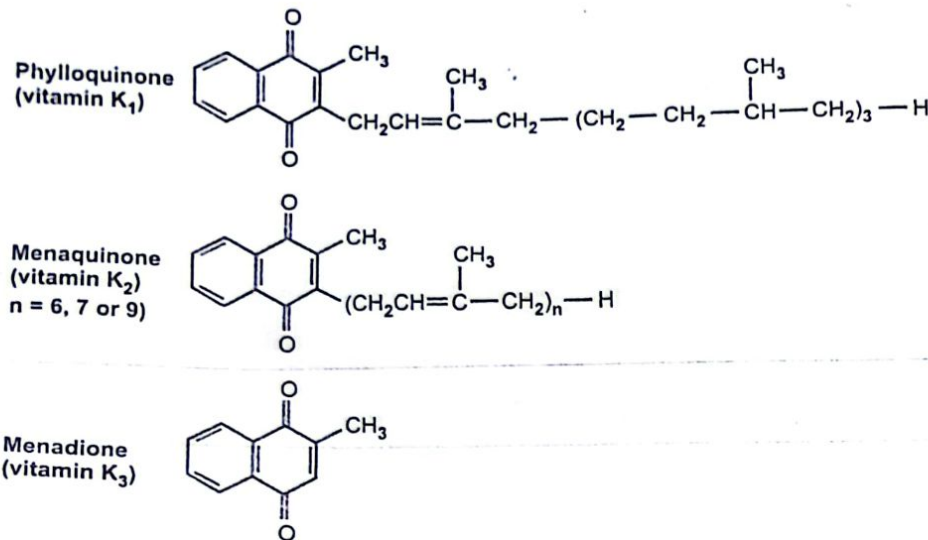


FIGURE 10.11 Vitamin K.

three classes of vitamin K, which are K_1 , K_2 and K_3 (K_1 – phylloquinone and K_2 – menaquinone are naturally occurring, while K_3 – menadione is synthetic). As earlier said, the major function is the role it plays in blood coagulation by the activation of blood clotting factors produced in the liver in the inactive form (Reddy and Jialal, 2018).

Deficiency of this vitamin can lead to generalized bleeding, prolonged clotting time in adults and development of hemorrhagic disease in new borns (Reddy and Jialal, 2018). Excessive intake can lead to hyperbilirubinemia, hemolytic anemia and jaundice. Good sources of this vitamin include fresh green vegetables, lettuce, cabbage, cauliflower, spinach, tomatoes, liver, egg yolk, etc.

10.3.1.2 Water-Soluble Vitamins

10.3.1.2.1 Vitamin B_1 (Thiamine)

This vitamin consists of a pyrimidine ring attached to a thiazole ring by a methylene bridge (Figure 10.12). The active coenzyme form of this enzyme is thiamine pyrophosphate (TPP).

Vitamin B_1 plays a key role in carbohydrate metabolism, especially in hexose monophosphate shunt. It is also a very efficient neuro-protective agent (Ikeda *et al.*, 2016). Thiamine is a co-catalyst

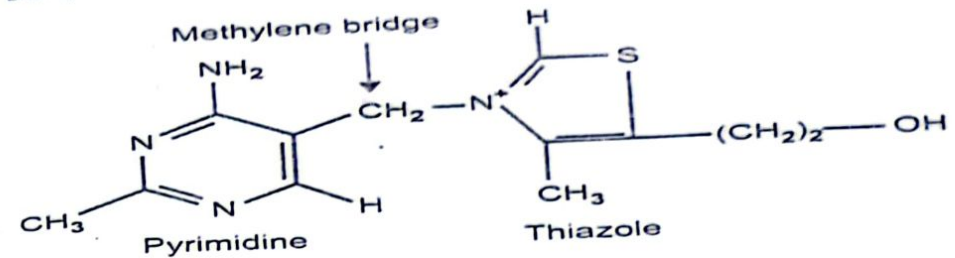


FIGURE 10.12 Thiamine.

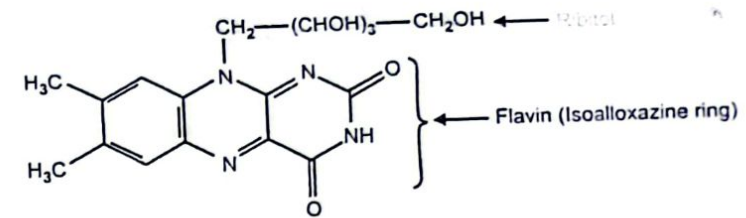


FIGURE 10.13 Riboflavin.

in sugar digestion and is necessary to the function of the heart, nerves, and muscles. (Muhammad *et al.*, 2020). Deficiency of vitamin B_1 results in a condition known as beri-beri, while its excess can lead to tachycardia, migraines and peevishness (Wiley and Gupta, 2019). Sources of this vitamin include unrefined cereals, wheat germ, nuts, lentils, green vegetables, etc.

10.3.1.2.2 Vitamin B_2 (Riboflavin)

Riboflavin is a yellow crystalline substance that consists of an isoalloxazine ring with a ribitol (sugar alcohol) side chain (Naik, 2012) (Figure 10.13).

Its derivatives FAD and $FADH_2$ are involved in oxidative-reduction reactions. Vitamin B_2 is also involved in protection against peroxidation in metabolism of xenobiotics and maintenance of mucosal epithelial and ocular tissue (Naik, 2012). Its deficiency results in ariboflavinosis (Muhammad *et al.*, 2020). Sources of vitamin B_2 include green verdant vegetables, liver, oats, milk, grain, etc.

10.3.1.2.3 Vitamin B_3 (Niacin)

Niacin is a simple derivative of pyrimidine and it is a general name for nicotinic acid and nicotinamide (Figure 10.14) (Naik, 2012).

It is a precursor of coenzymes NAD^+ and $NADH^+$ which are involved in many oxidation-reduction reactions like the oxidative pathways, reductive synthesis, etc. (Muhammad *et al.*, 2020). Deficiency results in pellagra, while high intake leads to vasodilation, flushing and liver damage (Naik, 2012). Sources of vitamin B_3 include yeast, legumes, liver, etc., while limited quantities of this vitamin can be obtained from tryptophan (Naik, 2012).

10.3.1.2.4 Vitamin B_5 (Pantothenic acid)

Pantothenic acid is a vitamin formed by combination of pantoic acid and β -alanine (Naik, 2012). It is widely distributed in food. This vitamin has components of coenzymes that participate in reactions

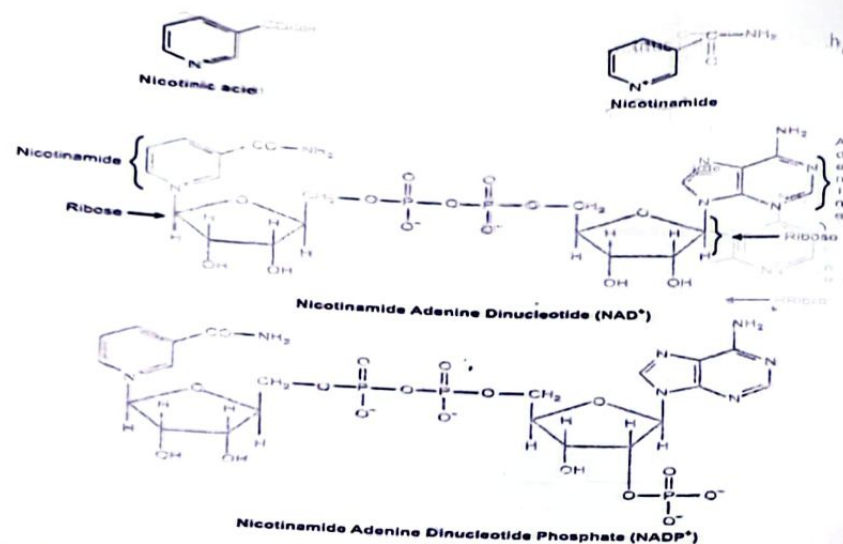


FIGURE 10.14 Structure and active coenzyme forms of niacin.

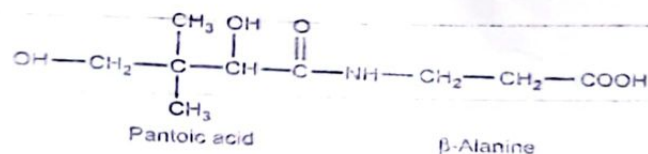


FIGURE 10.15 Pantothenic acid.

concerned with fatty acid synthesis. It also plays a key role in homonogenesis and energy production (Figure 10.15) (Muhammad *et al.*, 2020).

Deficiency of this vitamin may lead to burning feet syndrome, dermatitis, alopecia, etc. (Lykstad and Sharma, 2019). As stated earlier, its wide distribution in food allows for varieties of sources, and these include yeast, liver, wheat germs, cereals, eggs, etc.

10.3.1.2.5 Vitamin B₆ (Pyridoxine)

Three natural vitamins (different forms of the vitamin) of vitamin B₆ – namely, pyridoxine, pyridoxamine and pyridoxal – are known, and they can be interconverted in the body. The active form of vitamin B₆ is pyridoxal phosphate, and it is formed from the phosphorylation of the three forms of Vitamin B₆ (Figure 10.16).

The active form of this vitamin acts as coenzyme in major reactions of amino acid metabolism, and this includes transamination reactions, decarboxylation, nonoxidative deamination condensation of amino acids (Naik, 2012). This vitamin is of high therapeutic use, as it is actively involved in the treatment of autism, seizures, Down's syndrome, premenstrual tension syndrome, etc. Deficiency can lead to irritability, nervousness and depression. Sources of this vitamin include mainly plant products (for pyridoxins), whereas, for pyridoxamine and pyridoxal, they

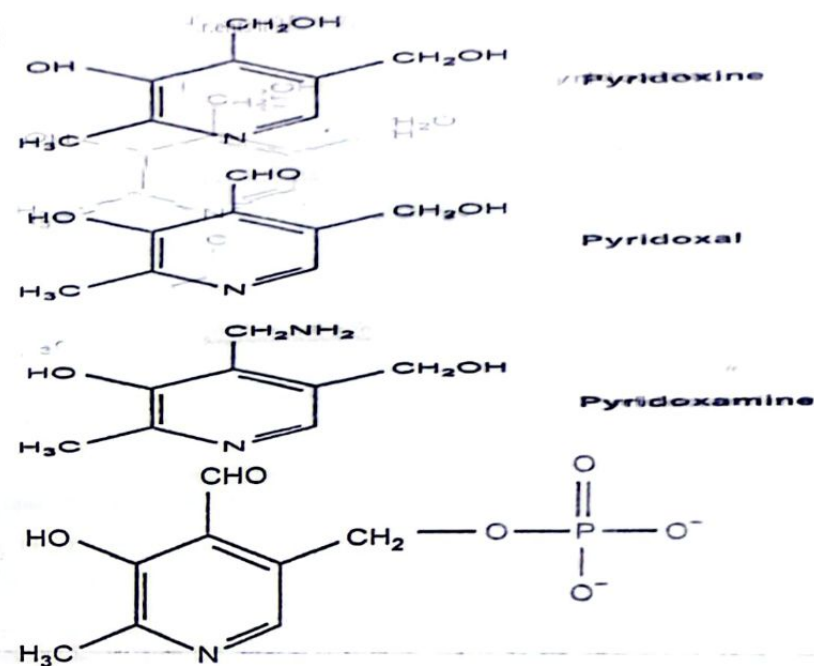


FIGURE 10.16 The three forms of pyridoxine and pyridoxal phosphate.

are animal products. However, there are excellent dietary sources, which include yeast, pulse, meat, poultry, fish, etc.

10.3.1.2.6 Vitamin B₇ (Biotin)

Biotin, formerly known as vitamin H, is an imidazole derivative that consists of a tetrahydrothiophene ring that is bound to an imidazole ring and a valeric acid side-chain (Figure 10.17). It plays a crucial role in glucose, vitamin B₁₂ and folic acid utilization, metabolism of protein and synthesis of fatty acids. Although some scientists believe that there are no known effects of the deficiency and excess of biotin (Muhammad *et al.*, 2020), it is also documented by some that biotin deficiency causes anorexia, glossitis, alopecia, depression, muscular pain, etc. Dietary sources of biotin include green beans, egg yolk, dark green vegetables, liver, kidney.

10.3.1.2.7 Vitamin B₉ (Folic acid)

Three components make up folic acids, and they are pteridine ring, p-amino benzoic acid (PABA) and L-glutamic acid (Figure 10.18) (Muhammad *et al.*, 2020). The synthesized form of folic acid is folate, which is now converted to the active form tetrahydrofolate.

Folic acid is an essential molecule in the synthesis of nucleic acids (DNA and RNA) and also plays a key role in the metabolism of amino acids (Lykstad and Sharma, 2019). Deficiency causes neural tube defects, megaloblastic and macrocytic anemia and hyperhomocysteinemia (Hodgetts *et al.*, 2015). Dietary sources include green vegetables, liver, yeast, fruits

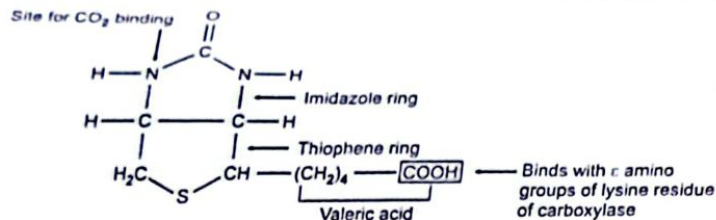


FIGURE 10.17 Biotin.

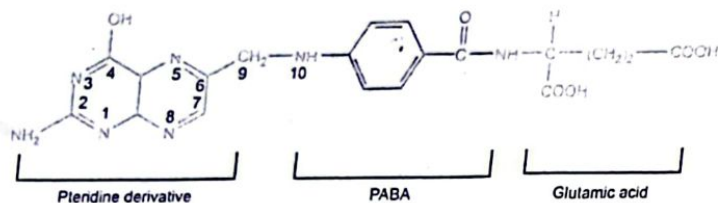


FIGURE 10.18 Folic acid.

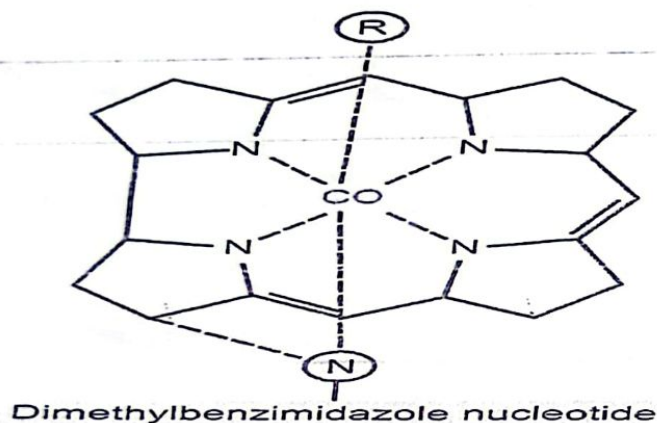


FIGURE 10.19 Cobalamin (R: either methyl or deoxyadenosyl or hydroxy group).

10.3.1.2.8 Vitamin B₁₂ (Cobalamin)

Vitamin B₁₂ bears a complex corrin ring (containing pyrroles similar to porphyrin), linked to a cobalt atom held in the center of the corrin ring by four coordination bonds with the nitrogen of the pyrrole groups (Naik, 2012). The remaining coordination bonds of the cobalt are linked with the nitrogen of dimethylbenzimidazole nucleotide, and the sixth bond is linked to either methyl or 5'-deoxyadenosyl or hydroxy group to form methylcobalamin, adenosylcobalamin or hydroxycobalamin, respectively (Figure 10.19) (Naik, 2012). The active forms of cobalamin are methylcobalamin and deoxyadenosylcobalamin.

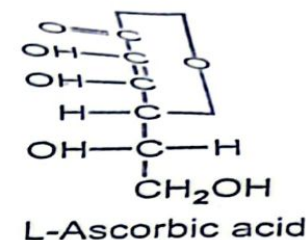


FIGURE 10.20 Ascorbic acid.

They play a key role in normal production of red blood cells by the bone marrow, growth of nervous cells and metabolism of amino acids. Deficiencies can lead to pernicious and megaloblastic anemia, methylmalonic aciduria as well as neuropathy (Lykstad and Sharma 2019; Ankar and Kumar, 2019). Dietary sources are mainly animal products like meat, dairy products, fish, eggs, etc.

10.3.1.2.9 Vitamin C (Ascorbic acid)

Vitamin C is also known as ascorbic acid, and it is a six-carbon sugar derivative (Figure 10.20). Most animals can synthesize vitamin C but humans cannot due to lack of the enzyme gluconolactone oxidase, a key enzyme required for the synthesis of vitamin C. Vitamin C is a crystalline solid soluble in water (Halliwell, 2001).

Vitamin C acts as antioxidant and free oxygen radical scavenger and can be used topically in skin disorders, including those caused by photo-aging (Sorice *et al.*, 2014; Luis Gomez *et al.*, 2018). It also performs various metabolic processes, which include collagen biosynthesis, degradation of tyrosine, absorption of iron and steroid synthesis. Deficiency of vitamin C can lead to poor wound healing, abnormal bone development and osteoporosis, scurvy, spongy swollen bleeding gums, etc. Dietary sources are leafy vegetables and fruits, especially citrus fruits, strawberries, tomatoes, etc.

10.3.2 MINERALS AND HEALTH BENEFITS

Minerals play a vital role in the human body; they are required for major physiological function and also play a role in the functions of important biomolecules present in the body. The minerals that are required for human nutrition are classified into macrominerals and microminerals based on their daily requirement.

10.3.2.1 Macrominerals

10.3.2.1.1 Sodium

Sodium is a vital cation of the extracellular fluid. It serves as a buffer for the body system. It regulates muscle and nerve irritability at the proper level. It ensures cell membrane permeability (Cogswell *et al.*, 2016). An insufficient amount of sodium in the body leads to acidosis, while its excess leads to hypertension and edema. Dietary sources include table salt, salty food, animal food and milk.

10.3.2.1.2 Potassium

Potassium is a major intracellular cation. It is also a constituent of the buffer, and it plays a key role in acid and base balance. It is essential for many enzymatic reactions (Weaver, 2013). Several

TABLE 10.1
Minerals Required in Human Nutrition

Macrominerals	Microminerals, or trace elements
Sodium	Chromium
Potassium	Cobalt
Chlorine	Copper
Calcium	Fluoride
Phosphorus	Iodine
Magnesium	Iron
Sulfur	Manganese
	Molybdenum
	Selenium
	Zinc

Source: Naik (2012).

glycolytic enzymes require potassium ions to function properly. It is required for the normal functioning of the heart and skeletal muscle fibres. It is also required in protein metabolism and transmission of nerve impulses. Deficiency of this macromineral leads to hypokalemia, cardiac disturbances and paralysis, while excess of it can lead to hyperkalemia, cardiac disturbances and paralysis (He and MacGregor, 2008). Dietary sources include whole and skimmed milk, banana, meat, tender coconut water.

10.3.2.1.3 Chloride

Chloride is a principal extracellular anion that is required for electrolyte, osmotic and acid base balance. It is required for the formation of hydrochloric acid in the gastric mucosa and for the activation of the enzyme amylase (Naik, 2012). Deficiency results in metabolic acidosis, vomiting and excessive sweating, while excessive concentration leads to dehydration and metabolic acidosis. Dietary sources of this include table salt, vegetables, milk, egg.

10.3.2.1.4 Calcium

Calcium is the most abundant mineral in the human body, and it is essential for adequate growth and bone development. It is also involved in various metabolic processes, which include release of hormones and neurotransmitters, blood coagulation, muscle contraction and cardiac activity (Hall *et al.*, 1991). Deficiency of calcium can result in rickets, osteoporosis and osteomalacia, while its excess can result in kidney stones.

10.3.2.1.5 Phosphorus

Phosphorus is an important mineral in the bones and teeth; likewise, it is an important component of ribonucleic acids; it is present in phospholipids; and it forms parts of cell membranes. Deficiency of phosphorus results into growth retardation, skeletal deformities, muscle weakness and cardiac arrhythmia, while hyperphosphatemia can result in renal failure (Arai and Sakuma, 2015).

10.3.2.1.6 Magnesium

The human body contains about 25 g of magnesium, of which about 55% of it is found in the bone. Therefore, it is an important constituent of the bone, thereby maintaining bone growth and integrity. Magnesium influences the secretion of parathyroid hormone by the parathyroid gland, and it also functions in the regulation of cardiac cycle. Deficiency diseases associated with lack of magnesium

include hypomagnesaemia and neuromuscular irritability, while symptoms due to toxicity of magnesium are hypotension, respiratory failure and cardiac disturbances (Allen and Sharma, 2019). Dietary sources are cereal, meat, milk, green leafy vegetable, banana, etc.

10.3.2.1.7 Sulfur

The major source of sulphur in the body is mainly from protein-rich foods, especially the sulphur-containing amino acids (Naik, 2012). They are therefore constituents of proteins. Likewise, they are a component of bile acid, glycans, thiamine, lipoic acid and are also involved in detoxification processes. The effect of their deficiencies and excessive intake are not known yet. Dietary sources are plant and animal proteins, eggs, cauliflower.

TABLE 10.2
Microminerals: Functions and Sources

S/N	Minerals	Functions	Sources	References
1	Iron (Fe)	Helps in the formation of heme proteins needed for the transport of oxygen to the red blood cells, flavoproteins and other enzymes.	Fe is widely distributed in organ meats, red meats (30–70% is haem iron), egg yolks; legumes; dried fruits; dark, leafy greens; iron-enriched breads and cereals; fortified cereals; fish; poultry; shellfish.	Fairweather-Tait and Hurrell (1996)
2	Copper (Cu)	Part of many enzymes including metalloenzymes; needed for red blood cell formation, connective tissues.	Foods high in copper include liver, kidney, shellfish, whole-grain cereals and nuts. Soft or acidic water passing through copper pipes can also contribute copper to the diet.	Fairweather-Tait and Hurrell (1996)
3	Zinc (Zn)	It plays main roles in cell-mediated immunity, bone formation, tissue growth, brain function, growth of the fetus and child. It also has role in pathogenesis of some dermatological disorders.	Meats, fish, poultry, oysters, leavened whole grains, vegetables.	Bagherani and Smoller (2016)
4	Iodine (I)	Growth and development, metabolism, reproduction, thyroid hormone production.	Seafood, foods grown in iodine-rich soil, iodized salt, bread, dairy products.	Fairweather-Tait and Hurrell (1996)
5	Selenium (Se)	Anti-oxidant; selenium is needed for the proper functioning of the immune system and appears to be a key nutrient in counteracting the development of virulence and inhibiting HIV progression to AIDS. It is required for sperm motility and may reduce the risk of miscarriage.	Meats, seafood, grains, cereals, seafood and meat products are the richest sources of Se and are the main contributors to the daily Se intake, whereas vegetables, fruits and beverages are generally rich in Se.	Combs (1988), Fairweather-Tait and Hurrell (1996) and Margaret (2000)
6	Chromium (Cr)	Chromium acts as an antioxidant. It also helps to decrease insulin resistance in diabetic patients.	Dietary sources of chromium include brewer's yeast, cheese, pork kidney, whole grain breads and cereals, molasses, spices and some bran cereals. Lean beef, oysters, eggs, and turkey are sources of chromium.	Anderson <i>et al.</i> (1992), Anderson (2000 and Tulasi and Rao (2014)

(Continued)

TABLE 10.2 (Continued)
Microminerals: Functions and Sources.

S/N	Minerals	Functions	Sources	References
7	Manganese (Mn)	It activates numerous enzymes – such as hydrolases, transferases, kinases, and decarboxylases – and is a constituent of some enzymes. Manganese also plays a role in blood clotting and hemostasis in conjunction with vitamin K.	Manganese is present in a wide variety of foods, including whole grains, clams, oysters, mussels, nuts, soybeans and other legumes, rice, leafy vegetables, coffee, tea and many spices, such as black pepper.	Watts (1990), Aschner and Aschner (2005) and Buchman (2014)
8	Fluoride (F)	It is involved in formation of bones and teeth; helps prevent dental decay and cavities.	Drinking water (either fluoridated or naturally containing fluoride), fish and most beverages, from oral toothpastes as well.	O'Mullane <i>et al.</i> (2016)
9	Molybdenum (Mo)	Functions as a cofactor for at least four enzymes: sulfite oxidase, xanthine oxidase, aldehyde oxidase and mitochondrial amidoxime reducing component.	Legumes; nuts, breads and grains; leafy greens; leafy, green vegetables; milk; liver.	Novotny (2011)

Source: Modified from www.uofmhealth.org/health-library/ta3912.

10.4 PHYTONUTRIENTS

Phytonutrients are bioactive substances found in plant-based foods that offer various health benefits to humans. They include essential nutrients like vitamins and minerals as well as antioxidants and phytochemicals. Phytochemicals, specifically, are a diverse group of plant compounds that are known to prevent chronic illnesses such as heart disease, cancer and diabetes. There are numerous phytochemicals, such as beta-carotene and lycopene, that are found in fruits and vegetables with unique structures and functions. In addition to phytochemicals, plant-based foods also contain vitamins and minerals that are crucial for good health. Incorporating plant-based foods into the diet can help reduce the risk of chronic diseases and promote overall well-being.

10.4.1 TYPES OF PHYTONUTRIENTS AND DIETARY SOURCES

10.4.1.1 Flavonoids

Flavonoids are a large and diverse class of phytochemicals that are found in fruits, vegetables and grains. Flavonoids have been linked to a range of health benefits, such as reducing the risk of cardiovascular disease, cancer and neurodegenerative diseases. One study found that flavonoids can modulate signaling pathways involved in inflammation and cancer development (Panche *et al.*, 2016; Oladele *et al.*, 2020).

10.4.1.2 Carotenoids

Carotenoids are another class of phytochemicals that are found in fruits and vegetables. They are responsible for the bright red, orange and yellow colors of many plant-based foods. Carotenoids have been linked to a range of health benefits, such as reducing the risk of cardiovascular disease and cancer. One study found that carotenoids have antioxidant and anti-inflammatory properties that may help protect against chronic diseases (Goltz and Campbell, 2012).

10.4.1.3 Phenolic Acids

Phenolic acids are a class of phytochemicals found in fruits, vegetables, whole grains and legumes. They have been shown to have antioxidant and anti-inflammatory properties and may help reduce the risk of chronic diseases such as cardiovascular disease and diabetes (Liu, 2013).

10.4.1.4 Alkaloids

Alkaloids are a diverse group of phytochemicals found in various plants, including coffee, tea and cocoa. Alkaloids have various biological effects, including acting as stimulants, analgesics and anti-inflammatory agents. One study found that caffeine, an alkaloid found in coffee, has neuroprotective effects and may reduce the risk of neurodegenerative diseases (Cao and Loewenstein, 2021).

The phytochemistry of phytonutrients is a complex area of study with potential health benefits. Consuming a diverse range of plant-based foods is important to ensure a variety of phytonutrients in diet.

10.4.2 PHARMACOLOGICAL AND BIOLOGICAL ACTIVITIES OF PHYTONUTRIENTS

10.4.2.1 Antioxidant Activities of Phytonutrients

10.4.2.1.1 Turmeric

The phytonutrients in turmeric have potent antioxidant properties. Specifically, curcumin, which is the main active ingredient in turmeric, was found to exhibit strong antioxidant activity (Oladele *et al.*, 2020, 2023).

10.4.2.1.2 Garlic

The phytonutrients in garlic, particularly allicin, were found to have significant antioxidant activity, according to a study by Agarwal and Gupta (2019). The study suggested that the antioxidant properties of garlic may be useful in preventing diseases related to oxidative stress.

10.4.2.1.3 Cinnamon

The phytonutrients in cinnamon, particularly cinnamaldehyde, were found to have strong antioxidant activity (Zare *et al.*, 2019; Oladiji and Oladele, 2023). The study also suggested that cinnamon may be a promising candidate for preventing and treating oxidative stress-related diseases.

10.4.2.1.4 Granola

According to Liu *et al.* (2020a, 2020b), granola's phytonutrients, especially polyphenols, have potent antioxidant activity. The study suggested that the antioxidant properties of granola may be beneficial in reducing oxidative stress and inflammation in the body.

10.4.2.1.5 Oregano

Eşrefoğlu *et al.* (2020) found that oregano's phytonutrients, particularly phenolic compounds, have strong antioxidant activity. The study also found that oregano extract was effective in scavenging free radicals.

10.4.2.2 Anti-inflammatory Activities of Phytonutrients

Inflammation is a natural process that the body's immune system uses to defend against foreign pathogens and injury. Excessive and prolonged inflammation can lead to various diseases, such as diabetes, cancer and cardiovascular diseases (Oladele *et al.*, 2020). Phytonutrients are bioactive compounds present in plant-based foods that have anti-inflammatory properties (Oladiji and Oladele, 2023).

Curcumin is a polyphenol that is commonly found in turmeric and has been widely researched for its anti-inflammatory effects (Oladele *et al.*, 2023). It inhibits the activation of NF- κ B, a transcription

factor that regulates inflammation. A study conducted by Aggarwal *et al.* (2007) showed that curcumin can reduce the production of pro-inflammatory cytokines such as IL-1, IL-6 and TNF- α .

Resveratrol is another polyphenol found in grapes, berries and peanuts (Oladele *et al.*, 2021). It has been shown to have anti-inflammatory properties by inhibiting the activation of NF- κ B and the production of pro-inflammatory cytokines. Resveratrol also inhibits COX-2, which is a crucial enzyme involved in the inflammatory response (Chen *et al.*, 2014; Oladele *et al.*, 2022).

Quercetin, a flavonoid, is present in many fruits and vegetables (Oladele *et al.*, 2021). It has anti-inflammatory properties by inhibiting the production of pro-inflammatory cytokines such as IL-1, IL-6 and TNF- α (Kim *et al.*, 2015). Quercetin also inhibits the activation of NF- κ B (Oladele *et al.*, 2021).

EGCG is a catechin that is present in green tea. It has been shown to have anti-inflammatory properties by inhibiting the production of pro-inflammatory cytokines and the activation of NF- κ B (Mokra *et al.*, 2023). EGCG also inhibits the expression of COX-2.

10.4.2.2.1 Turmeric

Curcumin, which is the primary phytonutrient in turmeric, has been found to have anti-inflammatory properties in a review conducted by Gupta *et al.* (2013). The review suggests that curcumin's anti-inflammatory effects may be beneficial in preventing and treating different inflammatory diseases.

10.4.2.2.2 Garlic

The phytonutrients present in garlic, particularly allicin, were found to have potent anti-inflammatory activity in a study by Rahman *et al.* (2021). The study proposes that garlic may have therapeutic potential in the treatment of inflammatory diseases.

10.4.2.2.3 Cinnamon

In a study by Yerra *et al.* (2019), it was discovered that the phytonutrients in cinnamon, especially cinnamaldehyde, exhibit anti-inflammatory properties. The study suggests that cinnamon could have therapeutic applications in the treatment of inflammatory diseases (Oladiji and Oladele, 2023).

10.4.2.2.4 Granola

The polyphenols present in granola were found to have significant anti-inflammatory activity in a study by Liu *et al.* (2020a). The study suggests that the anti-inflammatory properties of granola may be useful in reducing inflammation and associated disorders.

10.4.2.2.5 Oregano

Carvacrol and thymol, the primary phytonutrients in oregano, were found to have potent anti-inflammatory activity in a study by Silva *et al.* (2020). The study suggests that oregano may have therapeutic potential in the treatment of inflammatory diseases due to its anti-inflammatory and antioxidant properties.

Phytonutrients like curcumin, resveratrol, quercetin and EGCG have been found to have anti-inflammatory properties. These compounds can reduce the activation of NF- κ B and the production of pro-inflammatory cytokines, which play a crucial role in the inflammatory response. Consuming these phytonutrients through a balanced diet may help to prevent chronic diseases by reducing inflammation.

10.4.2.3 Antiviral Activities of Phytonutrients

Viruses are a significant cause of infectious diseases globally, and while vaccines and antiviral drugs exist, drug-resistant strains and high treatment costs have emphasized the need for alternative options. Phytonutrients are bioactive substances found in plant-based foods that have antiviral properties. Several phytonutrients such as quercetin, EGCG, curcumin and resveratrol have antiviral effects against various viruses, including influenza, hepatitis B and C, HIV and herpes simplex

virus. These phytonutrients work by inhibiting viral entry, viral gene expression and viral assembly and release.

Quercetin is a flavonoid found in many fruits and vegetables and has antiviral activity against influenza, hepatitis C and HIV. EGCG is a catechin present in green tea and has antiviral effects against influenza, hepatitis B and herpes simplex virus. Curcumin, a polyphenol found in turmeric, exhibits antiviral activity against influenza, hepatitis B and herpes simplex virus. Resveratrol, a polyphenol found in grapes, berries and peanuts, shows antiviral activity against influenza, HIV and herpes simplex virus.

10.4.2.3.1 Turmeric

In a review study conducted by Oladiji and Oladele (2023), it was discovered that the phytonutrient curcumin found in turmeric has antiviral properties. The research suggests that curcumin has potential as an antiviral agent against various viruses.

10.4.2.3.2 Garlic

A review by Nantz *et al.* (2012) indicates that garlic has antiviral properties, particularly against influenza viruses. The study suggests that phytonutrients such as allicin and alliin present in garlic have the potential to treat and prevent viral infections.

10.4.2.3.3 Cinnamon

A study conducted by Khan *et al.* (2020a) found that the phytonutrient cinnamaldehyde present in cinnamon has antiviral properties against several viruses. The research suggests that cinnamon can be a potential natural antiviral agent.

10.4.2.3.4 Granola

In a study by Kim *et al.* (2018), it was discovered that oats, a primary ingredient in granola, contain phytonutrients that have antiviral properties against several viruses. The research suggests that oats' antiviral properties can help prevent and treat viral infections.

10.4.2.3.5 Oregano

Astani *et al.* (2010) conducted a study on oregano and discovered that its phytonutrients, including carvacrol and thymol, have antiviral properties against several viruses. The research suggests that oregano has potential as a natural antiviral agent.

10.4.2.4 Immunological Activities of Phytonutrients

Phytonutrients help improve immune system functioning through multiple mechanisms, such as augmenting immune cell activity and mitigating inflammation. For instance, quercetin is a phytonutrient that may improve immune function by improving immune cell function. Another phytonutrient, beta-carotene, which is converted to vitamin A in the body, plays a crucial role in immune function. Furthermore, curcumin, found in turmeric, has anti-inflammatory and antioxidant characteristics that enhance immune function.

10.4.2.4.1 Turmeric

According to research conducted by Aggarwal *et al.* (2007), the presence of curcumin in turmeric has immunomodulatory properties. The study suggests that curcumin can boost the immune system's function and response.

10.4.2.4.2 Garlic

A review by Oladiji and Oladele (2023) suggests that garlic has immunomodulatory properties. The research indicates that phytonutrients present in garlic, including allicin and alliin, can enhance the immune system's response to infections and diseases.

10.4.2.4.3 Cinnamon

Oladiji and Oladele (2023) found that cinnamon has immunomodulatory properties. The study indicates that the presence of cinnamaldehyde, a phytonutrient in cinnamon, can stimulate the immune system's function and response.

10.4.2.4.4 Granola

Delaney *et al.* (2003) found that oats, which are a primary ingredient in granola, have immunomodulatory properties. The research indicates that beta-glucans, a type of phytonutrient present in oats, can enhance the immune system's response.

10.4.2.4.5 Oregano

According to Leyva-López *et al.* (2017), oregano has immunomodulatory properties. The research indicates that phytonutrients in oregano, including carvacrol and thymol, can enhance the immune system's function and response.

10.4.2.5 Antibacterial Activities of Phytonutrients

Phytonutrients are natural compounds that occur in plants and have been linked to various health benefits, including antibacterial properties. According to research, flavonoids, phenolic acids and terpenoids are among the phytonutrients with the potential to hinder the growth of bacterial pathogens, including those that are multidrug-resistant (Khan *et al.*, 2020b).

For instance, flavonoids like quercetin and kaempferol have been proven to impede the growth of diverse bacterial strains, including *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa* (Kumar *et al.*, 2019). Additionally, phenolic acids like gallic acid and ellagic acid have demonstrated antibacterial effects against several bacterial species (Borges *et al.*, 2013). Similarly, terpenoids such as carvacrol and thymol, present in essential oils, have exhibited potent antibacterial activity against both Gram-positive and Gram-negative bacteria.

10.4.2.5.1 Turmeric

Curcumin, a phytonutrient found in turmeric, has been found to possess antibacterial properties in a study conducted by Khan *et al.* (2020b). Their research has demonstrated that curcumin can inhibit the growth of different bacterial strains, including *E. coli*, *S. aureus* and *P. aeruginosa*.

10.4.2.5.2 Garlic

According to Khan *et al.* (2020b) and Oladiji and Oladele (2023), garlic has been identified to possess antibacterial properties. The research suggests that phytonutrients, such as allicin and ajoene, found in garlic, can prevent the growth of different bacterial strains.

10.4.2.5.3 Cinnamon

Oladiji and Oladele (2023) have found that cinnamon has antibacterial properties. Their review suggests that cinnamaldehyde, a phytonutrient in cinnamon, has the potential to inhibit the growth of various bacterial strains, including *E. coli*, *S. aureus* and *P. aeruginosa*.

10.4.2.5.4 Granola

In a study by Delaney *et al.* (2003), beta-glucans, a type of phytonutrient present in oats, a primary ingredient in granola, were found to possess antibacterial properties. The research indicates that beta-glucans can prevent the growth of different bacterial strains.

10.4.2.5.5 Oregano

Oregano has been identified to possess antibacterial properties, according to a review by Leyva-López *et al.* (2017). The research suggests that carvacrol and thymol, phytonutrients in oregano, can prevent the growth of different bacterial strains.

10.4.2.6 Antifungal Activities of Phytonutrients

Phytonutrients are active compounds found in plants and are known to have various therapeutic properties, including antifungal activity. The antifungal potential of phytonutrients is due to their ability to interfere with fungal cellular machinery, leading to cell death. Recent research has shown that several types of phytonutrients, including phenolics, flavonoids and terpenoids, exhibit antifungal activity against different fungal pathogens (Mishra *et al.*, 2021; Oladele *et al.*, 2022b).

For instance, essential oils containing phenolic compounds such as eugenol and thymol have potent antifungal activity against *Candida albicans* and *Aspergillus fumigatus* (Kumar *et al.*, 2017). Flavonoids, like quercetin and kaempferol, have also been found to possess antifungal properties and can inhibit the growth of *Candida* species (Silva *et al.*, 2017). Terpenoids, including carvacrol and linalool, have been shown to be effective against several fungal pathogens, including *Candida* and *Aspergillus* species (Soliman *et al.*, 2017).

The antifungal potential of phytonutrients highlights their potential as alternative treatments for conventional antifungal agents. Moreover, the use of phytonutrients as adjunct therapy to conventional antifungal agents could be a strategy to combat antifungal resistance, which is an increasingly concerning issue.

10.5 BIOAVAILABILITY OF PHYTONUTRIENTS

Phytonutrients are natural compounds found in plants that offer various health benefits. The degree and speed at which they are absorbed into the bloodstream and reach the target tissues, known as bioavailability, determines their positive impact on health. The bioavailability of phytonutrients can be influenced by various factors, including the food matrix, processing and individual factors such as age and gut microbiota. The food matrix, which refers to the physical and chemical structure of the food, can affect the solubility, stability and absorption of phytonutrients. Processing techniques like cooking, grinding and fermentation can also alter the chemical and physical properties of phytonutrients, affecting their bioavailability. Individual factors like aging and gut microbiota composition can affect the absorption of phytonutrients. Understanding these factors is crucial in optimizing the health benefits of phytonutrients. Techniques like optimizing the food matrix, preserving the integrity of phytonutrients during processing and regulating gut microbiota can help improve their bioavailability. Proper bioavailability of phytonutrients ensures the maximum health benefits that they offer.

10.6 CONCLUSION AND FUTURE PROSPECTS

Dietary fibres and phytonutrients are important components of our diet and have various health benefits. This might be due to their structural properties and their interaction with other components of the biological system. Vitamins and minerals are micronutrients required in smaller quantities when compared with macronutrients. They are very key to normal body functioning and health status of the body. Phytonutrients are bioactive compounds found in plant-based foods that offer a range of potential health benefits. They have been linked to reduced risk of chronic diseases such as cancer, heart disease and diabetes as well as improved overall health and well-being. While more research is needed to fully understand the mechanisms of phytonutrients and their effects on the body, incorporating a variety of colorful fruits and vegetables into the diet is a simple and effective way to increase intake of these important nutrients. Future research is to focus on the mechanistic interaction of the constituents of these dietary molecules with the biomarkers known for specific health challenges.

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