



Phytochemicals in Vegetables and Health Protective Effects

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Introduction

Phytochemicals/ phytonutrients/ phytonutriceuticals are organic compounds derived from plants that have health protective effects. Besides the common nutrients such as carbohydrates, amino acids and protein, there are certain non- nutrient phytochemicals in vegetables that have biological activity against chronic diseases. They are low in fat and like all plant products, contain no cholesterol. Most phytochemicals are found in relatively small quantities in vegetable crops. However, when consumed in sufficient quantities, phytochemicals contribute significantly towards protecting living cells against chronic diseases.

Major phytochemicals have been classified in to ten different classes based on their biological activities including: (1) Carotenoids (α - and β - carotene, β - cryptoxanthin, lutein, lycopene, and zeaxanthin), (2) Glucosinolates (sulforaphane, indole-3 carbinol), (3) Phenols (flavanoids), (4) Cyclic phenolics (chlorogenic acid, ellagic acid, and coumarins) (5) Saponins, (6) Phytosterols (campesterol, β - sitosterol, and stigmasterol), (7), Sulfides and thiols (8) Phyto-estrogens (isotlavones, daidzenin, genistein, and lignans), (9) Protease inhibitors, and (10) Inositol phosphates (phytate, inositol tetra and penta phosphates). Vegetables have been shown to protect against specific types of cancer for example, the crucifers (*Brassicaceae*) including Broccoli, Brussels sprouts, Kale and Cabbage have been shown to protect against lung and chemically induced cancers. The alliums (*Liliaceae*), including garlic, chive, and onion have been shown to protect against stomach cancer, the solanaceous vegetables

(*Solanaceae*) including tomatoes and pepper have been shown to protect against esophageal, gastric, and prostate cancers.

The chenopods (*Chenopodiaceae*) including spinach and chard have been shown to inhibit DNA synthesis in proliferating human gastric adenocarcinoma cells. There is increasing evidence for a link between antioxidant nutrients (e.g. vitamin C, vitamin E, β - carotene and selenium) in fruits and vegetables and lower risk of cardiovascular disease. Studies have found 35 per cent reduction in mortality due to cardiovascular disease among those who consumed vegetables rich in vitamin E and C. A 40-50 percent reduction in risk of colon cancer in populations with higher vegetable consumption, especially garlic and dietary fiber has also been reported. In addition to reducing cancer and cardiovascular diseases, a diet high in vegetables has also been linked to reducing rheumatoid arthritis, anemia, diabetes, macular degeneration and gastric ulcer. The carotenoids, Vitamin E, and Vitamin C are now firmly established as protective dietary antioxidants with additional beneficial functions. Polyphenols and flavonoids are also gaining prominence and the protective role of folate is above dispute. All of these components are uniquely found in fresh and cooked vegetables, which underline the importance of vegetables in healthy diets.

The exact mechanism by which vegetable consumption reduces human diseases have not yet been fully understood, however Research over the last 2 decades has provided a scientific basis to support the common wisdom

that fruit and vegetable-rich diets are beneficial to health. The protective role of AO- rich diets in disease progression and ageing are beyond doubt, and advances in medicine over the past half century have resulted in a significant increase in lifespan in the developed world.

Why are the Components of Vegetables so Important for Health Protective Effects?

Antioxidant nutrients: Antioxidants protect the body from adverse biological reactions involving oxygen. This may sound strange, because we know that oxygen is necessary for the body to function; without oxygen, our cells die within minutes. A great irony of nature is that the body's natural metabolism involving oxygen also generates a host of toxic compounds / reactive by products called "free radicals", which are highly unstable and destructive. Left unchecked, these free radicals can attack lipids in cell membranes, destroy cellular enzymes and even damage the genetic material deoxyribonucleic acid (DNA). If the injury to DNA by free radicals is not immediately repaired, the damaged DNA is replicated in new cells and deterioration occurs. It is this gradual deterioration that may be responsible for ageing and the development of heart disease, cancer and cataracts.

Fortunately the body has a natural defense system against cellular damage by free radicals, which comprise primarily of antioxidant nutrients (e.g., vitamin E, vitamin C, and certain carotenoids), which are assisted by a variety of phyto-chemicals from the diet.

Antioxidants counteract, or neutralize, the harmful effects of free radicals. These antioxidants act as scavengers for these free radicals and reactive oxygen species, thereby preventing them from disrupting the chemical stability of the cells. A variety of external factors such as inflammation, cigarette smoke, air pollutants, radiation (X-rays and ultra-violet rays), carcinogens and excessive tension and exercise can promote free radical formation in our body. Consequently, individuals exposed to these sources of oxidants would require a greater supply of dietary antioxidants. Orange and yellow fruits and vegetables, as well as green leafy vegetables, are rich sources of carotenoids. Citrus fruits, strawberries, green peppers, tomatoes, and kiwi are examples of foods high in vitamin C. Good sources of vitamin E include nuts and seeds, wheat germ, and vegetable oils. With the exception of vitamin E, these antioxidants are widely distributed in fruits and vegetables.

Table 1: Major antioxidants in vegetable crops

Major antioxidants	Sources
β -Carotene	Carrot, fennel, kale, mustard greens, pumpkin, red pepper, lettuce, spinach, sweet potatoes, Swiss chard, winter squash
Vitamin C	Broccoli, Brussels sprouts, watermelon, cauliflower, green pepper, red cabbage, red pepper, potatoes
Lutein/zeaxanthin	Kale, broccoli, spinach, winter squash, Brussels sprouts, celery, leeks, mustard greens, peas, green onions, summer squash
Lycopene	Tomato, watermelon
Vitamin E	Dark green leafy vegetables, sweet potatoes
Lipoic acid	Dark leafy green vegetables, especially spinach and broccoli
Flavonoids	Onions and soybeans
Polyphenols	Grapes, nuts, oranges, strawberries, green tea, black tea, red wine

Carotenoids: Carotenoids are yellow, red and orange pigments present in many fruits and vegetables. β - carotene is probably the most familiar carotenoid, but it is only one of six hundred different carotenoids found in nature. However, only 40 are present in a typical human diet and only 20 have been identified in animal and blood tissue. The other abundant carotenoids in vegetables are α - carotene, lycopene, lutein, zeaxanthin, and β - cryptoxanthin. Three of these carotenoids (α - carotene, β carotene and β -cryptoxanthin) can be converted into Vitamin A, while lycopene, lutein, and zeaxanthin have no vitamin A activity. In the diet they act as powerful antioxidants and are believed to protect the body against free radical attack and hence reduce the incidence of cataracts, heart disease and certain cancers.

It is not clear which specific carotenoids are most important in reducing the cancer risk. Previously, scientists believed that β -carotene had important cancer prevention properties. In several recent studies, however, β -carotene supplements did not lower the risk of cancer. The antioxidant activity of carotenoids differs among the different compounds. Studies have shown that the singlet oxygen quenching capacity of lycopene is twice that of β -carotene and ten times that of tocopherol. Several studies on the bioavailability of β -carotene from vegetables in the human diet have shown that in broccoli it ranges from 22-24%, in carrots 19-34%, and in leafy vegetables it ranges from 3-6%. Studies have also shown that combination of fatty foods with carotenoid rich vegetables enhanced carotenoids uptake. Most recent studies have shown that the bio availability of lycopene from tomato has increased dramatically by heat treatment in the presence of oil. For

example, lycopene was found to be more bio-available from tomato paste than from fresh tomato due to heat treatment and presence of oil content in the paste. It has also been shown that lutein, which has no vitamin- A activity is five times more readily available than β -carotene. Carotenoids are powerful antioxidant that may reduce the incidence of age-related diseases such as cancer and coronary heart disease.

Vitamin C: Vitamin C or ascorbic acid is an essential vitamin to humans and other mammals that lack the ability to synthesize this vitamin, as they are deficient in the enzyme L-gulonolactone oxidase, involved in the biosynthesis of Vitamin C via the glucuronic acid pathway. The biological function of vitamin c is based on its ability to donate electrons. In mammalian cells, vitamin C serves as cofactor for reactions that require reduced iron and /or copper metallo-enzymes. Another important indirect function of vitamin C is its ability to regenerate other biologically important antioxidants such as I glutathione and vitamin E into their reduced state.

Capsaicin ($C_{18}H_{27}NO_3$): It is the source of heat found in chili peppers. Possible benefits include reduced risk of colon, gastric and rectal cancers; inhibits tumor growth. May significantly reduce chronic, debilitating nerve pain associated with a range of diseases when used in high doses.

Lycopene: It is a phytochemical that gives tomatoes their red color and appears to offer potential health benefits. Lycopene is a carotenoid. It is a linear hydrocarbon containing 11 conjugated carbon-carbon double bonds; this particular chemical structure gives the molecule its physico-chemical properties. One of the most important properties is its Lipophilicity, for Lycopene is completely insoluble in water. Because of this chromophore, Lycopene possesses its characteristics red color and a specific UV-visible spectrum. Another consequence is the instability of the molecule under various conditions. Thus, when isolated, Lycopene is very sensitive to oxygen and light. The main subsequent degradation products are cis-isomers and cleavage compounds. Lycopene is more stable when present in the food matrix, in which it is somehow protected by other bio molecules. The antioxidant property of Lycopene refers to (1) its ability to quench singlet oxygen, even more efficiently than the other carotenoids and (2) its ability to quench free radicals. Tomato Lycopene is the most potent free radical scavenger of all the carotenoids. It is four times powerful than alpha-carotene regarding its anti carcinogenic effect on endometrial cells. It is known to reduce prostate cancer risk significantly.

Lycopene also plays a role in other processes, like maintaining the cell's capacity to synthesise the

cytoplasmic bridges that act as information exchanges allowing healthy cells to defend themselves against potential sources of cancer metastases.

Tocopherols: Tocopherol general known as vitamin E consist of eight naturally occurring fat soluble tocols and tocotrienols. They are made up of four tocol structures consisting of a saturated phytyl C16 side chain (α , β , γ , and 0-tocopherols) and four toco rienols bearing three double bonds in the phytyl side chain (α , β , γ , and 0-tocotrienols). The most predominant and most active form of Vitamin E is α -tocopherol. Vitamin E is protective against several cellular abnormalities including cardiovascular disease, cancer, sterility, muscular dystrophy, changes in the central nervous system, and anaemia development.

Flavonols: Flavonols include quercetin, kaempferol, fisetin, and myricetin. Quercetin is the most important flavonoid in vegetables. It has been detected in onion, and to a lesser extent in tomato and bean. Kaempferol, myricetin, and fisetin have been detected in onion, lettuce, and endive. Many investigators have studied the effect of flavonols on carcinogenesis and cardiovascular diseases in human and laboratory animals. Several mechanisms have been proposed for the mode of action of these compounds including inhibition of estrogen binding in mammalian cells, induction of the phase II enzyme quinone reductase in murine hepatoma cells, antioxidant protection from oxygen radicals and induction of apoptosis.

Flavones: Flavones include apigenin and luteolin. Flavones have been detected in conjugated form in celery, tomato, brinjal, garlic and onion. The mechanism of action of flavones on chronic diseases is similar to that of other flavonoids. They were proposed to function primarily as antioxidants by conserving α -tocopherol content of low-density lipo-proteins and membrane lipids in the reduced state.

Isoflavonoids: Isoflavonoids include diadzein and genistein and have limited distribution in vegetables. They exist mainly in legumes including soybean, lentil and chickpea. Small quantities have been detected in vegetables such as broccoli, asparagus, alfalfa sprouts, okra and mushrooms. A health benefit of iso-flavonoids has been due to the phytestrogenic response of genistein. As a phytoestrogen, genistein is believed to block estrogen perception by actively competing for binding sites or by blocking estrogen synthesis. Studies have confirmed the role of early exposure to estrogen in reducing hormone dependent and chemically induced cancers. Studies have shown that Asian women who consumed a diet rich in soy products had relatively low risk of breast cancer.

Polyphenols: Polyphenolics are a diverse group of compounds (nearly 8000 structurally known polyphenolics) widely distributed in the plant kingdom. It

constitutes the largest ubiquitous group of phytochemicals in vegetables. Polyphenolics have been divided into ten different classes based on their basic chemical structure. Phenolics (mostly flavanoids) and terpenoids represent the most important classes of polyphenolics in vegetables. One group of polyphenols, called flavonoids, appears to be beneficial in lowering the risk of certain cancers. The health benefit of flavonoids is linked primarily to their antioxidant potential. As we already know, the induction of virtually all diseases occur as result of processes that generate highly reactive oxidative compounds (free radicals) or exposure to chemical toxicants that affect specific molecular targets such as cellular DNA or low density lipoproteins. In animal models the flavonoids have been shown to regenerate Vitamin C, which in turn regenerates Vitamin E. To overcome the potential hazards from the oxidative damage in the body, consumption of diet rich in the antioxidant phenolics, including flavonoids, are considered the first time of defense against highly reactive toxicants.

Anthocyanins: Anthocyanins give vegetable leaves and fruits their purple and or/red colour, such as in purple cabbage, purple broccoli, eggplant, purple sweet potato, rhubarb, purple radish and onion. Anthocyanins have also been shown to protect mammalian cell lipoproteins from damage by free radicals. Nasunin, an anthocyanin from brinjal has been shown to inhibit brain cell lipid peroxidation caused by hydroxyl free radicals.

Terpenoids: It is one of the most important groups of phyto-chemicals in vegetables of particular importance are the roles of tocopherols and carotenoids. The antioxidant activity of tocopherols and carotenoids have attracted significant scientific attention especially their *in vitro* and *in vivo* roles in reducing atherosclerosis, by inhibiting low-density lipo-protein oxidation.

Fiber: Fiber, or roughage, is a group of substances chemically similar to carbohydrates. It is only found in foods derived from plants, and never occurs in animal products. Fiber provides bulk in the diet, so foods rich in fiber satisfies hunger without contributing excessive calories: A diet high in fiber may help prevent colon cancer and other types of cancer. Most health agencies recommend that adults should consume 20-35 grams of fiber daily. This is not difficult to do if you eat an average of five servings of fruits and vegetables a day, and regularly include whole grain breads, cereals, and legumes in your diet. Some excellent sources of fiber are kidney beans, bran-rich breakfast cereals, and baked potatoes with skin, apples, oranges, pears, spinach, oatmeal, and popcorn.

Folic acid: Several studies have suggested that folic acid, also called folate, may reduce the risk of colon and rectal

cancer. In one study involving more than 25,000 adults, those who ate diets high in folate had fewer pre-cancerous polyps, which are associated with the eventual development of colorectal cancer. This benefit of folate did not occur among people who consumed more than two alcoholic drinks per day. There is also accumulating evidence that folate may lower the risk of pancreatic cancer and breast cancer. Good sources of folate are dark green leafy vegetables, legumes, citrus fruits and juices, and fortified breakfast cereals and grain products. Dietary supplements are a good way of obtaining this vitamin, since the body better absorbs the folic acid in supplements than the folate naturally occurring in foods.

Glucosinolates and Chemoprevention of Cancer

Glucosinolates or β -D-thioglucosides are a diverse class of S- and N-containing secondary metabolites that are mainly found in members of the *Brassicaceae* (*Cruciferae*) and in 15 other families of dicotyledonous angiosperms. Glucosinolates molecule comprises of a skeletal β -thioglucose moiety, a sulfonated oxime moiety (glucone), and a variable aglucone R-group that defines the structure of each glucosinolate. The biosynthetic origin of glucosinolates is derived from a number of common amino acids. In crucifers, the dominant glucosinolates are derived from methionine, phenylalanine, tryptophan, valine and tyrosine. About 120 different glucosinolates have been identified so far, but only about 20 have been detected in vegetable crops. Based on their R-group structure, glucosinolates have been classified into aliphatic, aromatic and indolyl. Crucifer vegetables *viz.*, Broccoli, Brussels sprouts, kale, Chinese cabbage, Red cabbage, Savoy cabbage are the main source of glucosinolates. Broccoli has the maximum content of glucosinolate, in which it constitutes about 0.05-0.2% of the fresh weight of broccoli (0.05 to 1.0g/kg). Several studies have suggested that intact glucosinolates have no biological activity against cancer, however the breakdown products have been shown to stimulate mixed function oxidases involved in the detoxification .of carcinogens. Upon tissue disruption, glucosinolates are rapidly hydrolyzed by myrosinase (thioglucoside glucohydrolase; EC 3.2.3.1) to unstable intermediates that, as dictated by chemical conditions, spontaneously rearrange to isothiocyanates, thiocyanates, or nitriles.

Although the primary biological function of glucosinolates in plants is unknown, glucosinolate breakdown products are proposed to act as allelo-chemicals and to play a role in plant defenses against herbivores, pests, and pathogens. Furthermore, indolyl glucosinolates can be converted into indoleacetic acid and may thus contribute to active auxin levels in cruciferous plants. As components of food for humans and feed for livestock, the biological activities of glucosinolate hydrolysis products have generated

considerable toxicological and pharmacological interest. Depending on glucosinolate composition and on the prevalence of hydrolysis products, consumption of glucosinolates by mammals has been linked with goitrogenic effects (thiocyanates) or with a reduced risk of developing cancer (isothiocyanates) in experimental animals. Studies have shown that rat fed on a diet containing intact glucosinolates from broccoli had no effect on the metabolism of the carcinogens *viz.*, antipyrine and metronidazole, however, glucosinolate hydrolyzed by myrosinase prior to feeding, enhanced the detoxification of the two carcinogens by 67 and 200 percent respectively, suggesting, that glucosinolate breakdown product and not intact glucosinolate are biologically active against chemical toxicants. Sulforaphane (4-methylsulfinylbutyl isothiocyanate) and indole-3-carbinol are the two most widely studied glucosinolate breakdown products exhibiting anti-carcinogenic properties.

Sulforaphane is the breakdown product of the aliphatic glucosinolate glucoraphanin, while indole-3-carbinol is the breakdown products of indolyl glucosinolate glucobrassicin. Other breakdown products of glucosinolates that have been shown to protect human and animal cells against carcinogenesis are phenyl isothiocyanate, 1-cyano-2-hydroxy-3-butene and breakdown products from sinigrin and glucoiberin that have yet to be characterized. Studies on laboratory animals and human subjects have shown that induction of detoxification enzymes (phase II enzymes) and inhibition of activation enzymes (phase I enzymes) are two major mechanism of cancer prevention by glucosinolate breakdown products.

The exact mechanism has not yet been fully characterized, but it has been suggested that Phase II enzymes are capable of conjugating with activated carcinogens and converting them into inactive water-soluble compounds that can be easily cleared by the kidney. Mechanistic studies have shown that isothiocyanates such as sulforaphane, indole-3-carbinol and phenylethylisothiocyanates target mammalian Phase II drug-metabolizing enzymes, resulting in increased carcinogenic detoxification. For example, the methionine derived isothiocyanate sulforaphane, have been shown to be potent inducers of the phase II enzymes glutathione-S-transferase, quinone reductase, NADPH reductase and glucouronyl transferase in hepatoma cells. Sulforaphane is the most powerful natural inducer of chemo protective enzymes thus far reported and has become a metabolic target of breeding strategies to enhance the anti carcinogenic potency of cruciferous vegetables. A second mechanism for the glucosinolate breakdown products involves inhibition of enzymes involved in the induction of cancer. Chemical carcinogens generally require metabolic activation in order to be able to bind to DNA and contribute to cancer development. Phase I enzymes are responsible for *in vivo*

and *in vitro* metabolic activation of most carcinogens in human and animal cells. Studies have shown that, under certain conditions, the products of Phase I enzymes serve as substrates for Phase II enzymes, which convert them into electrophilic carcinogens that can easily be excreted through the urine. There is also ample evidence that some glucosinolate breakdown products inhibit the catalytic activity of Phase I enzymes (Cytochrome P450 enzymes). Cytochrome P450 enzymes are a battery of Phase I enzymes that have been shown to metabolically activate chemical carcinogens such as nitrosamines and aflatoxins. The glucosinolate break down products can be mono-or-bi-functional inducers based on their effect on Phase I and Phase II enzymes. Sulforaphane and phenylethyl isothiocyanates are mono-functional inducers that induce Phase II enzymes and either has no effect or inhibit phase I enzymes, while indole-3-carbinol and its parent glucosinolate glucobrassicin, and neo-glucobrassicin are bi-functional inducers that induce both Phase I and Phase II enzymes. In addition to modulating the Phase I and Phase II enzymes, the glucosinolates and their breakdown products have also been shown to have a direct effect on the cancer development by suppressing the promotion phase of cancer cell formation and reducing invasion and metastasis. Recent evidences also suggest that isothiocyanates may regulate cancer cell development by promoting apoptosis. Apoptosis, or programmed cell death, is genetically encoded active cell destruction. Indole-3-carbinol has been shown to promote apoptosis in rodent cell lines. Glucosinolate breakdown products have also been shown to prevent and/or suppress estrogen dependent cancers, such as cervical and breast by blocking the estrogen receptor function.

The chemo-protective properties of natural isothiocyanates have renewed interest in glucosinolate biosynthesis. While significant progress has been made in understanding the biochemistry and enzymology of glucosinolate synthesis, little is known about the structural and regulatory genes involved.

Thiosulfides: These are organo sulfur compounds found in alliums including garlic, onions, leeks, chive and green onions. Alliin (S-(2-propenyl)-L-cysteine sulfoxide), γ -glutamylcysteine and methiin (S-methyl-L-cysteine-sulfoxide) are the major thiosulfides in intact tissues of alliums. Other minor thiosulfides include S-propenyl-L-cysteine sulfoxide and S-ethyl-L-cysteine, commonly known as ethiin. None of the thiosulfides found in alliums have been detected, in other vegetables, except methiin, which was recently detected in cabbage leaves. Allicin, the most abundant thio-sulfide in intact garlic, is highly unstable. When the tissue is cut, chewed or dehydrated, cytosolic aliin is rapidly lysed by the vacuolar enzyme aliinase or aliin lyase (E.C. 4.4.1.4) into a highly unstable diallyl thiosulfinate transient intermediate called allicin.

Allicin then converts into several lipid soluble alkyl alkanethiosulfonates, including allyl sulfide, diallyl disulfide, diallyl trisulfide, allylmethyl disulfide. These lipid soluble compounds form the odiferous and aromatic characteristic of garlic.

Consumption of alliums has been found to retard growth of several types of cancers. It has generally been accepted that the *in vitro* and *in vivo* anti proliferative effect of allium vegetables results from the breakdown of alliin into active organo sulfur compounds. Several allyl sulfides have been found to inhibit human tumour growth including prostate, colon, skin, breast, lung, lymphoma, erythroleukemia, and lymphocyte tumors. The cancer prevention by organo sulfur compounds is due to their function as blocking agents. They act during the initiation stage of carcinogenesis by either inhibiting the activation of procarcinogens, trapping reactive species, or by enhancing the activity of Phase II detoxification enzymes. Studies have shown that DNA adducts induced in animal cells during exposure to chemical carcinogens, such as di methyl benzene, anthracene and N-methyl nitrosourea, are suppressed by S-allyl cysteine supplement. In addition to enhancing the activity of Phase II detoxification enzymes, allyl sulfides also inhibit phase I enzymes, such as cytochrome 450, which has been shown to activate chemical carcinogens, and promote apoptosis.

Tomato Antioxidants and Biosynthesis

Many studies have demonstrated that the daily consumption of tomatoes decreases the cancer risk to the upper respiratory and digestive tracts, to the lungs and to the stomach. The same protective effect is conceivable for the mouth and the pharynx, and is presently being demonstrated against prostate cancer. The tomato fruit contains many antioxidants such as carotenoids, including lycopene and β -carotene, vitamin C, Vitamin E and polyphenols such as kaempferol and quercetin. Lycopene, β -carotene and polyphenols are primarily found in the skin and pericarp. Vitamin C is largely present in the pulp and vitamin E is exclusively present in the seeds.

The antioxidant levels in tomatoes can be influenced by environmental factors, like temperature, light and growing practices. A temperature range between 12 and 32°C is required for lycopene biosynthesis. Outside of this range, the synthesis of lycopene precursors is inhibited and lycopene production is discontinued. The influence of temperature on vitamin C, vitamin E and phenols accumulation is not so clearly stated. At favourable temperatures (22-25°C), the biosynthesis rate of lycopene is increased by illumination. But lycopene accumulation can be hindered by excessive sunlight (ideal conditions are suitably high temperatures together with dense foliage that protects the fruit from direct exposure to sunlight). On the

contrary, the vitamin C content as well as the phenolics content is positively influenced by light exposure. No information is available about the influence of light resources on vitamin E accumulation. Few studies have been dedicated to the influence of water availability on lycopene content and results are contradictory. But, it seems fairly clear that water shortage tends to increase tomato fruit vitamin C content (as well as Brix degree and acidity). No information about the influence of water availability has been found for vitamin E and phenolic compounds.

The influence of fertilizers on the antioxidant content is complex and not very well documented. The influence of the nitrogen supply on the lycopene content has not been assessed. However, a number of studies over the last 50 years seem to demonstrate that increasing rates of nitrogen tend to decrease the vitamin C content (possibly because dense foliage decreases illumination) and probably the level of phenolic compounds. The effect of phosphorus fertilization on antioxidants has not been frequently studied. Only the effect of potassium fertilization on the lycopene content has been the object of various studies. Potassium deficiency may lower the lycopene content of the fruit. However, very high potassium supplies (>800 kg/ha) would be necessary for a noticeable decrease in colour uniformity disorders and this is not really fitted to modern agricultural practices. No reference was found about fertilization and vitamin E. The biosynthesis pathways of carotenoids and polyphenols are now well characterized and some of the specific genes are cloned. Thus by classic breeding methods, it is possible to produce yellow, orange and red tomatoes. An alternative method consists in activating specific genes to produce lycopene-rich or kaempferol-rich tomatoes. In the first case, tomatoes produce more lycopene in the pericarp. In the second case, kaempferol may be produced throughout the fruit.

Toxic Metabolites and Anti-Nutritional Factors in Vegetables

Trypsin inhibitors: These are proteins distributed widely in plant foods like legumes. They generally inhibit the activity of trypsin in the gut and interfere with the digestibility of dietary proteins and reduce their utilization.

Phytate: Phytate is hexaphosphate of inositol. These phytates bind iron, zinc, calcium and magnesium. In presence of Ca^{2+} and Mg^{2+} it forms insoluble complexes with iron and thus reduces iron bioavailability. On germination of the grains, the phytate content reduces due to enzymatic break down of phytate that improves iron availability.

Oxalates: Green leafy vegetables and some legumes are rich source of oxalates and are known to interfere with

calcium absorption by forming insoluble salts with calcium. Complexation of calcium by oxalate may result in calcium deficiency. Dietary oxalates can be absorbed and contribute to increased excretion of oxalates in urine. High oxalate excretion may predispose to oxalate crystals leading to urinary stones. Thus, stone patients are advised to avoid high oxalate containing foods. However, vegetables rich in calcium e.g. fenugreek, colocasia, sweet potato, ridge gourd and snake gourd rich in insoluble calcium oxalate are not likely to be harmful. Maximum oxalate concentration is found in Amaranth and Spinach leaf (44-157 g/kg dry wt.). A substantial portion of it (39-48 percent) may be in water-soluble form. The most obvious method of reducing the risk of oxalate poisoning is to cook the leaves, which reduces the water-soluble oxalates.

Tannins: There are condensed polyphenolic compounds which are present in high amount in seed coat of most legumes and certain vegetables and fruits. Tannins bind with iron irreversibly and interfere with iron absorption.

Glucosinolates: Glucosinolates are thioglucosides, which are widely distributed in plants, particularly among members of cruciferae upon hydrolysis by plant microbial thioglucosidase (myrosinase) isothiocyanate and nitriles are released. The isothiocyanate residues are known to possess goitrogenic properties which inhibits iodine uptake by thyroid glands.

Nitrates: Vegetables are the single largest source of nitrate

in human diet. Nitrate accumulation can have serious deleterious effects. Within the gastrointestinal tract Nitrate (NO_3) is reduced to nitrite (NO_2), which is absorbed into the blood stream where it binds with haemoglobin, oxidizing Ferrous iron to Ferric iron to form methaemoglobin. This form of haemoglobin complex is incapable of O_2 transport. The result is anoxia, specifically referred to as methaemoglobinemia.

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