Review Article

Potential Health Benefits and Problems Associated with Phytochemicals in Food Legumes

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Abstract: Phytochemicals are a naturally occurring group of chemicals in plants and plant-derived foods. Presence of phytochemical components such as phytohemagglutinins, tannins, phytic acid, saponins, protease inhibitors, oligosaccharides and phytoestrogens in food legumes has both health benefits and adverse effects. These have been associated with numerous health benefits, including reduced cardiovascular and renal disease risks, health care treatments including anti-aging, enhancement of brain function, lower glycemic index for persons with diabetes, increased satiation and cancer prevention. Health benefits resulting from ingestion of oligosaccharides which have been developed in the past few years to use as physiologically functional foods consist of proliferation of bifidobacteria and reduction of detrimental bacteria, diminution of toxic metabolites, anti-cancer effect and protection of liver function. These biologically active compounds in food legumes also have immense potential in biomedical application. On the other hand, phytochemicals have adverse effects as they limit the digestibility of proteins and carbohydrates or reduce the bioavailability of certain nutrients, interfere with normal growth, reproduction and flatulence production. Moreover, phytoestrogens have been linked with infertility problems. The synergistic or antagonistic effects of mixtures of these phytochemicals from food legumes, their interaction with other components of the diet and the mechanism of their action have remained a challenge with regard to understanding the role of phytochemicals in health and diseases. Current researches in phytochemicals are exploring various potentials and utilization in foods and drugs which could be used as front-line defences against numerous life threatening diseases including HIV/AIDS. Because of the potential health benefits of phytochemicals in food legumes, it is probably inappropriate to refer to these substances as natural toxins. The time has come for us to re-evaluate their presence in our diet. Their mitigating effects and the mechanism of their action need to be further addressed if we are to understand the role of phytochemicals in health and diseases.

Keywords: Adverse Effects; Food Legumes; Health Benefits; Phytochemicals; Natural Toxins

1. Introduction

Food legumes are major sources of dietary protein in the East and Great Lakes Region of Africa where legume utilization in traditional dishes is enormous. Food legumes synthesize several chemical substances termed as phytochemicals. Phytochemicals are a naturally occurring group of chemicals in plants and plant-derived foods. Many phytochemicals function as crucial components in the natural defence system of their host plants, defending against infections and microbial invasions. Other phytochemicals give plants their flavours, aromas and pigments (Lee *et al*., 2000a). These phytochemicals from food legumes such as raffinose family sugars, phytohemagglutinins (lectins), phytic acid (phytate), phenolic compounds, saponins, trypsin inhibitors and phytoestrogens are attracting considerable interest as a result of their diverse properties, both deleterious and beneficial (Ali and Muzquiz, 1998; Lila and Raskin, 2005).

Phytochemicals may provide health benefits which prevent or delay the onset or continuation of chronic diseases in humans and animals beyond the nutrients they contain (Guhr and LaChance, 1997; Hasler, 1998). The healing power of foods is a popular concept that focuses on how legume source foods can have health-protecting properties. Most of the phytochemicals are characterized by anti-oxidant properties (Geil and Anderson, 1994; Arkadiusz *et al.,* 2002). Animal foods contain a similar group of disease-preventing nutrients-the term zoochemical has been suggested for them.

Phytochemicals and zoochemicals-unlike carbohydrates, fats, proteins, vitamins and minerals-are not considered essential for life and have therefore been assigned quasi-nutrient status (Frias *et al*., 2000). Several disease-preventive benefits have been proposed for phytochemicals and zoochemicals. Research shows individual nutrients can facilitate cell-to-cell communication (Kelly, 1999), modify cellular receptor uptake of hormones (Potter, 1995) , convert to vitamin A (Shils *et al.,* 1994), repair DNA damage from toxic exposure (Jenkinson *et al.,* 1999), detoxify carcinogens through the activation of the cytochrome P450, and Phase II liver enzyme systems (Persky and Van Horn, 1995), serve as anti-oxidants to help prevent various forms of cancer (Steinmetz and Potter, 1996), cause apoptosis (cell death) in cancer cells (Mo and Elson, 1999), enhance immune response (Zhang *et al.,* 1997) and help to prevent cardiovascular disease (Gaziano *et al.,* 1995), osteoporosis (Head, 1999), muscular degeneration and cataracts (Seddon *et al.,* 1994).

Additionally, phytochemicals from food legumes carry out a variety of functions, acting as anti-oxidants, protective (immune-boosting), therapeutic effects, anti-aging and other health-promoting properties of active compounds (Mary and Ilya, 2005). With the shift towards a more plant-based diet, food legumes will be potent tools

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in the treatment and prevention of chronic diseases (James *et al.,* 1999).

The physiological effects of different legumes vary significantly. These differences may result from polysaccharide composition, in particular quantity and variety of dietary fibre and starch, protein make-up, and variability in phytochemicals content (Enneking and Wink, 2000). Fenugreek (*Trigonella foenum graecum*) and isolated fenugreek fractions have been shown to act as hypoglycaemic and hypocholesterolaemic agents in both animal and human studies. The unique dietary fiber composition and high saponin content in fenugreek appears to be responsible for these therapeutic properties. Faba beans (*Vicia faba*) have lipid-lowering effects and may also be a good source of anti-oxidants and chemopreventive factors. Mung beans (*Phaseolus aureus, Vigna radiatus*) are thought to be beneficial as an anti-diabetic, low glycaemic index food, rich in anti-oxidants. Evidence suggests that these novel sources of legumes may provide health benefits when included in the daily diet (Zecharia and Aliza, 2002a).

Though the mechanism is not completely clear, the actions of phytochemicals may protect us from a host of diseases (Mary and Ilya, 2005). Some of these beneficial chemicals block various hormone actions and metabolic pathways that are associated with the development of cardiovascular disease and cancer, and other chemicals stimulate protective enzymes. The phytochemicals appear to work alone and in combination, and perhaps in conjunction with vitamins and other nutrients in food, to prevent, halt or lessen disease.

Research is currently very active in exploring the potential of phytochemicals for biomedical applications. Investigators are constantly striving and deciphering the many ways of utilization of phytochemicals (plant chemicals) in foods and drugs which might be used as front-line defences against many life-threatening diseases, including HIV/AIDS, cancer, heart disease (heart attacks), osteoporosis (bone disease), improving brain function, cardiovascular disease and diabetes**.** As scientists continue to identify individual constituents in plants, they are discovering more human health benefits. Several studies have explored the many uses of botanical-derived chemicals-everything from powerful anti-oxidants to potential cancer cures (Asanaka *et al.,* 1988; Kabir *et al.,* 1998; Kabir *et al.,* 2000; Marcia, 2000; Zecharia and Aliza, 2002b). Some of the phytochemicals are already available on the market, such as flava soy capsule for the relief of menopausal symptoms.

Phytochemiclas have always been associated with a number of substances which inhibit specific physiological functions of animals including digestion, enzyme activity, metabolism and absorption of nutrients. These factors negatively affect the nutritive value of beans through direct and indirect reactions (Shimelis and Rakshit, 2005a). They inhibit protein and carbohydrate digestibility, interfere with mineral bio-availability, induce pathological changes in intestine and liver tissues thus affecting metabolism, inhibit a number of enzymes and bind nutrients making them unavailable (Bressani, 1993). They also produce gas and cause much discomfort to individuals who consume beans (Ologhobo and Fetuga, 1984). A number of these phytochemicals are under study for their potential health benefits. Different food processing methods are used for the reduction/removal of these bioactive compounds for consumption (Binyam *et al.*, 1995; Shimelis and Rakshit, 2007).

The review of literature reveals that a considerable amount of work has been generated over the years on the effectiveness of different processing methods to reduce/remove phytochemical compounds using plant breeding, biotechnological techniques, and chemical and physical treatments. However, conclusions are often reached that no one method is superior to another and it is perfectly feasible to achieve removal/reduction of phytochemicals for the benefits of consumers with similar quality using different methods. Lack of threshold levels makes a choice difficult (Shimelis, 2005). Currently, determination of the threshold level is under study using experimental animals (Zecharia and Aliza, 2002a). The threshold levels at which undesirable components may exert adverse effects need to be established.

The aim of this paper is to describe some of the benefits and problems associated with the phytochemicals in food legumes. A number of phytochemicals are present in foods but this paper will describe only a few of those in which health benefits have also been reported.

2. The Adverse Effects

2.1. Phytohaemagglutinins

Phytohaemagglutinins (lectins) are proteins or glycoprotein substances, usually of plant origin, that bind to sugar moieties in cell walls or membranes and thereby change the physiology of the membrane to cause agglutination, mitosis or other biochemical changes in the animal red blood cells (Liener, 1983; Gupta, 1987). Generally, lectins are classified into animal, plant, bacterial, fungal and virus lectins. Legumes' lectins are one of the largest lectin families with more than 70 types have been reported. Lectins are found in most plant foods including those that may be eaten without heat treatment or processing (Nachbar and Oppenheim, 1980). Lectins are specific not only in the sugars that they bind to the cell membranes but also in their toxicity. The lectins from legumes are all toxic when taken orally (Liener, 1989b).

The seeds of many edible legumes have long been known to contain proteins which agglutinate erythrocytes. Some of these phytohaemagglutinins have been suggested to contribute to the poor nutritive quality of raw legumes (Jaffe, 1980). Phytohaemagglutinins are the main toxic components in food legumes, sugar-binding proteins that bind to and agglutinate animal red blood cells. The toxicity of phytohaemagglutinins is characterized by growth depression (inhibition) in experimental animals and diarrhea, nausea, bloating and vomiting in humans (Liener, 1983). Several outbreaks in England after the intake of improperly cooked beans have been related to the presence of lectins in the beans (Noah *et al.,* 1980). Heat processing can reduce the toxicity of lectins as it can be denatured by heat, but low temperature of slow cooking may not be enough to completely eliminate its toxicity (Thompson *et al.,* 1983).

The toxic effects of lectins relate to their binding with the specific receptor sites on the epithelial cell of the intestinal mucosa which then causes lesion, disruption and abnormal development of the microvillae (Liener, 1989b). Consequently, absorption of nutrients is impaired. The intake of raw beans or purified lectins from beans has been shown to decrease the absorption of sugars (Donatucci *et al.,* 1987), amino acids (Kawatra and Bhatia, 1979), lipid, nitrogen and vitamins B_{12} (Dobbins *et al.,* 1986). Lectins can also impair the nutrient absorption by reducing the activity of brush border enzymes, e.g. peptidases, disaccharides, alkaline phosphatase, glutamyl transferase (Rouanet *et al.,* 1988; Liener, 1989a), pancreatic and salivary amylase (Fish and Thompson, 1991). The increased secretion of mucin and the increased weight and number of intestinal mucosal cells in the presence of lectins (Pusztai, 1986) have also been thought to lead to endogenous loss of nitrogen and aggravated toxic effects of lectins with respect to protein utilization. The carbohydrates or proteins, those that are undigested and unabsorbed in the small intestines, reach the colon where they are fermented by the bacterial flora to short-chain fatty-acids and gases. This increased fermentation contributes to some of the gastrointestinal symptoms associated with the intake of raw beans or purified lectins. Bacterial overgrowth or colonization of coliform bacteria in the small intestine has been observed upon feeding raw beans or purified lectins and this has also been suggested to contribute to lectin toxicity (Liener, 1989b). How lectins increase bacterial colonization is unclear but it may be related to the polyvalent nature of lectins; this allows lectins to bind to both the mucosal cells and bacteria at the same time and fix the bacteria close to the intestinal mucosa. The lectin-induced disruption of the intestinal mucosa may allow entrance of the bacteria and their endotoxins to the blood stream and cause a toxic response (Banwell *et al.,* 1985). Lectins, themselves, may also be internalized and cause systemic effects such as increased protein catabolism and breakdown of stored fat and glycogen, and disturbance in mineral metabolism (Pusztai, 1986; Liener, 1989b). No recognizable patterns exist between the chemical and biological properties of the lectins and their taxonomic distribution in the leguminous family (Liener, 1983).

2.2. Saponins

Saponins are widely distributed in many plant species and have complex chemical structures consisting of a variety of tri-terpenoidal or steroidal aglycons and various carbohydrate moieties (Park *et al.*, 2000). They are bitter tasting, foam producing tri-terpene glycosides and serve as natural anti-biotics for plants. Saponins are a diverse group of compounds commonly found in cereals and legumes, e.g. chick peas, soya beans, lentils, peanuts, *Phaseolus* beans and alfalfa sprouts; and in some plants commonly used as flavorings, herbs or spices, e.g. ginseng, fenugreek, sage, thyme and nutmeg (Oakenful and Sidhu, 1990). Saponins are composed of a steroidal or tri-terpene aglycone (sapogenin) linked to one or three saccharide chains of variable size and complexity *via* ester and ether linkages (Price and Fenwick, 1984) (Figure 1). The presence of both polar (sugar) and non-polar (steroid or tri-terpene) groups provide saponins with strong surface-active properties which then are responsible for many of its adverse and beneficial biological effects (Duhan *et al.,* 2001). Saponins in food legumes especially in beans are with varying degree of haemolytic and foam producing activity.

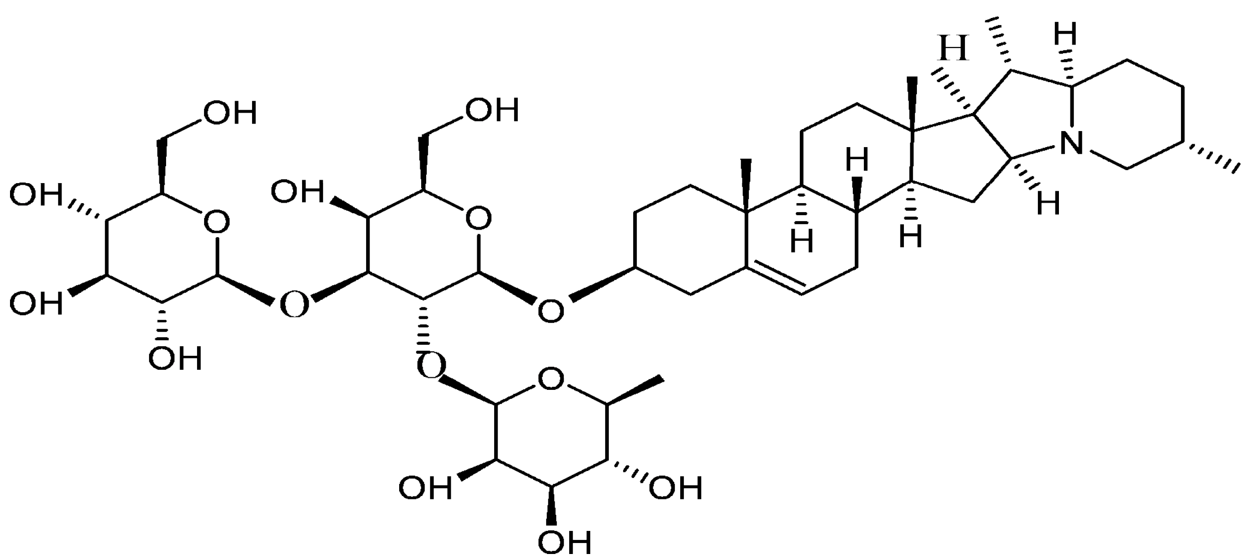

Figure 1. Chemical structure of soyasaponin (Price and Fenwick, 1984)

Among the better-known biological toxic effects of saponins is their capacity to cause lysis of erythrocytes (Kahlil and El-Adawy, 1994), this, in general, being due to its interaction with the cholesterol in the erythrocyte membrane (Birk and Peri, 1980) and make the intestinal mucosa permeable (Johnson *et al.,* 1986). Scott *et al.* (1985)

reported that intravenous injection of saponins to mammals can cause local inflammation, and in large doses, can result in death due to massive release of erythrocyte debris and reduction in the oxygen-carrying capacity of the blood. Saponins can also lyse other cells such as those found in the intestinal mucosa and consequently affect nutrient absorption. Decreased weight gain has been observed with high saponin intake due to a number of reasons including reduced food intake attributable to the bitter taste of saponins (Birk and Peri, 1980), or decreased absorption and utilization of nutrients caused either by the inhibition of metabolic or digestive enzymes (Cheeke, 1976). Saponins also decrease re-absorption of bile cholesterol into the body.

2.3. Trypsin Inhibitors or Protease Inhibitors

Trypsin is an enzyme involved in protein digestion and trypsin inhibitors that can result in a decreased level of bioavailability of protein. Trypsin inhibitors are abundant in raw cereals and legumes seeds and are capable of binding to the trypsin enzyme. These have been associated with growth inhibition, thus inhibiting its activity, interfering with the digestion of proteins and resulting in an increased pancreatic secretion and hypertrophy of the pancreas (Birk, 1989; Shimelis and Rakshit, 2005b). Dry beans are quite rich in cystine containing trypsin inhibitors. About 30-40% of the total cystine content of the food comes from beans, although the inhibitor makes the cystine unavailable. Generally, all legumes studied to date have been found to contain trypsin inhibitors in varying amounts. When beans are ingested by humans and mono-gastric animals in significant amounts, they disrupt the digestive process and may lead to undesirable physiological reactions (Collins and Beaty, 1980). The adverse effect of protease inhibitors have been observed primarily in animals with a high weight of pancreas, expressed as a percentage of body weight (0.29-0.80), such as rats, mice, chicken, hamsters and young guinea pigs. The effect of protease inhibitors on the pancreas of humans remains unclear and needs further elucidation (Mary and Ilya, 2005).

2.4. Phytoestrogens

Phytoestrogens are plant-derived substances that are structurally and functionally similar to endogenous estrogens of humans and other members of the animal kingdom. Principally, there are three main classes of phytoestrogens-isoflavones, coumestans, and lignans which are found in many food legumes (Murkies *et al.*, 1998) (Figure 2).

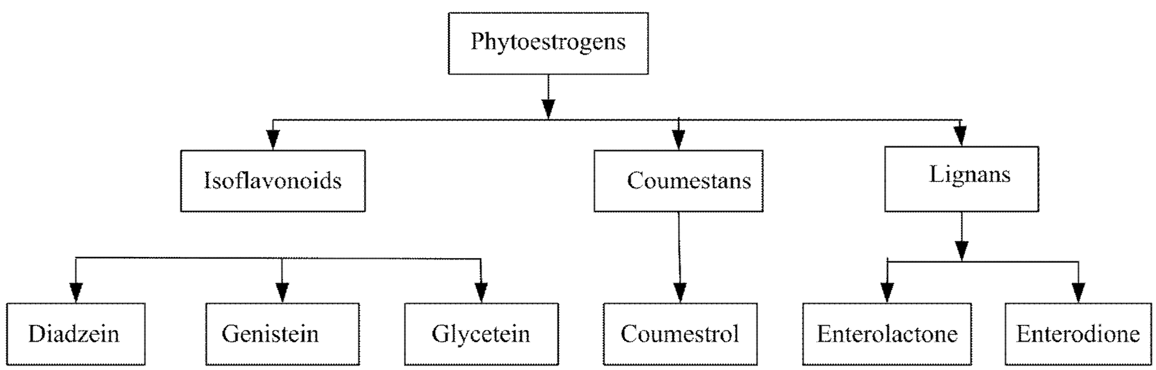

Figure 2. Classification of phytoestrogens

Phytoestrogens are widely distributed in the plant kingdom including legumes, cereals, oilseeds, fruits and vegetables. Lignans are a group of diphenolic compounds with dibenzylbutane skeleton structures and similar characteristics to the phytoestrogens (Setchell and Adlercreutz, 1988). Many different plant lignans have been identified and/or isolated but recently the mammalian lignans enterolactone [(*trans*-2, 3-bis-(3-hydroxybenzylyl)-butyrolactone)] and enterodiol [(2, 3-bis (3-hydroxybenzylyl) butan-1, 4-diol)] have gained much attention. They are produced by the bacterial flora in the colon from the plant lignans matairesinol and secoisolariciresinol, respectively, and have been detected in the biological fluids of man and animals. The two main classes of phytoestrogens are the isoflavones and the coumestans, the former having attracted greater attention (Setchell and Adlercreutz, 1988). The phytoestrogens, plant lignans, and their bacterial products undergo enterohepatic circulation and some have been detected in the urine. The structures of the main phytoestrogens are shown in Figure 3.

Phytoestrogens have been linked with infertility problems (Setchell *et al.,* 1987). Reports of infertility in sheep in Western Australia indicated that, the infertility syndrome, characterized by a cystic condition of the ovaries, an irreversible endometriosis and failure to conceive, appear to have been caused by grazing in pasture having a high content of clover (*Trifolium subterraneum*) which is rich in dietary phytoestrogens. In addition, there are concerns that phytoestrogens may enhance tumor growth since oestrogens have growth-stimulatory effects (Miller, 1990; Allred *et al.,* 2001). Some purified lignans are toxic when taken in high doses and resulted in renal impairment, nausea, vomiting, delirium, stupor and coma (Ayres, 1990). Women who consume more soya products containing phytoestrogens and protease inhibitors might have lower cancer risks but seem to have reproductive problems (Messina and Barnes, 1991; Rishi, 2002).

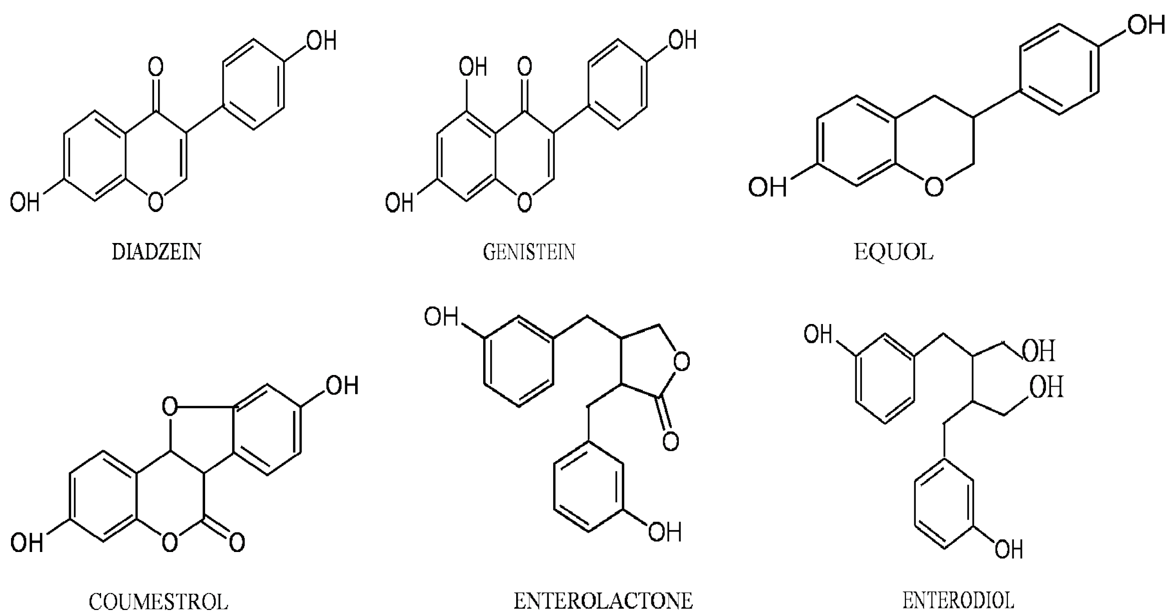

Figure 3. Structure of important phytoestrogens (Bingham *et al.*, 1998; Setchell, 1998)

2.5. Tannins

Tannins are polyphenolic compounds which has the ability to precipitate proteins from aqueous solution (Swain, 1985). Tannins consist mainly of gallic acid residues that are linked to glucose *via* glycosidic bonds as shown in Figure 4. It is generally agreed that tannins precipitate proteins because they contain a number of functional groups which complex strongly with two or more protein molecules, building up a large cross-linked protein-tannin complex. Tannins are present in food legumes, though generally not in such high amounts in some cereals such as brown sorghum and finger millet. They are known to inhibit the activities of trypsin, chymotrypsin, amylase and lipase, decrease the protein quality of foods and interfere with dietary iron absorption (De Lumen and Salamat, 1980).

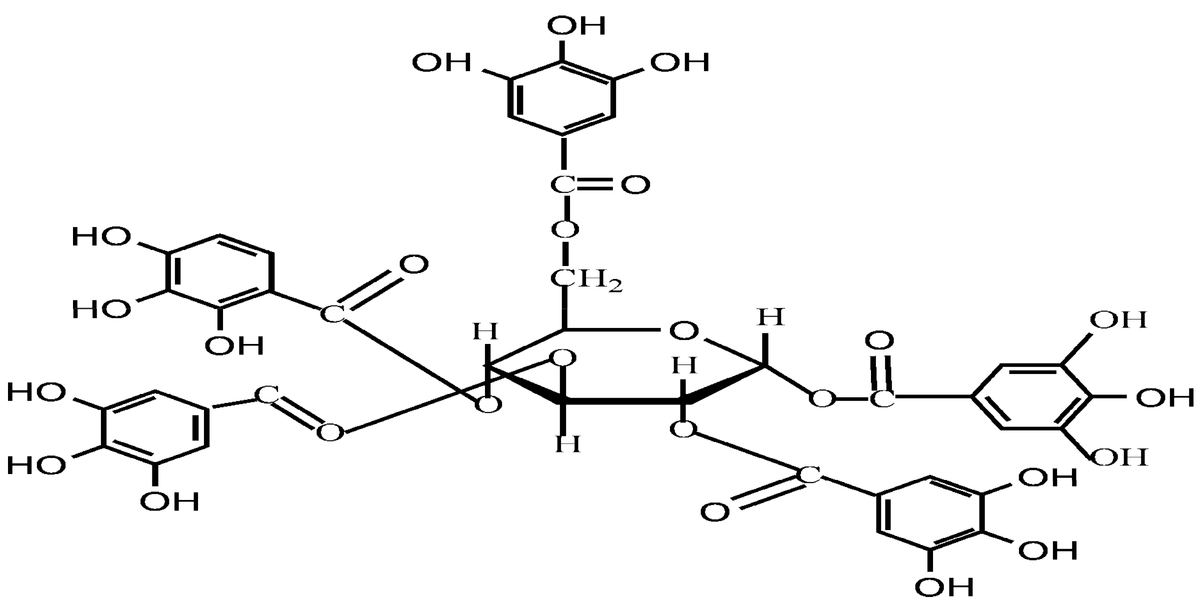

Figure 4. Basic structure of tannin (Peter, 2003)

Tannins form insoluble complexes with protein and inhibit several enzymes (Bressani *et al.,* 1983). Poor digestibility and biological utilization of bean protein from cooked beans of the colored cultivars have been directly related to the tannins' content of these beans. Tannins (particularly the condensed types) inhibit several enzymes and they are located mainly in the seed coat of grains (Elias *et al.,* 1979). Many investigators observed that tannins and related polyphenols can react with proteins, decrease protein digestibility and therefore reduce protein quality (Bressani *et al.,* 1983; Shimelis and Rakshit, 2008).

The nutritional effects of tannins on poultry feed, egg production, rats, swine, ruminants and insects have been investigated (Awika and Rooney, 2004). Toxic effects of tannins have been categorized as causing depression in food/feed intake, decreased nitrogen retention (increased nitrogen excretion and/or reduced protein digestibility) by allowing tannin complexes with dietary protein or other dietary components (formation of the less digestible tannin-dietary protein complexes). Tannin complexes with digestive enzymes (interfering with normal digestion), inhibition of digestive enzymes, increased excretion of endogenous protein, malfunctions in the digestive tract, tannin effect on the digestive tract (alimentary canal) and toxicity of absorbed tannin or its metabolites (Salunkhe *et al.*, 1990; Deshpande *et al.,* 2000). The biochemical nature of how the food tannins bind to food proteins is difficult to discern, primarily due to the complexity of tannin chemistry as well as the number of tannin species present in food (Sathe and Salunkhe, 1984).

In conclusion, the presence of tannins in food can therefore lower feed efficiency, depress growth, decrease iron absorption, damage the mucosal lining of the gastrointestinal tract, alter excretion of cations, and increase excretion of proteins and essential amino acids (Reddy and Pierson, 1994).

2.6. Oligosaccharides

Flatulence-causing α-galactosides are oligosaccharides of the raffinose-series, which are considered as unwanted components due to their role in flatus production and accumulation of gas in the intestinal tract which results in discomfort, abdominal rumblings, cramps, pain and diarrhea. Oligosaccharides of the raffinose family of sugars (raffinose, stachyose and verbascose) (Figure 5) are known to produce flatus in human and other monogastric animals, pigs and poultry (Vidal-Valverde *et al.,* 1992). This is due to the lack of the necessary α-galactosidase enzyme which helps to break down raffinose-series oligosaccharides during consumption of food legumes (Salunkhe and Kadam, 1989). These sugars pass to the large intestine where they get fermented by colon bacteria giving CO_2, H_2 and CH_4 as the main components of flatus gases (Rao and Belavady, 1978; Shimelis and Rakshit, 2008).

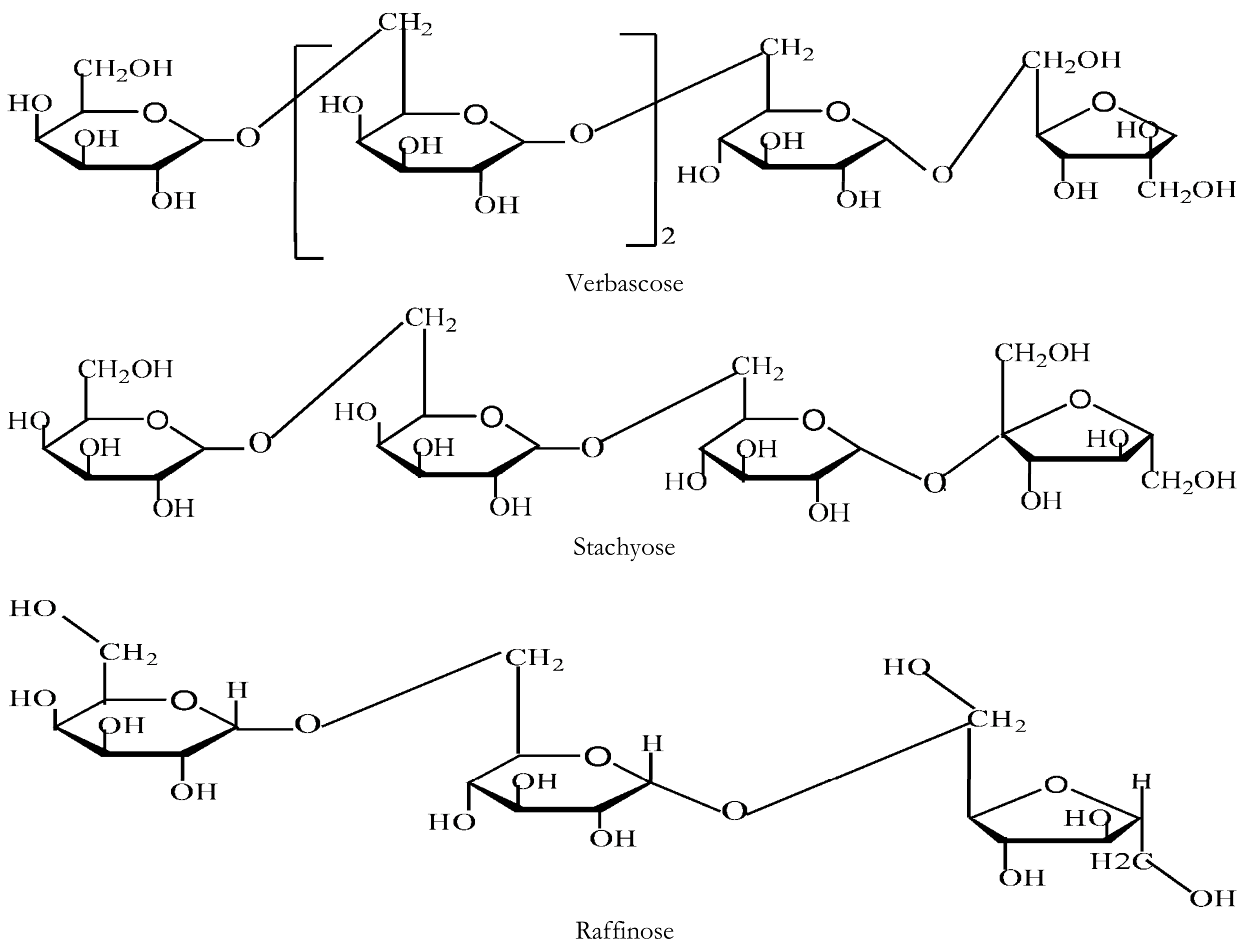

Figure 5. Structure of raffinose family sugars (Nakakuki, 1993; Yasushi *et al.*, 1993)

Sucrose, stachyose and raffinose are the major sugars in haricot beans when ingested by mammalian digestive systems. Sucrose is hydrolyzed and absorbed, but the raffinose family of sugars remains unhydrolyzed due to the absence of α-galactosidase enzyme activity in the small intestine, which is capable of hydrolyzing the α-D-1-6 galactosidic linkage, and hence they are not absorbed. A number of investigators have demonstrated that the oligosaccharides; raffinose and stachyose, are the principal causes of flatulence in human and animals (Rackis *et al.,* 1970; Reddy *et al.,* 1980; Fleming, 1981).

Oligosaccharides are associated with a low food intake in animal experiments (Frias *et al.,* 2000). The phytochemicals activity of food legumes is also frequently associated with the presence of these oligosaccharides, which are not hydrolyzed in the upper gut. Therefore, raffinose family oligosaccharides are a limiting factor in the use of kidney beans in monogastric diets. Consequently, the presence of these sugars in food legume seeds is one of the major constraints in their full utilization as human food.

2.7. Phytic Acid

It is now generally believed that the compound phytic acid can be commonly called *myo*-inositol hexaphosphoric acid (IP6) or, scientifically, 1,2,3,4,5,6-hexakis (di-hydrogen phosphate) *myo*-inositol is composed of an insitol sugar (John *et al.*, 2004) (Figure 6), similar in structure to D-glucose, with six phosphate groups attached to each hydroxy (Wodzinski and Ullah, 1996).

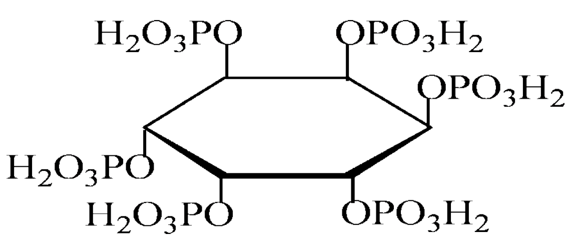

Figure 6. Molecular structure of phytic acid (John *et al.*, 2004)

Phytic acid has been considered as an anti-nutritional component in cereals, seeds and beans. Phytates represent a complex class of naturally occurring compounds that can significantly influence the functional and nutritional properties of foods. Research has traditionally focused on its structure that gives it the ability to bind minerals, proteins and starch, and the resulting lower absorption of these elements. However, recent researches have shown that phytic acid has many health benefits. Phytic acid has anti-oxidant, anti-cancer, hypocholesterolemic and hypolipidemic effects. Phytic acid may have health benefits for diabetes patients. It lowers blood glucose response by reducing the rate of starch digestion and slowing the gastric emptying. Studies also show that phytic acid may reduce inflammation (Shamsuddin, 2002; Catherine, 2007).

Phytic acid is the principal storage form of phosphorus in many plant tissues, especially in most grains, seeds and beans. Rich sources of phytic acid are bran and flaxseed (3% phytic acid). Phosphorus in this form is generally not bioavailable to non-ruminant animals because they lack the digestive enzyme, phytase, required to separate phosphorus from the phytate molecule. On the other hand, ruminants readily utilize phytate because of the phytase produced by rumen microorganisms (Yoon *et al.*, 1983; Flanagan, 1984).

Food legumes contain significant amounts of inositol hexaphosphates (IP6). Phytate is a strong chelator of important minerals such as calcium, magnesium, iron and zinc and can therefore contribute to mineral deficiencies in developing countries (Habtamu and Kelbessa, 1997; Hurrell, 2003). For people with a particularly low intake of essential minerals, especially young children and those in developing countries, this effect can be undesirable. Phytate has long been recognized as phytochemical, affecting the bioavailability of minerals (Ca^{2+}, Mg^{2+}) and trace elements such as Zn^{2+}, Fe^{2+}, Cu^{2+}, Mn^{2+}, Se^{4+}, Mo^{3+} and B^{3+} (Reddy *et al.,* 1982) through formation of insoluble complexes at intestinal pH (Erdman, 1979) and inhibits several proteolytic enzymes and amylases (Singh and Krikorian, 1982). Zinc appears to bind phytic acid in physiological pH range more tightly than other minerals (Lönnerdal, 2002).

Phytate in food legumes complexes with proteins by forming phytate-protein compound which may result in reduced solubility of proteins which can affect the functional properties of proteins (Laurena *et al.,* 1994). The reduction or removal of phytic acid to increase mineral bioavailability is essential while processing weaning foods in the African context where zinc is a serious limiting factor (Shimelis, 2008). In formulation of baby foods at industry or household level; phytic acid needs to be properly inactivated to ensure the bioavailability of minerals in the final product.

3. The Health Benefits

Human consumption of biologically active natural products is not limited to pharmaceutical products. A much greater number is ingested as foods or dietary supplements (nutraceuticals) just as likely to exert biological effects that go far beyond providing calories and essential nutrients. Health-related phytochemicals interactions lead to a more holistic approach to disease prevention and treatment (Sur *et al.,* 2001; Lila and Raskin, 2005; Shimelis and Rakshit, 2005a).

Phytochemicals present in food legumes have health benefits which appear to be similar to those suggested for the dietary fibers in fruits, vegetables and other crops. Studies in phytochemiclas indicate that they have a capacity to lower blood glucose and hormonal responses to starchy foods (legumes), decrease blood lipids, and decrease cancer risks (Lila and Raskin, 2005). New research on phytochemicals is underway, including impact of food processing on bioavailability of phytochemicals, developing an *in vitro* bioavailability estimation method for bioactive compounds, application of phytochemicals as nutraceuticals, functional foods and cosmetics (Craig, 1997). Additionally, studies are being undertaken to indicate the main groups of bioactive compounds, giving a description of their localization, chemical properties and biological actions.

3.1. Phytic Acid

Phytin is a complex salt of phytic acid, inorganic cations and proteins; isolated from plants and belongs to the group of organic phosphates. It is a mixture of calcium-magnesium salt of inositol hexaphosphoric acid. Phytin as salts is found in plants (predominately in seeds) as well as in animal tissues and organs. Phytic acid contents were found to be higher in the outer coverings of seeds than in the whole seeds (Mukhamedova and Akramov, 1977). Like the other phosphorous-containing preparations, phytin stimulates hemopoiesis (production of red blood cells by bone marrow) and increases the haemoglobin oxygen transportation capacity, inhibits lipid peroxidase and concomitant injuries of the intestinal and liver cells, potentiates bone growth and development and improves the functions of the nervous system. The raw material for phytin production is food legumes (especially of the bean species), cereal grains, rice bran, as well as oil plant cakes obtained as by-products of the food processing and oil producing industries. Currently, Sopharma AD manufactures phytin from food legumes. Phytin and its finished dosage form can be used for therapeutic and prophylactic effects; such as the relief of physical and mental overloading (enhancement of brain function). It can also be used as a food supplement to various diets, depending on the condition of the organism. Phytin also helps peel away dry surface cells and supports anti-aging and skin care treatments.

The inhibitory effect of phytic acid on the proliferation of human immune deficiency viruses (HIV), implicated as causative agents of the acquired immune deficiency syndrome (AIDS), has been tested *in vitro* (Lin *et al.,* 1996). They reported that phytic acid at a concentration of 1.67 mg ml^{-1} inhibits the cytotoxic effect of the immune deficiency virus and the specific anti-genic reaction in the affected cells.

Starchy foods which are slowly digested and result in lower blood glucose response have been suggested to be more beneficial to health, and in the management of diabetes and hyperlipidaemia (Wolever, 1990). Besides its well-known negative properties, phytate has been found to form chelates *in vitro*, inhibiting the formation of iron-catalyzed hydroxyl radicals (Fenton reaction) and lipid per-oxidation. As a result, phytic acid has gained in significance as a naturally occurring anti-oxidant (Empson *et al.,* 1991). The potential beneficial effects of phytic acid, such as a delayed postprandial glucose absorption (Yoon *et al.,* 1983), a decrease in plasma cholesterol and triglycerides (Katayama, 1995), reduction of proliferation in different cell lines, including erythroleukaemia human mammary cancer cells (Shamsuddin, 1995) and anti-cancer function of phytic acid (Shamsuddin, 2002) have been recently discussed in the literature. Hirose *et al.* (1991) demonstrated, using a rat wide-spectrum organ carcinogenesis model, that dietary phytate inhibited development of hepatocellular carcinomas and putative preneoplasmatic lesion in the pancreas. Protective effects of phytic acid were also observed in azoxymethane (Shamsuddin and Ullah, 1989) and dimethylhydrazine (Shamsuddin *et al.,* 1989) induced colon carcinogenesis, and in the case of transplanted fibrosarcoma, in mice and rats. The basic mechanism of the anti-carcinogenic effect of phytic acid is still unclear. However, it is thought that its anti-carcinogenic benefits may be in part attributable to its anti-oxidant capability.

3.1.1. Anti-oxidant Properties of Phytic Acid

A function of phytic acid as a natural anti-oxidant was first postulated by Graf *et al.* (1984). In molar ratios of 0.25 phytate-to-iron and above, the generation of hydroxyl radicals *via* the Fenton reaction was almost completely blocked (Graf *et al.,* 1987) with hydroxyl radical formation measured spectrophotome trically by the formation of formaldehyde in the presence of dimethyl sulphoxide. In a further *in vitro* experiment, electron spin resonance spectroscopy (ESR) was applied in combination with spin trapping to study the anti-oxidant properties of phytic acid (Rimbach and Pallauf, 1998). Spin trapping provides an opportunity not only to detect radicals, but also to characterize partially the type of radicals formed. The ESR studies indicated that the anti-radical effect of phytic acid occurs by chelating iron required for the generation of hydroxyl radicals *via* the Fenton reaction, due to the phosphorus moieties of the phytic acid molecule. Midorikawa *et al.* (2001) conclude that phytic acid acts as an anti-oxidant to inhibit the generation of reactive oxygen species from H_2O_2 by chelating transition metals, such as copper and iron, thereby possibly mediating anti-carcinogenic properties. Several studies also provide evidence for anti-oxidant properties of phytic acid *in vivo* (Shan and Davis, 1994; Rimbach and Pallauf, 1998; Porres *et al.,* 1999).

Anti-oxidant effects of phytic acid are mainly mediated through its iron chelating and copper properties, although the molecular mechanisms are not fully understood. However, under *in vivo* conditions, phytic acid has not always been demonstrated to have a significance effect on the oxidant or anti-oxidant status (Lee *et al.,* 2000b). Ultimately, phytic acid as a major component food legume is considered an important anti-oxidant and is increasingly used in various therapeutic diets for its protective effect on cancer of the colon and rectum (Reddy *et al.,* 1982; Shamsuddin, 1995; Shamsuddin, 2002; Tran *et al.,* 2003).

3.1.2. Anti-cancer Function of Phytic Acid

Experiments of *in vivo* and *in vitro* have demonstrated striking anti-cancer (preventive as well as therapeutic) effects of phytic acid (Fournier and Gordon, 2000). Phytic acid can prevent the formation and incidence of several cancers in experimental animals in soft tissue, colon, metastatic lung cancer and mammary cancers (Shamsuddin *et al.,* 1989; Vucenik *et al.,* 1992, 1995, 1997;

Sun and Liu, 2006). Researches on the anti-cancer function of phytic acid conclude that inclusion of phytic acid (IP_6) for prevention and therapy of various ailments, cancer in particular, is warranted (Shamsuddin, 2002; Singh *et al.,* 2004). Phytic acid has been also suggested to have a role in the prevention of dental caries (John *et al.*, 2004) and platelet aggregation, in the treatment of hypercalciuria and kidney stones, and as anti-dote against acute lead poisoning, primarily due to its mineral-binding ability (Lila and Raskin, 2005). Thus, utilization of physiologically functional foods which are botanical sources can reduce risks of many life-threatening diseases in Africa, such as breast cancer risk.

3.2. Protease Inhibitors

Legumes contain protease inhibitors which are being studied as anti-cancer agents. Recently, the US National Cancer Institute identified a number of foods, including legume based, which are thought to be protective against cancer (Troll and Kennedy, 1989; Messina and Barnes, 1991; Caragay, 1992). Several substances which are responsible for the cancer protective effect have been suggested and many of them are phytochemicals including trypsin inhibitors, phytic acid, phytoestrogens and lignans, saponins and tannins.

While the protease inhibitors have been linked with pancreatic cancer in animal studies, they may also act as anti-carcinogenic agents as suggested by animal studies, *in vitro* cell culture work, and epidemiological data which show low cancer mortality rate in human population with high dietary intake of protease inhibitors. These were discussed in studies (Messina and Barnes, 1991; Messina and Messina, 1991). Of the protease inhibitors, the most effective are those with chymotrypsin inhibitor activity found in soy bean, haricot bean and chick pea.

Several mechanisms whereby protease inhibitors inhibit carcinogenesis have been hypothesized (Kennedy and Billings, 1987; Troll, 1989). The inhibitor may reduce the digestion of proteins and thus the amino acids available to the growing cancer cells; deprivation of amino acids particularly leucine, phenylalanine and tyrosine has been shown to prevent the growth of mouse hepatoma and mammary adenocarcinoma (Troll *et al.,* 1987). The inhibitors may stop the ongoing cellular process begun by carcinogen exposure by reversing the carcinogen-induced change in oncogene expression. They may inhibit the formation of super oxide anion radicals (O_2^-) and hydrogen peroxide (H_2O_2) by neutrophils induced through tumour promoters; these oxygen-reactive species can damage or modify cellular DNA. The inhibitors may inhibit the oxygen radical-induced DNA polymerase, the enzyme involved in the formation of poly (ADP-ribose).

3.3. Saponins

Saponins are a group of plant glycosides consisting of a steroid or tri-terpenoid aglycone to which one or more sugar chains are attached. They exhibit cell membrane-permeabilizing properties and, thus, have been investigated for their therapeutic potential (Bachran *et al.*, 2006). Saponins are found primarily in legumes, with the greatest concentration occurring in soybeans. Saponins have been shown to have diverse biological properties including fungistatic, haemolytic, insecticidal and diverse pharmacological activities. Results of recent investigations suggest that saponins have cholesterol-lowering, anti-cancer and immuno-stimulatory properties (Oakenfull *et al.,* 1979; Gurfinkel and Rao, 2003), and important in human diets to reduce the risk of heart disease (Potter *et al.,* 1980). Anti-cancer properties of saponins appear to be the result of anti-oxidant effects; immune modulation and regulation of cell proliferation (Rao, 1996).

Soyasaponins are bioactive compounds found in many legumes. Although crude soyasaponins have been shown to have anti-colon carcinogenic activity, purified soyasaponins and soyasapogenins were tested for their ability to suppress the growth of HT-29 colon cancer cells, as determined by the WST-1 assay, over a concentration range of 0-50 ppm. Soyasaponin I and III, soyasapogenol B monoglucuronide, soyasapogenol B, soyasaponin A_1, soyasaponin A_2, and soyasapogenol A were evaluated. Consequently, results from *in vitro* fermentation suggested that colonic microflora readily hydrolyzed the soyasaponins to aglycones. These observations suggest that the soyasaponins may be an important dietary chemopreventive agent against colon cancer, after alteration by microflora (Gurfinkel and Rao, 2003). Recently, a non-permeabilizing concentration saponinum album from *Gypsophila paniculata* L. has been described to enhance the cytotoxicity of a chimeric toxin in a cell culture model. The saponin-mediated enhanced uptake of targeted saporin-based drugs is strongly dependent on the saponin structure (Bachran *et al*., 2006). Furthermore, saponins nowadays are used for health care treatments (Duhan *et al.,* 2001).

3.4. Phytoestrogens

Epidemiological data and biological properties of phytoestrogens suggest that they may also be important in the prevention and control of cancer, particularly the hormone-dependent ones. The urinary excretion of lignans and the isoflavonic phytoestrogens was significantly lower in breast cancer patients and omnivores than in the vegetarians with a lower risk of cancer (Adlercreutz *et al.,* 1986, Harris *et al*., 2005). How phytoestrogens may influence carcinogenesis is still unclear but several mechanisms have been postulated in several reviews (Adlercreutz, 1991; Adlercreutz *et al.,* 1991).

Generally, phytoestrogens may be protective against various types of cancers, menstrual irregularities, osteoporosis, and cardiovascular disorders (Rishi, 2002). Within the past few years, phytoestrogens have attracted considerable attention for their potential anti-cancer activity. Since almost all anti-cancer drugs have serious side effects, the search is underway for "natural" alternatives or complements to traditional therapy. Further, the increased enthusiasm towards phytoestrogens as potential anti-cancer agents is shown by the published data. The population-based studies show that the mortality due to breast, ovarian, prostate, and colon cancer has a negative correlation with the phytoestrogens and cereal intake in the diet (Rose *et al.*, 1986)). There are hundreds of *in vitro* studies, which show that phytoestrogens can inhibit a wide range of both hormone-dependent and hormone-independent cancer cells (Anderson *et al.*, 1999; Safe *et al.,* 2001).

The elevated cholesterol levels accompanied by loss of endogenous estrogen secretion increases the risk of developing coronary artery disease (CAD) in postmenopausal women (Dewell *et al.*, 2002). Current evidence suggests that phytoestrogens have significant potential in reducing CAD *via* favorable effects on the lipid profile. The epidemiological data also suggests that phytoestrogen consumption contributes to the lower incidence of cardiovascular disease in Asian countries and in vegetarians and that phytoestrogens may be cardioprotective (Adlercreutz, 1990).

In postmenopausal women, estrogen deficiency is a major risk factor for osteoporosis (Dempster, and Lindsay, 1996). The incidence of hip fracture increases and may lead to immediate disability. It has been observed that osteoporosis and risk of hip fracture is lower in postmenopausal Japanese women than their Western counterparts (Cooper *et al.*, 1992). Hormone replacement therapy (HRT) has been proven to lower the risk of cardiovascular disease and osteoporosis (Arjmandi, 2001). The consumption of phytoestrogens has been shown to be protective in the prevention of thyroid, lung, stomach, colon, and skin cancers (Messina *et al.*, 1994; Horn-Ross *et al.*, 2002), however, further research is warranted at this time. There is increasing evidence that phytoestrogens may be beneficial in chronic renal disease (Velasquez and Bhathena, 2001).

The global movement for consuming a phytoestrogen-rich diet is increasing and tabletized concentrated isoflavone extracts are being promoted heavily. This is because epidemiological data and animal, human and *in vitro* studies support the role of phytoestrogens in lowering the risk of various types of cancers (especially breast and prostate cancer) and cardiovascular disease. However, contradicting reports are also emerging simultaneously, which is creating confusion. Due to this, there is difficulty in making widespread recommendations about dietary intake of phytoestrogens. Thus, more research is required to establish the role of phytoestrogens in the above discussed conditions. Evaluation of benefits and risks of phytoestrogens is a complex task due to inter-individual variation and complexity in absorption and metabolism. Overall, it is naive to assume that consumption of phytoestrogens may be good. On the other hand, inappropriate or excessive use may be detrimental. Before making widespread recommendations for phytoestrogens intake, extensive data on specific intracellular effects, duration of exposure and disease, and results from prospective randomized studies in humans is essential. It is also necessary to determine the potential side effects of phytoestrogens. Out of various phytoestrogens, isoflavones (genistein and diadzein) have been studied in the greatest depth. Studies on lignans are few and for coumestans very few. This might be due to lack of industrial funding and problems in analytical techniques. Study of effects of individual compounds in various clinical conditions is essential at this time. Based on dietary phytoestrogens, structure activity relationship studies should be carried out and more synthetic and semisynthetic compounds (likeipriflavone) should be evaluated (Zhi-qiang *et al.*, 2006). Genetic modification of food legumes and improvement in food technology/engineering to enhance phytoestrogen production is predictable.

3.5. Oligosaccharides

Oligosaccharides are one of the most popular functional food components in Japan and are exported to many countries including USA. The number of consumer products containing oligosaccharides includes soft drinks, cookies, cereals and candies. Physiologically functional oligosaccharides meet two specific requirements: (1) they are not digestible by human digestive juices and (2) they are preferentially consumed by beneficial intestinal bacteria, bifidobacteria, in the colon.

Ingestion of oligosaccharides increases the bifidobacteria population in the colon which, in turn, contributes to human health in many ways. The benefits of oligosaccharides ingestion arise from increased population of indigenous bifidobacteria in the colon which by their antagonistic effect, suppress the activity of putrefactive bacteria and reduce the formation of toxic fermentation products. *Lactobacilli* show similar effects, mainly in the upper gut. The toxic metabolites formed during fermentation of foods in the colon include ammonia (liver toxin), amines (liver toxin), nitrosoamines (carcinogens), phenols and cresols (cancer promoters), indole and skatole (carcinogens), estrogens (suspected carcinogens or breast cancer promoters), secondary bile acids (carcinogens or active colon cancer promoters), aglycones (often mutagenic), and others (Hespell and Jeffrey-Smith, 1983; Hylemon and Glass, 1983; Kanbe, 1988; Mitsuoka, 1990; Hideo, 1994). Additionally, a number of adverse consequences result from toxic metabolites formed during fermentation of legume foods in the colon which are possible causes of aging, immunity decreases, and adult diseases as a result of diminishing secretion of gastrointestinal juices in old age and adult diseases such as cancer and arthritis (Benno and Mitsuoka, 1986; Mitsuoka, 1990; Mizutani, 1992). Mental stresses, which are already known to affect human health through hormonal disturbance, also change the intestinal microflora profile, drastically decreasing bifidobacteria and increasing bacteria (Komai, 1990). Incorporation of bifidobacteria, instead of oligosaccharides, into processed foods is quite difficult because of their high susceptibilities to oxygen, shear, heat and acids (Hideo, 1994).

Health benefits resulting from ingestion of oligosaccharides are proliferation of bifidobactria and reduction of detrimental bacteria (Wada *et al.,* 1991), reduction of toxic metabolites and detrimental enzymes (Saito *et al.,* 1992), prevention of pathogenic and autogenous diarrhea (Kurmann and Rasic, 1991), prevention of constipation (Matsunami *et al.,* 1992), protection of liver function (Takasoye *et al.,* 1990), reduction of serum cholesterol and blood pressure (Hidaka *et al.,* 1986; Masai *et al.,* 1987), anti-cancer effect (Hirota, 1990) and production of nutrients (Hughes and Hoover, 1991). Bifidobacteria produce the vitamins B-1, B-2, B-6, B-12, nicotinic acid, and folic acid. Bifidobacteria, however, cannot produce vitamin K (Hughes and Hoover, 1991).

Human studies have shown an increase in bifidobacteria resulting from oligosaccharide ingestion and a reduction in detrimental bacteria such as *Clostridium perfringens* (Masai *et al.,* 1987; Wada *et al.,* 1991). Ingestion of 2-10 g/day for several weeks effectively increased bifidobacteria population in the human intestine by an average of 7.5 times and decreased *C. perfringens by* an average of 81%. With some oligosaccharides, *lactobacilli* also increased 2-3 times and C. *perfringens* decreased by 0.50-0.06 times (Hideo, 1994).

Bifidobacteria prevent the growth of exogenous pathogenic microbes and the excessive growth of indigenous detrimental microflora through production of short-chain fatty acids (mainly acetic acid and lactic acid at a 3:2 mole ratio) and an ability to produce some anti-biotic materials. The growth-inhibiting and destructive effects of acetic and lactic acids on undesirable bacteria are known (Rasic and Kurmann, 1983). The suppressive effects of these acids against *Salmonella* (Chung and Goepfert, 1970) and *E.coli* (Tamura, 1983) were reported. Reduction of toxic metabolites and detrimental enzymes by oligosaccharides ingestion has been shown in human tests and *in-vitro* human-faeces culture tests (Kato *et al.,* 1992; Saito *et al.,* 1992).

The reductions of toxic metabolites by the ingestion of oligosaccharides or bifidobacteria alleviate the detoxifying load of the liver (Takasoye *et al.,* 1990). The advantages oligosaccharides have over dietary fiber are that they have a smaller daily requirement (usually 3 g/day), do not cause diarrhea in recommended doses, are slightly sweet, have neither bad texture nor bad taste, are completely water soluble, do not build viscosity, do not bind minerals, are physically stable, and are easier to incorporate into processed foods and drinks.

4. Other Benefits

Lignan-rich plant products are components of many Chinese and Japanese folk medicines (Ayres, 1990). Rheumatoid arthritis, gastric and duodenal ulcers, scrofula (tuberculosis-like disease of the lymph glands, generally localized in the neck), venereal wart, nasal papillomas and psoriasis are diseases reported to be treated by lignan-rich plant products (Ayres, 1990) although more studies are needed to confirm that lignan is the active ingredient in these products. Phytic acid has been suggested to have a role in the prevention of dental caries and platelet aggregation, in the treatment of hypercalciuria and kidney stones, and as anti-dote against acute lead poisoning, primarily due to its mineral-binding ability (Graf, 1986; Graf and Eaton, 1990).

Tannins occur in a wide variety of plants, where they often provide a natural protective system against attack by microorganisms or against being eaten by animals. Presumably, the effectiveness of tannins in protecting plants against invasion by microorganisms is a result of the strong affinity of tannins for either digestive enzymes secreted by the microorganisms (Jones *et al.,* 1976) or proteins on its surface. Many gastrointestinal microbiologists postulate that the excessive formation of secondary bile acids and steroids is related to the high incidence of colon cancer after use of animal sources of high-dietary fat (Gorbach and Goldin, 1990; Lambert *et al*., 2005). Thus, utilization of physiologically functional foods which are botanical foods can reduce the causes of high breast cancer risk.

Saponins are present in a number of herbal remedies, e.g. ginseng, liquorice and sarsaparilla, which appear to have expectorant and anti-flammatory effects (Shibata, 1977). Several phenolic compounds, e.g. monomeric hydrolysable tannins, oligomeric ellagitannins and condensed tannins, having galloyl groups or hexahydroxydiphenoyl groups, have potent inhibitory effect on herpes simplex virus types 1 and 2 (HSV-1, HSV-2) infection (Fukuchi *et al.,* 1989). These viruses are linked to several human diseases including gingivostomatitis, stomatitis, meningitis and venereal transmitted genital disease. Three hydroxyl groups in the benzene ring and high molecular weight of the phenolic compounds are needed for the inhibition of the virus to take place. Interestingly, protein binding and anti-tumour activities also are related to molecular weight, and dimeric ellagitannins with high molecular weight also have strong anti-HIV activity (Asanaka *et al.,* 1988; Fukuchi *et al.,* 1989).

5. Conclusions

Recent investigations have demonstrated that both adverse effects and health benefits could be attributed to phytochemicals in food legumes. Different food processing methods are used for the reduction/removal of the adverse effects of these bioactive compounds for consumption. However, threshold levels at which undesirable components may exert adverse effects need to be established. It is evident that, in many cases, the same interactions that make them adverse are also responsible for their beneficial effects. However, health benefits are possible at a certain level of phytochemicals' intake without causing many adverse effects. Based on the data available in literature, it appears that source of legumes have a wide variety of health-promoting activities and may have potential as functional foods. In addition, it should be noted that different food legumes have greater potential to act as therapeutic agents. Ultimately, the greatest promise of phytochemicals investigation might be its ability to spark a dramatic and widespread shift in the understanding and appreciation of plant foods.

Indeed, the physiological effects of phytochemicals are related to their level of intake and the conditions in which they are taken, e.g. presence of other dietary constituents, health and nutritional status of the individual.

Consequently, to balance their risks with benefits, there is a need to obtain more information on the concentration of phytochemicals in food legumes and their level of intake. More work is required on dose-response studies to determine the minimum amount needed to have a specific beneficial health effect without causing any adverse effect. After their intensive study, phytochemicals could be used as potential health bodyguards for the 21st century. Owing to the potential health benefits of phytochemicals in food legumes, it is perhaps incorrect to refer to these plants and plant-derived group of chemicals as natural toxins. The time has come for us to reconsider their presence in our diet. The mitigating effects and the mechanism of their action need to be further addressed *via* investigation of the main groups of bioactive compounds which can give a description of their localization, chemical properties and biological actions.

In conclusion, their true properties and biomedical applications, in fact, have not yet been fully explored. However, with the availability of crucial research outputs from African agricultural research centers and higher learning institutions, a number of new applications in the future are likely. Research and development studies on indigenous and improved varieties of African food legumes and other plants will help to explore new demands on phytochemicals for health benefits in the region. Improvement in food process technology and food engineering to enhance phytochemicals production is inevitable.

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