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Health Promising Medicinal Molecules in Vegetable Crops

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Introduction

Vegetables play a vital role in human nutrition and health by providing nutrients, vitamins, antioxidants, phytosterols, and dietary fiber. In the developing world, vegetable farming is a considerable part of the agricultural economy of different nations [1]. Due to the potential health benefits provided by bioactive medicinal molecules such as lycopene, resveratrol, tannins, indoles, glucosinolates, polyphenols, phytoestrogens, carotenoids and anthocyanins etc; vegetables are receiving increased attention now a days [2,3]. These bioactive medicinally important natural compounds present in vegetables are now being studied in the prevention of cardiovascular disease, cancer and other diseases to impart health benefits globally. Table 1 explains the detail vegetable botanical classification with major bioactive medicinal compound and their benefits, which could eventually be helpful in drawing the attention of researchers and scientists to work on it for its genetic advancement with therapeutically potential. Recent advancements in plant genetics, molecular biology and biotechnological techniques in conjunction with traditional/ conventional breeding programs have tremendous potential for developing vegetable varieties rich in different bioactive compounds.

Among different medicinally important molecules/bioactive compounds present in vegetables, glucosinolates is most studied bioactive compounds present in cruciferous vegetable (Cauliflower, broccoli) which attributed to anti-cancerous property. The *Brassicaceae* family is mainly associated with glucosinolate production. The metabolic products of glucoraphanin and glucobrassicin-sulforaphane, and indole-3-carbinol respectively, have been the subject of intense examination by cancer researchers [4]. The most characterized isothiocyanate is sulforaphane (SFN) that present in higher concentration in broccoli - high value vegetable crop [5,6].

Monocotyledonae
Amaryllidaceae (Alliaceae)
Onion (*Allium cepa*) - (Allyl sulfides and Quercetin) - as antioxidant, protection from cardiovascular disease and certain type of cancer etc.
Garlic (*A. sativum*) - (Allicin, Alliin and Ajoene) - antibacterial and antioxidative etc.
Leek (*A. porrum*) - (Flavonols - Kaempferol or Quercetin derivatives) - protection from cardiovascular disease and cancer disease etc.
Liliaceae
Asparagus (*Asparagus officinalis*) - (Steroidal Saponins, Flavanoides, Glycosides) - In ayurveda, effective in treating madhur rasam, madhur vipakam, seet-veeryam, som rogam, chronic fever and internal heat. Effective in problems related with female reproductive system.
Dioscorecaeae
Yam (*Dioscorea alata*) - (Diosgenin) - used as a moderate laxative and vermifuge; treatment of fever, gonorrhea, leprosy, tumors and inflamed hemorrhoids.
Araceae
Colocasia (*Colocasia esculenta*) – (Alkaloids and Glycosides) - protection from cardiovascular disease etc.
Graminae
Sweet corn (*Zea mays*) – (Carotenoids, Phenolic compounds and Phytosterols) - preventing chronic diseases.
Dicotyledonae
Cruciferae (Brassicacaeae)
Broccoli (*Brassica oleraceae var. italica*) – (Isothiocyanates, Glucosinolates, Sulforaphane, Lutein, Zeaxanthin, β -carotene, flavnoids) - Antioxidant and anticancerous properties etc.
Cabbage (*Brassica oleraceae var. capitata*) – (Anthocyanins and Sulforaphane) – Prevent cardiovascular disease and cancer etc.
Cauliflower (*Brassica oleraceae var. botrytis*) - (Indole-3-carbinol, Sulforaphane) - Anti-inflammatory and anticancerous etc.
Chinese cabbage (*B. Campestris var. pekinensis*) – (Glucosinolates) - Anti-tumor, immunomodulating, antioxidant etc.
Brussels sprout (*Brassica oleraceae var. gemmifera*) – (Organosulfur compounds) - Antioxidant properties.

Raddish (*Raphanus sativus*) – (Glucosinolate, Myrosinase, Isothiocyanate, Triterpenes, Alkaloids, Flavonoids, Tannins, Saponin and Coumarins) - Considered anthelmintic, antifungal, antibacterial, antiscorbutic, diuretic, laxative, tonic, carminative, corrective, stomachic, cholagogue, lithotriptic, emmenagogue.

Turnip (*B. campestris var. rapa*) - (Lutein and Glucosinolates) – Anticancerous etc.

Mustard (*B. juncea*) – (Allyl isothiocyanate) - Cancer chemo-preventive etc.

Cucurbitaceae

Cucumber (*Cucumis sativus*) – (Alkaloid, 9-beta-methyl-19-norlanosta-5- ene glycoside, Steroid, Saponin and Tannin) – Antiulcer, diuretic and anthelmintic etc.

Pumpkin (*Cucurbita moschata*) – (Alkaloids, Flavonoids, and Palmitic, Oleic and Linoleic acids) - Anti-diabetic, antioxidant, anti-carcinogenic, anti-inflammatory.

Water melon (*Citrullus lanatus*) – (Lycopene, Cucurbitacin) – Diuretic, cardiovascular activity, anti-inflammatory activity.

Summer squash (*Cucurbita pepo*) – (Cucurbitacins, Avenasterol, Spinasterol, Triterpenoids, Sesquiterpenoids, Squalene, Tocopherols, Carotenoids) - Antiandrogenic activity, immunological activity, antiviral activity, antifungal activity, cardiovascular activity, anti-inflammatory activity and hepatoprotective activity.

Winter squash (*Cucurbita maxima*) – (Flavonoids, Polyphenolics, Saponins, Cucurbitaxanthin and α-tocopherol) - Antidiabetic, antitumor, antihypertensive, antiinflammatory and immunomodulatory etc.

Bottle gourd (*Lagenaria siceraria*) – (β -carotene, Cucurbitacins, Saponins, Flavone-C-glycoside and Polyphenol) – Antioxidant, antihepatotoxic, antitumor, immunoprotective and antipoliferative activity etc.

Bitter gourd (*Momordica charantia*) – (Steroidal glycosides, Insulinomimeticlectins and Alkaloids) – Antidiabetic, antitumor etc.

Ridge gourd (*Luffa acutangula*) – (Flavonoids, Saponins, Luffangulin, Sapogenin, Oleanolic acid and Cucurbitacin) - Diuretic, antioxidant, expectorant, laxative, purgative, hypoglycemic agent etc.

Sponge gourd (*Luffa cylindrica*) – (Alkaloids, Saponins, Carotenoids, Terpenoids) - Antioxidant, antimicrobial, anticancer, cardioprotective, gastroprotective, antidiabetic, hypolipidemic, hepatoprotective properties.

Snake gourd (*Trichosanthes cucumerina*) – (Triterpenoids, Saponins, Cucurbitacins) - Anti-inflammatory activity, ant-diabetic activity etc.

Solanaceae

Tomato (*Solanum lycopersicum*) – (Lycopene, Carotenoids, Polyphenols, quercetin, naringenin, chalcone and chlorogenic acid) – Antioxidant and anticancerous etc.

Potato (*Solanum tuberosum*) – (Carotene-ß, Cryto-xanthin-ß, Lutein-xanthin) - Antiscorbutic, aperient, diuretic, galactagogue, stimulant, emollient, antidote, antispasmodic etc.

Sweet pepper (*Capsicum annuum var grossum*) (Polyphenols, Carotenoids, Capsaicinoids and Ascorbic acid) - Antioxidants, anticancerous, anti-inflammatory, antiallergic and antibacterial activities.

Hot pepper (*Capsicum annuum var annuum*) – (Carotenoids - capsanthin, capsorubin and cryptocapsin) - Carminative, anti-inflammatory, antigenotoxic, anticarcinogenic, and antioxidant properties.

Brinjal (*Solanum melongena*) – (Anthocyanins, Polyphenols, Alkaloids) - Antioxidants, anticancerous, anti-inflammatory etc.

Leguminosae (Fabaceae)

Cluster bean (*Cyamopsis tetragonoloba*) – (Gallotannins, Gallic acid derivatives, Campesterol, Avenasterol, Stigmasterol) acts as an appetizer, digestive aid and laxative etc.

Indian bean/Hyacinth bean (*Dolichos lablab*) – (Alkaloids, Tannins, Flavonoids, Saponins, Coumarins, Terpenoids, Glycosides, Anthnanoids) - Antidiabetic, antiinflammatory, analgesic, antioxidant, cytotoxic, hypolipidemic, antimicrobial, insecticidal, hepatoprotective, antilithiatic, antispasmodic effects.

Lima bean (*Phaseolus lunatus*) – (Lunatusin) – Antibacterial, antifungal, antiproliferative etc.

Kidney/snap/French bean (*Phaseolus vulgaris*) – (Alkaloids, Anthocyanin, Catechin, Flavonoids, Glycosides, Phasine, Quercetin, Polyphenols, Saponins, Steroids, Tannins, and Terpenoids) - Depurative, resolvent, carminative, diuretic, antidiarrheal, emollient, antioxidant, antidiabetic, osteoprotective properties etc.

Cow pea (*Vigna sinensis*) – (Folic Acid) - Prevent neural tube defects in unborn babies.

Winged bean/Goa bean (*Psophocarpus tetragonolobus*) – (Sterols, folates, niacin) - Antimicrobial, anti-inflammatory, anti-nociceptive, antioxidant properties etc.

Sword bean (*Canavalia gladiata*) – (Methyl gallate, Digalloyl hexoside and Digallic acid) – Antoxidative, potential health benefits against oxidative stress-related chronic diseases.

Methi/fenugreek (*Trigonella foenum- graecum*) – (Galactomannan, 4-OH isoleucine, and Steroidal saponin) – Treatments of diabetes, hypercholesterolemia, inflammation and cancers.

Umbelliferae

Carrot (*Daucus carota*) - Polyacetylenes (Falcarinol, Falcarindiol and Falcarindiol-3-acetate) and carotenoids (β-carotene and Lutein) - Treatment of leukaemia etc.

Coriander (*Coriandrum sativum*) - (Caffeic, Chlorogenic acid, Quercetin, Keampferol, Rhamnetin and Apigenin) - Antibacterial, antifungal and antioxidant activities etc.

Celery (*Apium graveolens*)- (Limonene, Selinene, Frocoumarin glycosides, Flavonoids) – Antioxidant, different healing effects etc.

Compositae (Asteraceae)

Lettuce (*Lactuca sativa*) – (Lactucin, Lactucopicrin, Lactuerol) – Antimalarial, analgesic and sedative properties.

Globe artichoke (*Cynara scolymus*)- (Chlorogenic acid, Cynarin, Luteolin-7-rutinoside, and Cynaroside) - Antioxidative, hepatoprotective, choleretic and anti-cholestatic effects etc.

Jerusalem artichoke (*Helianthus tuberosus*) – (Sesquiterpene lactones, Phenolics)-Antifungal, antioxidant, anticancer activities etc.

Chenopodiaceae

Beet (*Beta vulgaris*) – (Betaine and Betalain) - Treat a wide variety of ailments, treatment for fevers and constipation etc.
Spinach (*Spinacia oleracea*) – (Flavonoid - 5,3‘,4‘-trihydroxy-3-methoxy-6:7-methylenedioxyflavone-4‘-glucuronide, Glycosides) - Protection from eye disorders, oxidative stress, iron deficiency etc., reducing risks of specific diseases like diabetes, cancer and hepatotoxicity.
Palak (*Beta vulgaris var. bengalensis*) - (Betaine and betalain) - Treat a wide variety of ailments, treatment for fevers and constipation etc.
Aizoaceae
New Zealand spinach (*Tetragonia expansa*) – (Saponin, Vitamin C, E, K and Nitrates) - Antiscorbutic, anticancerous etc.
Araliaceae
Udo (*Aralia cordata*) – (Saponins, Sesquiterpenes and Diterpene acids) - Analgesic, antiinflammatory, carminative, diuretic, febrifuge, stomachic.
Convolvulaceae
Sweet potato (*Ipomoea batatas*) – (Anthocyanins, Phenolics, Coumarins, Phenolics, Caffeoylquinic acid derivatives etc.) - Anti-cancer, antidiabetic, and anti-inflammatory activities.
Euphorbiaceae
Tapioca/cassava (*Manihot esculenta*) – (Mandiocin - glucoside; Flavonoids, Saponins) - Anti-inflammatory and antimicrobial activity etc.
Malvaceae
Okra/ Bhendi (*Abelmoschus esculentus*) – (Phenolics, Quartering and Flavonol derivatives, Catechin oligomers and Hydroxycinnamic derivatives) - antioxidants activity, help to lower serum cholesterol, reducing the risk of heart diseases etc.

Table 1: Vegetable botanical classification with major bioactive medicinal compound and their benefits

SFN has considerable attention due its ability to concurrently modulate multiple cellular targets involved in cancer development, including: (a) DNA protection by modulating carcinogen-metabolizing enzymes and blocking mutagens action; (b) cell proliferation inhibition and apoptosis induction, thereby retarding or eliminating clonal expansion of initiated, transformed, and/or neoplastic cells; (c) inhibition of neoangiogenesis, progression of benign tumors to malignant tumors, and metastasis formation. Therefore SFN is able to prevent, delay, or reverse preneoplastic lesions, as well as to act on cancer cells as a therapeutic agent and viewed as a conceptually promising agent in cancer prevention and/or therapy [4]. Using plant genetic engineering approaches chromosome segments from a wild ancestor, *Brassica villosa*, was introgressed in broccoli which resulted with enhance glucosinolate levels in three high-glucoraphanin F1 broccoli hybrids [7].

Other molecule such as allicin, allyl propyl disulfide, di-allyl disulfide present in onion, garlic etc. help to protect against certain cancers and heart disease; and also acts as immunobooster. Using genetic engineering, transgenic onion plants containing antisense alliinase gene constructs (a CaMV 35S-driven antisense root alliinase gene, a CaMV 35S-driven antisense bulb alliinase, and a bulb alliinase promoter-driven antisense bulb alliinase) have been produced by Eady et al. [8]. Quercetin is also important medicinal important bioactive compound present in onion prevents from heart disease, diabetes, peptic ulcer, inflammation, asthma, gout, viral infections. Beta-carotene enriched vegetables such as carrot, cantaloupe, pumpkin, sweet potato and cauliflower has higher antioxidant properties. Betacyanins present in beet root also contributed towards high anti-oxidative as well as free radical scavenging activities. Anthocyanins enriched vegetables are brinjal, carrot, amaranth, bean, cabbage and broccoli prevents from cardiovascular dysfunction and protective effect on pancreatic cells.

Using molecular breeding the gene aubergine (Abg) associated with carotenoids was introgressed from *Solanum lycopersicoides* induce strong and variegated pigmentation in the tomatoes peel [9]. In carrot, seven monogenic traits viz. yel, cola, Rs, Mj-1, Y, Y2, and P1 for total carotenoids and five component carotenoids; phytoene, α-carotene, β -carotene, zeta-carotene, and lycopene and the majority of the structural genes of the carotenoid pathway in its genetic map was investigated. Cervantes-[10] have also reported QTLs in sweet potato for high dry matter, starch content and β -carotene which leads to opening up the possibility of genetic manipulation and further enhancement of root crops [2]. Diretto et al. [11] have silenced the first step in the beta-epsilon branch of carotenoid biosynthesis, lycopene epsilon cyclase (LCY-e) in potato, a tuber crop that contains low levels of carotenoids. This antisense tuber-specific silencing of the gene results in significant increases up to 14-fold more Beta-carotene in carotenoid levels. In tomato, overexpression of anthocyanin-1 (Ant1), a transcription factor regulating anthocyanin production has led to increased accumulation of anthocyanins in tomato fruit [12]. Maligeppagol et al. [13] developed transgenic tomato accumulating high amounts (70-100 fold) of anthocyanin in the fruits by fruit specific expression of two transcription factors, Delila and Rosea [1] isolated from Antirrhinum majus. Stushnoff et al. [14] identified 27 genes in potato that are differentially expressed in purple and white tuber tissues. Through transgenic approach; Diretto et al. [15] introduced three genes, encoding phytoene synthase (CrtB), phytoenedesaturase (CrtI) and lycopene beta-cyclase (CrtY) from Erwinia in potato to produce β-carotene. Gerjets and Sandmann developed genetically engineered potato for the production of commercially important keto carotenoids including astaxanthin (3, 3'-dihydroxy 4, 4'-diketo-β-carotene). Kim et al. [16] developed transgenic sweet potato through the inhibition of hydroxylation of β -carotene with silencing effects of CHY-b in carotenoid biosynthetic pathway. Lu et al. [17] produced transgenic cauliflower with high levels of β-carotene accumulation. Transformation of the 'or' gene into wild type cauliflower converts the white colour of curd tissue into distinct orange colour with increased level of β-carotene. Flavonoids (isoflavones) rich in beans lower the cholesterol and protect against cancer. Lutein- bioactive compound present in sweet pepper, carrot and yellow-corn are also beneficial for eyes. Chlorophyll present in broccoli, cabbage, kale, Spinach, and asparagus acts as a chemo preventive compound.

Tomato and brinjal are the globally important vegetable also acts as modal vegetable crop for vegetable breeding programs. Brinjal as high value vegetable contains chlorogenic acid and nasunin that have anti-carcinogenic, anti-obesity, and anti-diabetic properties. Lycopene present in tomato, watermelon and carrot helps to protect against cancer and fight against infection. Potatoes are one of the low-fat foods with distinctive nutrients and phytochemical profiles and are particularly rich in, vitamin B-6, vitamin C, manganese, potassium and carotenoids (lutein and zeaxanthin), flavonoids (quercetin and kaempferol) and phenolic acids (chlorogenic acid and caffeic acid) [18]. Momordicin and charantin present in bittergourd has medicinal application in controlling diabetes, act as blood purifier, hypertension, dysentery and anathematic. Available literature suggested that health benefits of vegetables, fruits, staple food crops, whole grains, and other plant based foods are credited to the synergestic interactions of important bioactive compounds/molecules and other nutrients [19]. Therefore, consumers-end users should obtain their nutrients, antioxidants, phytochemicals or bioactive compounds from their balanced diet enriched with vegetables, fruits, whole grains, and other plant foods for optimal nutrition, health, and well-being.

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