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REVIEW ARTICLE

BIOPHARMACEUTICS

NUTRACEUTICAL ENRICHED VEGETABLES: MOLECULAR APPROACHES FOR CROP IMPROVEMENT

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ABSTRACT

Nutraceuticals have been explored recently as sustainable alternatives for the control and prevention of large number of diseases. They have received considerable attention because they are safe, efficacious and have potential nutritional value as well as therapeutic effects. Among natural dietary supplements, vegetables being low in calories are packed with vitamins, minerals, antioxidants and phytochemicals. They play an important part in the human diet and are a major source of biologically active nutraceuticals. Some popular phyto-nutraceuticals include lycopene from tomato, curcumin from turmeric, carotenoids from carrot etc. Majority of the vegetable originated nutraceuticals are claimed to possess multiple therapeutic benefits; though substantial evidence for their benefits as well as unwanted effects is lacking. The present review has been devoted towards better understanding of the phyto-nutraceuticals from different vegetables based on their disease specific indications and enhancing nutraceutical qualities of vegetables through biotechnological/molecular approaches.

KEYWORDS

Nutraceuticals, Vegetable crops, Phytochemicals, Molecular markers, Nutrigenomics

INTRODUCTION

Nutraceutical is a combination of the words "nutrition" and "pharmaceuticals," and can be defined as food-derived products that may have health benefits[1]. Vegetables are functional foods/nutraceuticals because they provide minerals and nutrients which are health promoting. "Functional" attributes of many traditional vegetables are being discovered, while new food products are being developed with additional nutraceutic components[2,3,4]. Vegetables form the most important component of a balanced diet. Vegetables vary markedly in their nutritional value according to the different parts of the plant consumed. Number of studies has proved that vegetables contain more health giving ingredients as sugars, amino acids and vitamins have long been recognized for their health benefits to humans. As technology and research techniques are improving, other substances in vegetables that were previously ignored are getting the spotlight.

Nutraceutical rich vegetables have medical health benefits including the prevention and treatment of diseases[5]. Vegetables are rich sources of bioactive compounds such as flavonoids, carotenoids, anthocyanins, vitamins and other polyphenolics[6]. Such compounds play a role in disease prevention/reduce disease risk factors through antioxidant activity. Researchers have identified hundreds of compounds in vegetable crops with functional qualities and they continue to make new discoveries surrounding the complex benefits of phytochemicals such as lycopene in tomatoes, cucumin in turmeric, gingerol in ginger, organosulphur compounds in allium species, omega-3fatty acids in cucurbitaceous vegetable seeds and so on[7,8,9]. The vegetable breeders have been able to boost the nutritional content of certain vegetable crops like vitamin-enhanced broccoli and essential amino acids enriched potatoes. There has been an explosion of consumer's awareness regarding the vegetables with physiologically-active specific nutraceuticals. Such products include food supplements, dietary supplements, value-added processed vegetables as well as non-food supplements such as tablets, soft gels, capsules etc[10,11].

The term vegetable is used to describe the tender edible shoot, leaves, fruits and roots of plants that are consumed whole or in part, raw or cooked as a food supplement.

Classification of vegetables: Vegetables may be classified on the basis of life cycle, edible parts of the plant, adaptation and botanical features. On the basis of part used they can be classified as-

a) **Root vegetables**: carrots, beets, turnips etc.
b) **Tuber vegetables**: potatoes, taro, sweet potatoes etc.
c) **Bulbous vegetables**: onions, garlic, leeks etc.
d) **Leafy vegetables**: cabbage, spinach, purslane, mallow, lettuce, grape leaves, chard, dill, mint, parsley, watercress etc.
e) **Flowery vegetables**: cauliflower, broccoli, globe artichoke etc.
f) **Fruity vegetables**: tomato, egg plant, squash, okra, chillies, cucumber, cantaloupe, watermelon, muskmelon etc.
g) **Stem vegetables:** asparagus, celery, kohirabi etc.
h) **Seed vegetables:** black-eyed peas, peas, kidney beans, beans, moongra, drumstick beans, guar beans, lentils, soybean etc.

Vegetables can also be categorized by colour and nutrient content. Pigments like chlorophyll, anthocyanin, carotenoids make vegetables colourful. These colours are indications for the

specific nutrients in it[12]. The darker vegetables have higher content of nutrients in them. Some information about the vegetables based on colour is summarized in Table 1. Green colour in vegetables indicates the richness of vitamins C and B complex, calcium, iron, phosphorus, fiber and beta carotene (pro-vitamin A). Yellow and orange vegetables are rich in pigments like lutein, zeaxanthin and carotenoids[13]. It is believed that carotenoid acts as an antioxidant that can repair damaged cells in the eye so that it can prevent the occurrence of cataracts and blindness. Similarly yellow vegetables are also beneficial to prevent heart and coronary diseases. Red colour shows the presence of anthocyanin and lycopene content, which are useful to prevent infections, bladder cancer and body dementia. Examples of red-coloured fruits and vegetables include guava, strawberry, watermelon, tomato, red spinach, red cabbage and carrot[14]. White coloured vegetables show the content of vitamin C and fiber that are useful to facilitate the digestive system and are believed to increase the resilience of the body exposed to various kinds of diseases.

In a research it was discovered that the protective value of antioxidants could be measured in Oxygen Radical Absorption Capacity units (ORAC). The highest protection is achieved when the daily diet provides 5000 ORACs. Colour is a good guide in determining the ORAC value of the plant food because deeper the colour of a fruit or vegetable, the higher is its ORAC score.

Table: 1
Classification of vegetables on the basis of colour

Colour	Contents	Benefits	Examples
Green Vegetables	Chlorophyll, fiber, lutein, zeaxanthin, calcium, folate, vitamin C, calcium and beta-carotene	Reduce cancer risks, lower blood pressure and LDL cholesterol levels, normalize digestion time, support retinal health and vision, fight harmful free-radicals, boost immune system activity	Asparagus, Broccoli, Brussel sprouts, Celery, Chinese cabbage, Cucumber, Green beans, Green cabbage, Green onion, Green peppers, Lettuce, Okra, Peas, Spinach
White Vegetables	Beta-glucans, EGCG, SDG and lignans	Provide powerful immune boosting activity. These nutrients also activate natural killer B and T cells, reduce the risk of colon, breast, and prostate cancers and balance hormone levels thus reducing the risk of hormone-related cancers	Cauliflower, Garlic, Ginger, Mushrooms, Onions, Potato, Shallots, Turnip, Radish
Red Vegetables	Lycopene, ellagic acid, quercetin and hesperidin	Reduce the risk of prostate cancer, lower blood pressure, reduce tumor growth, lower LDL cholesterol levels, scavenge harmful free-radicals, and support joint tissue in	Beets, Red apple, Red bell peppers, Red chili peppers, Red onion, Red potato, Tomato, Red Carrot

		arthritis cases	
Yellow/Orange Vegetables	Beta-carotene, zeaxanthin, flavonoids, lycopene, potassium and vitamin C	Reduce age-related degeneration and the risk of prostate cancer, lower LDL cholesterol and blood pressure, promote collagen formation and healthy joints, fight harmful free radicals, encourage alkaline balance	Carrot, Papaya, Pumpkin, Sweet potato, Yellow peppers, Yellow potato, Yellow summer squash, Yellow bell peppers, Yellow tomato, Yellow winter squash
Blue/Purple Vegetables	Lutein, zeaxanthin, resveratrol, vitamin C, fiber, flavonoids, ellagic acid and quercetin	Support retinal health, lower LDL cholesterol, boost immune system activity, fight inflammation, reduce tumor growth, act as an anti-carcinogen in the digestive tract, and limit the activity of cancer cells	Black salsify, Egg plant, Purple Belgian endive, Purple Potato, Purple asparagus, Purple cabbage, Purple carrot, Purple fig, Purple bell peppers, Purple onion, Purple broccoli, Purple cauliflower, Purple kohlrabi, Purple broad beans

Vegetables as natural vitamin source: Vegetables act as excellent sources of distinctive kinds of vitamins (Table-2). The nutrient and vitamin content of different kinds of vegetables differs considerably. Dark green leafy vegetables are good source of many vitamins (like vitamins A, C, and K and folate) and minerals (such as iron and calcium). Vitamins have diverse biochemical functions. Some act as hormones regulating mineral metabolism like vitamin D or others like vitamin A regulate growth and differentiation processes. However some vitamins like vitamin E and vitamin C act as antioxidants[15,16]. The largest group of vitamins, vitamin B complex, functions as precursors for enzyme cofactors, that act as catalysts regulating enzyme activity in metabolism[17,18,19,20].

Table: 2
List of some common vegetables used as different Vitamins' source

S. No.	Vitamins	Uses	Vegetable Sources
1.	Vitamin A (Retinol)	It helps cell reproduction; stimulates immunity; helps vision and promotes bone growth and tooth development; helps maintain healthy skin, hair and mucous membranes	Amaranth Leaves (*Amaranthus* sp.) Broccoli *(Brassica oleracea)* Brussels Sprouts *(Brassica oleracea gemmifera)* Butternut Squash *(Cucurbita moschata)* Carrots (*Daucus carota*) Chinese Broccoli *(Brassica alboglabra)* Chinese Cabbage *(Brassica rapa)* Peas (*Pisum sativum*) Pumpkin (*Cucurbita pepo)* Spinach (*Spinacia oleracea)*

			Sweet Potato (*Ipomoea batatas)* Swiss Chard *(Beta vulgaris)*
2.	Vitamin B1 (Thiamine)	Important in the production of energy; helps the body cells convert carbohydrates into energy; essential for the functioning of the heart, muscles and nervous system	Asparagus *(Asparagus officinalis)* Brussels Sprouts (*Brassica oleracea gemmifera*) French Beans *(Phaseolus vulgaris*) Lima Beans *(Phaseolus Lunatus)* Okra *(Abelmoschus esculentus)* Parsnip *(Pastinaca sativa)* Peas (*Pisum sativum*) Potato *(Solanum tuberosum)* Sweet Potato (*Ipomoea batatas)*
3.	Vitamin B2 (Riboflavin)	Is important for body growth, reproduction and red cell production	Amaranth Leaves (*Amaranthus* sp.*)* Artichoke *(Cynara scolymus)* Asparagus *(Asparagus officinalis)* French Beans *(Phaseolus vulgaris*) Lima Beans *(Phaseolus Lunatus)* Mushrooms *(Lycoperdon* sp.*,Calvatia* sp.*)* Peas *(Pisum sativum)* Pumpkin *(Cucurbita pepo)* Sweet Potato (*Ipomoea batatas)*
4.	Vitamin B3 (Niacin)	Assists in the functioning of the digestive system, skin and nerves	Artichoke *(Cynara scolymus)* Mushrooms *(Lycoperdon* sp.*,Calvatia* sp.*)* Okra *(Abelmoschus esculentus)* Parsnip *(Pastinaca sativa)* Peas *(Pisum sativum)* Potato *(Solanum tuberosum)* Pumpkin *(Cucurbita pepo)* Sweet Potato (*Ipomoea batatas)* Pigeon Beans *(Cajanus cajan)* Split Peas *(Pisum sativum)* Soy Beans *(Glycine max)*
5.	Vitamin B5 (Pantothenic acid)	Is essential for the metabolism of food as well as in the formation of hormones; lowers cholesterol level	Broccoli (*Brassica oleracea)* French Beans *(Phaseolus vulgaris*) Mushrooms *(Lycoperdon* sp.*,Calvatia* sp.*)* Okra *(Abelmoschus esculentus)* Parsnip *(Pastinaca sativa)* Potato *(Solanum tuberosum)* Pumpkin *(Cucurbita pepo)* Sweet Potato *(Ipomoea batatas)* Black Eye Peas *(Phaseolus aureus)* Lima Beans *(Phaseolus Lunatus)* Mung Beans *(Vigna radiate)* Soy Beans *(Glycine max)* Split Peas *(Pisum sativum)*
6.	Vitamin B6 (Pryidoxine)	Plays a role in the creation of antibodies in the immune system; maintains normal nerve function; helps in the formation of red blood cells	Amaranth leaves (*Amaranthus* sp.*)* Broccoli (*Brassica oleracea)* Brussels Sprouts (*Brassica oleracea gemmifera*) Celeriac *(Apium graveolens)* French Beans *(Phaseolus vulgaris*) Green Pepper *(Capsicum annuum)* Lima Beans *(Phaseolus lunatus)* Okra *(Abelmoschus esculentus)* Peas *(Pisum sativum)* Potato *(Solanum tuberosum)* Sweet Potato *(Ipomoea batatas)* Taro *(Colocasia esculenta)*

7.	Vitamin B9 (Folic acid)	It helps to produce red blood cells as well as components of the nervous system; helps in the formation and creation of DNA; maintains normal brain function; critical part of spinal fluid	Amaranth leaves *(Amaranthus sp.)* Asparagus *(Asparagus officinalis)* Beetroot *(Beta vulgaris)* Broccoli (*Brassica oleracea)* Brussels Sprouts (*Brassica oleracea gemmifera*) Chinese Broccoli *(Brassica alboglabra)* Chinese Cabbage *(Brassica rapa*) French Beans *(Phaseolus vulgaris*) Lima Beans *(Phaseolus lunatus)* Okra *(Abelmoschus esculentus)* Parsnip *(Pastinaca sativa)* Peas *(Pisum sativum)* Potato *(Solanum tuberosum)* Spinach (*Spinacia oleracea)*
8.	Vitamin C (Ascorbic acid)	Most important of all the vitamins; plays a significant role as an antioxidant, thereby protecting body tissue from oxidative damage and the harmful effects of free radicals, which are potentially damaging by-products of the body's metabolism	Amaranth leaves *(Amaranthus sp.*) Bok Choy (*Brassica* var. *Chinensis)* Broccoli *(Brassica oleracea)* Brussels Sprouts (*Brassica oleracea gemmifera*) Butternut Squash *(Cucurbita moschata)* Green Pepper *(Capsicum annuum)* Kale (*Brassica oleracea acephala)* Swiss Chard *(Beta vulgaris)*
9.	Vitamin D (Calciferol)	Also known as the "sunshine vitamin" since it is manufactured by the body after being exposed to sunrays; helps in regulating body levels of calcium and phosphorus, and in mineralization of bone	Mushrooms *(Lycoperdon* sp*., Calvatia* sp.*)*
10.	Vitamin E (Tocopherol)	Plays a significant role as an antioxidant, thereby protecting the body tissue from oxidative damage; important in the formation of red blood cells and the metabolism of vitamin K	Butternut Squash *(Cucurbita moschata)* Parsnip *(Pastinaca sativa)* Potato *(Solanum tuberosum)* Pumpkin *(Cucurbita pepo*) Spirulina (*Spirulina maxima)* Swiss Chard *(Beta vulgaris)* Taro *(Colocasia esculenta)*
11.	Vitamin K (Phylloquinone)	Plays a critical role in blood clotting; regulates blood calcium levels and activates proteins involved in bone health	Artichoke *(Cynara scolymus)* Asparagus *(Asparagus officinalis)* Broccoli *(Brassica oleracea)* Cabbage *(Brassica oleracea capitata)* Carrot *(Daucus carota)* Cauliflower (*Brassica oleracea botrytis)* Celery *(Apium graveolens)* Chinese Broccoli *(Brassica alboglabra)* Cucumber *(Cucumis sativus)* Okra *(Abelmoschus esculentus)* Peas *(Pisum sativum)* Spinach (*Spinacia oleracea)*

Medicinal value of vegetables: Some vegetables have medicinal qualities and are used in ethno-botanical tradition of the folk medicine on the basis of traditional knowledge. The entire group of the *Alliaceae* vegetables (garlic, onion, parsnip etc) contains organic

compounds with sulphur that intensify the redox cycle of glutathione and activate specific immunity types (Table 3). Their bioactivity includes antioxidant, antibacterial, anti-carcinogenic, immuno-stimulating and liver protective potential. Garlic prevents heart diseases (atherosclerosis, hypercholesterolemia, high blood pressure) and cancer[21]. It is also considered as an efficient remedy against the intestinal parasites. The regular use of onions or garlic can decrease the risk of stomach and colon cancer by 50 to 60 percent while the regular consumption of cabbage has been shown to decrease the risk of colon cancer by 60 to 70 percent[22,23]. The use of carrots and green leafy vegetables provide substantial protection against lung cancer. Regular consumption of tomatoes and strawberries is recently found to substantially protect against prostate cancer.

Table: 3
List of some common vegetables used as traditional herbal nutraceutical

Sr No.	Plant species	Common name	Properties/disease for which used	Plant part/forms used
1.	*Anethum graveolens*	Suwa	Used in flatulent colic, dyspepsia, for intestinal worms, dental pain, arthralgia, inflammation, amenorrhoea, dysmenorrhoea, hiccough, cough, asthma, bronchitis, fever, ulcers, skin diseases, liver spleen diseases, U.T.I., cardiac debility and hemorrhoids	Leaves and seeds
2.	*Amaranthus hybridus*	Chaulai	Used in cardiovascular diseases; tapeworm expellant; relieve pulmonary problems	Leaves, seeds, oil from seeds
3.	*Abelmoschus esculentus*	Okra	Improve and increase sperm count	Fruit
4.	*Allium cepa*	Onion	Used for heart diseases, diabetes, osteoporosis; has anti-inflammatory, anticholesterol, anticancerous and antioxidant properties	Bulb and leaves
5.	*Allium sativum*	Garlic	Used in chemopreventation, cancer, diabetes, arteriosclerosis, lowering cholesterol, respiratory infections	Fresh or dried cloves, capsules, odorless tablets, tinctures, aged garlic extracts
6.	*Amorphophallus companulatus*	Suran	Used in gastric troubles and rheumatic pain; potent drug for the treatment of piles	Root
7.	*Asparagus* sp.	Shatavari	Tonic, astringent	Root
8.	*Boletus* sp.	Mushrooms	Have promising cardiovascular, anticancer, antiviral, antibacterial, antiparasitic, anti-inflammatory, and antidiabetic properties	Whole plant body
9.	*Basella alba*	Poe	Used in some testosterone boosting supplements; leaf juice is a demulcent, used in cases of dysentery; is a diuretic, febrifuge, laxative and to treat catarrh	Leaves
10.	*Capsicum*	Red pepper	Anti-arthritic and anti-oxidant	Fresh and dried fruit,

	annum		action	powder
11.	*Chenopodium album*	Bathua	Used in bleeding piles, dysentery, cough and fever; used as antihelminthic, appetizer and laxative	Leaves and seeds
12.	*Curcuma longa*	Turmeric	Reduces inflammation; used in indigestion and liver problems; antioxidant	Dried root, whole or powdered
13.	*Cucurbita maxima*	Pumpkin	Antirheumatic; demulcent; diuretic; nervine; taenifuge	Fruit
14.	*Coriandrum sativum*	Dhania	Antioxidastive; antibacterial; diurectic	Leaves, fruit and root
15.	*Corchorus olitorius*	Tossa jute	Laxative; blood purifier	Seeds, leaves and fruit
16.	*Coccinia grandis*	Kundru	Treatment of diabetes and skin eruptions; antioxidant; immune system modulator	Root, leaves and fruit
17.	Citrullus fistulosus	Tinda	Anthelmintic activity	Fruit
18.	*Colocasia esculenta*	Arabi	Used in pitta, constipation, stomatitis, alopecia, hemorrhoids and general weakness	Leaves
19.	*Foeniculum vulgare*	Fennel	Used in stomach bloating, digestive spasms, catarrh; aphrodisiac; galactogogue	Whole seed, capsules, tinctures
20.	*Ipomea aquatica*	Karemua	Used in digestive problems and liver diseases	Leaves
21.	*Linum usitatissimum*	Flax seed	Used in constipation, irritable bowel syndrome; source of omega-3-essential fatty acids; controls cholesterol; chemopreventive; anti-arthritic	Seed powder, expressed oil of seed
22.	*Momordica charantia*	Bitter melon	Used to treat malaria, fever, diarrhoea, HBP dysentery, gonorrhea; laxative	Fruit
23.	*Nelumbo nucifera*	Lotus, Kamal gatta	Used to stop dysentery	Seeds, stem and root
24.	*Puereria tuberosa*	Bilikand	Eases bowel movement; useful in relieving constipation; used in skin diseases	Tubers
25.	*Portulaca oleracea*	Lunia	Used to treat infections or bleeding of the genito-urinary tract	Leaves
26.	*Silybum marianum*	Milk thistle	Used in liver disorders, lactation problems; anti-oxidant	Whole or powdered seed, capsules, tablets, tinctures
27.	*Spinacia oleracea*	Palak/spinach	Antioxidative; used to treat anaemia	Leaves
28.	*Trigonella foenum-graecum*	Fenugreek	Used to treat gastritis, excess cholesterol, diabetes, skin inflammation	Seed, whole or powdered; capsules, tinctures
29.	*Trichosanthes cucumerina*	Snake Gourd	Anti-inflammatory; Anti-diabetic	Leaves and fruit

30.	*Manihot esculenta*	Sabu	Leaves and pulped roots used as an application for tumors, coeliac disease	Leaves and root
31.	*Moringa oleifera*	Drumstick	An antiseptic; treats rheumatism, venomous bites	Bark, root, fruit, flowers, leaves, seed and gum
32.	*Solanum melongena*	Brinjal	Maintains blood cholesterol; helps in digestion; increases appetite	Fruit
33.	*Valeriana officinalis*	Valerian	Relieves from anxiety, insomnia, hypertension	Root, powder, capsules, tablets, tinctures, extracts
34.	*Luffa acutangula*	Patola	Considered demulcent, diuretic; seeds considered purgative and emetic	Fruit
35.	*Lagenaria vulgaris*	Lauki, Doodhi, Ghia	Used in urinary disorder, diarrhea, diabetes	Fruit
36.	*Oxalis debilis*	Khatti Booti	Used in diarrhoea, fever, scurvy, piles; used as an antidote to snake bite	Leaves
37.	*Zingiber officinale*	Ginger	Used in cough, indigestion, motion sickness, nausea; anti-oxidant; controls cholesterol level	Fresh or dried root, capsule, tablets, tinctures

Phytochemicals from vegetables*:* Vegetables contain various types of biologically active plant substances, so-called phytonutrients or phytochemicals that are produced by the plants to protect themselves against stress. Health experts believe that these natural substances are also beneficial for human health[24]. Natural compounds found in vegetables protect against many life threatening conditions like heart disease, arterial damage, cancer, as well as against premature ageing [25,26] (Table-4 and figure-1).

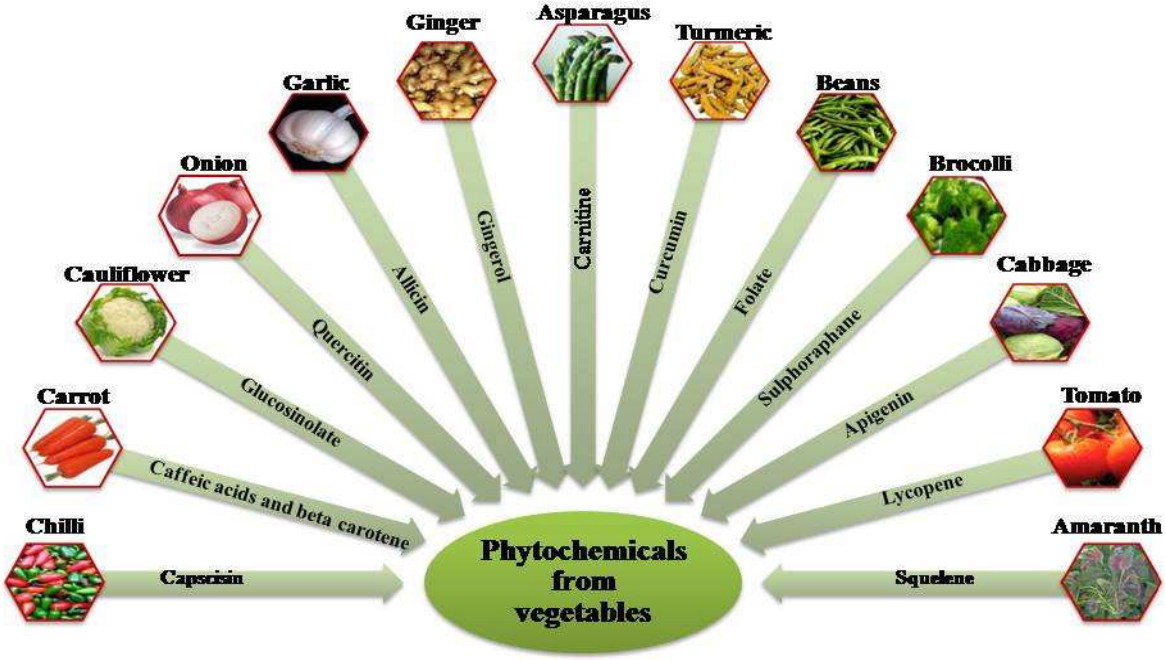

Figure-1
Different phytochemicals derived from vegetables used as nutraceutical

The natural pigments that give vegetables and fruits their characteristic colours are one of the important group of phytochemicals. Some of the pigments in vegetables, for example beta carotene in carrots and sweet potatoes; dehydro-tomatine, α-tomatine, lycopene in tomatoes and lutein in spinach, have antioxidant properties[27]. Antioxidants have the ability to reduce damage of cell's DNA from harmful free radicals produced in the body. Each colour group has a unique combination of nutrients and phytochemicals that have been associated with specific health benefits[28]. Some phytochemicals, like Indoles, which are found in cabbages, stimulate enzymes that make the estrogen less effective and could reduce the risk for breast cancer. Allyl sulfides, another group of phytochemicals found in onion and garlic, stimulate enzymes that help the body to get rid of harmful toxins and strengthen the immune system.

Table: 4

List of some common chemical compounds (Nutraceuticals) isolated from vegetables

S. No.	Chemical compounds	Plant source	Properties
1.	Allicin (organosulfur compound)	Garlic, onion, parsnip	Antifungal; antibacterial; antioxidant; used to treat arteriosclerosis
2.	Apigenin	Cabbage, celery, lettuce	4',5,7-trihydroxyflavone is a flavone that is the aglycone of several glycosides
3.	Beta carotene	Carrots, pumpkins, sweet potatoes, winter squash, broccoli, spinach and kale	Anti aging; anti cancerous; improve lung function; reduce complications associated with diabetes
4.	Betanin	Beets, chard	Natural colourant used in icecreams
5.	Betaine (Trimethyl Glycine)	Green leafy vegetables and germinated grains	Reduces toxic buildup of homocystine
6.	Capsaicin or trans-8-methyl-N-vanillyl-5 nonenamide	Red chilli	Used for pain relief topically and as a digestive aid when taken internally; antioxidant; antiallergic
7.	Carnitine or L-Carnitine	Shatavari	Responsible for the transportation of long-chain fatty acids groups into the mitochondria
8.	Caffeic acids	Carrot	Inhibitor of the lipoxygenase enzyme that forms leukotrienes from arachidonic acid
9.	Tocopherol	Broccoli, carrot, celery, onion	It is a fat-soluble antioxidant that stops the production of reactive oxygen species formed when fat undergoes oxidation
10.	Curcumin	Turmeric	Anticancerous; antioxidative
11.	Plant Glucosamine	Lettuce, peas, cabbage	Chondroitin and glucosamine are part of normal cartilage and act as a cushion between the joints
12.	Glutathione (GSH)	Cruciferous vegetables	A tripeptide, which provides antioxidant properties thereby protecting the cells against damage by free radicals

13.	Hesperitin	Green vegetables	Anti-inflammtory
14.	Saponin	Soybeans, beans, other legumes	Reduces blood cholesterol levels and the risk of cancer
15.	Quercitin	Onion, broccoli, cabbage, lettuce, tomato	Useful in the treatment of progressive Alzheimer's disease; used in cancer and heart disease
16.	Lignan	Rye, soybean, broccoli	Antioxidants; reduce ill effects in the body as cellular destruction, aging, etc.
17.	Luteoline	Cauliflower, celery , sweet pepper	A carotenoid which shows eye benefits
18.	Nattokinase	Soyabeans	Used as a clot-buster and blood thinner or as a substitute for daily aspirin therapy
19.	Ferulic acid	Turnip	Have anti-oxidizing properties that can moisturize skin, help with light and weather damage, might help tone down age spots
20.	Omega-3 Fatty Acids	Linseed	Omega-3 fatty acids have been associated with positive eye health; lowers cholesterol levels
21.	Sulphoraphane	Broccoli	Used against breast cancer
22.	Phytosterol	Germinated corn	Lower cholesterol absorption in the digestive tract thereby lowering overall cholesterol level in the bloodstream
23.	Proanthocyanin	Red cabbage, egg plant	Help in urinary tract infections by inhibiting adhesion of microorganisms like *E. coli* to the urinary tract wall
24.	Resveratrol	Red onion	Anti-inflammatory, inhibits COX-1 enzyme; blocks adhesion of blood cells to vessel walls shown to reduce skin and breast cancer
25.	Butylphthalide	Celery	Used in high blood pressure
26.	Zeaxanthin	Carrot , celery, kale, lettuce	Used for eye health and in age-related macular degeneration

Enhancement of nutraceutical properties of vegetables through biotechnological approaches: The health functionality of vegetable crops can be improved utilizing a variety of molecular and breeding techniques. Molecular-marker-assisted selection, transformation, chromosome manipulations and generation of useful mutant alleles are some of the approaches that can be used for improving vegetable health functionality[29]. Molecular techniques are helpful in improving bioavailability of the target compounds, their biosynthesis in plant species/tissues where these compounds are not naturally produced, over-expression of transgenes and removal of anti-nutritional factors. Plant breeders must therefore tailor strategies to improve species and naturally active compounds. Molecular approaches hold great promise for future modifications and require more interdisciplinary work that involves nutritional, food and biomedical scientists to ascertain the beneficial role and function of specific plant compounds[30]. The key areas in which biotechnology has applications to improve vegetable crops for nutraceutical values include:

1) *Multiplication/hybridization using tissue culture approaches:*

In vitro shoot culture allows regeneration of true to type disease free plantlets (clone). The application of *in vitro* mass propagation technique of cucurbitaceous vegetable crops has already been well demonstrated while embryo rescue technique enables to overcome from zygotic failure/abortive embryo resulted from interspecific crosses[31,32,33,34]. Several interspecific hybrids have been obtained in this way, for example- between *Lycopersicum* species, cucurbits, and among legumes. *In vitro* anther culture technique allows the regeneration of large number of haploid plants from which diploid plants (homozygous at all loci) can be obtained by colchicine treatment[35]. Lines produced from anther culture of hybrids are obtained in less time and show greater variability than those obtained by self-pollinated lines. Several varieties produced using this method have already been released. Direct culture of microspores has proved to be efficient in *Brassica* species. Molecular characterization of clonal micropropagated plants indicates genetic uniformity as well as certain polymorphism. Regeneration of plantlets through callus phase has been also reported from leaf, vegetative bud, ovary and anther explants of vegetable crops [36,37]. This system could be used for inducing somaclonal variation as conventional breeding in the vegetable crops which lack seed setting. Field evaluation of somaclones indicates variability with regard to various agronomic characters and other yield attributes[31].

2) Molecular breeding of vegetables: Developing new crop varieties through conventional breeding takes several years. However, the application of DNA (or molecular) markers in vegetables crops has considerably shortened this time period. Molecular markers are heritable entities that are associated with economically important traits that can be used by plant breeders as selection tools. Molecular markers can be used to identify the genotype of the individual plant and to identify and map the genes affecting complex plant traits such as yield and resistance to biotic or abiotic stresses, for example - identification and introduction of CBF genes to achieve chilling tolerance in tomato[38]; *Mannitol-1 phosphate Dehydrogenase (mtlD)*[39], gene encoding enzyme for enhancing osmotolerance during the stress period and *Dehydration responsive element binding factor (DREB/CRB3)*[40].

The common methods employed for the identification of DNA markers are: 1) restriction fragment length polymorphism (RFLP); 2) random amplified polymorphic DNA (RAPD); and 3) amplified fragment length polymorphism (AFLP). The application of RAPDs, SSRs, RFLPs, ESTs, STMs, SNPs has been useful in mapping beneficial genes and in the selection of qualitative and quantitative traits (figure-2). This technique has been used to study insect, pest and fungal disease resistance and for qualitative traits assessment. Molecular markers can be used in testing genetic variability, testing the degree of relatedness between different populations, marker-assisted selection and identifying genes useful to plant breeders. Most promising approach for cultivar development is marker assisted selection (MAS). MAS refer to the use of DNA markers that are tightly linked to target loci as a substitute for or to assist phenotypic screening [41]. The identification of genes, quantitative trait loci (QTLs) and DNA markers that are linked to the quantitative traits is accomplished via QTL mapping experiments[42]. QTL mapping thus represents the foundation of the development of markers for MAS. There are three levels of selection in which markers may be applied in backcross breeding: 1) Markers may be used to screen for the target trait, which may be useful for traits that have laborious phenotypic screening procedures or recessive alleles. 2) Selecting backcross progeny with the target gene and tightly linked flanking markers in order to minimize linkage drag ('recombinant selection'). 3) Selecting backcross progeny (that have already been selected for the target trait) with 'background' markers. Further gene pyramiding approach can be used to combine multiple genes/QTLs together into a single genotype.

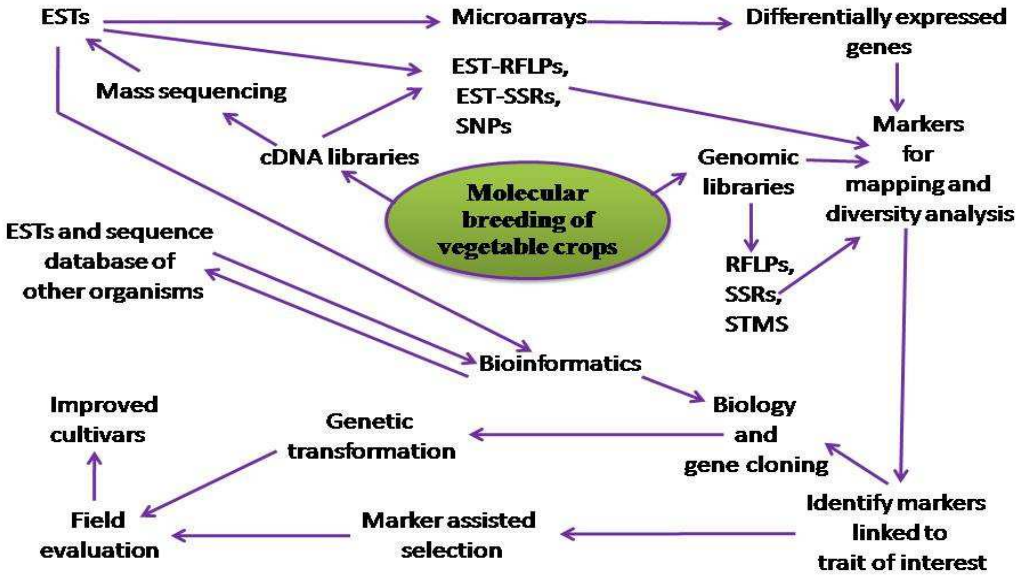

Figure- 2

Schematic presentation showing use of molecular markers for vegetable crops improvement

In the near future, efforts need to be devoted in obtaining transgenic plants with specific gene function helpful for stimulation of seed germination in recalcitrant species, improvement of reproductive developmental processes, host- pathogen interaction, diseases resistance and symbiotic nitrogen fixation. There is also a need to increase the number of isolated genes, particularly those conferring resistance to pests, diseases, and abiotic stresses, and for quality improvement. Mapping the genomes of the most important crops should be one of the priorities of current and future genetic research. This will result in the production of new vegetable crop plants with desirable traits and in a better understanding of plant physiological processes.

3) Nutri-geno-proteo-metabolo-mics for vegetable crop improvement:

It is essential that breeding efforts are concentrated on developing designer plants, rich in desired bioactive compounds suitable for industrial vegetable farming, employing conventional methods with molecular techniques[43]. Genetic engineering is useful for producing crops or food ingredients deprived of some undesirable elements or enriched with healthy substances, and therefore qualified as nutraceutics. Genomics and proteomics tools used in biotechnology have been applied to improving the sensory properties and shelf life of vegetables. Developments in agricultural biotechnology are primarily associated with genetic engineering[44]. In 1994, the first genetically engineered Flavr Savr® tomato reached to the consumer markets. Calgene's Flavr Savr® tomato received widespread publicity during development and commercial introduction in which blocking of the production of ethylene, a plant hormone produced in ripening fruit and other tissues, improves the shelf life of tomato[45,46].

Among the vegetables, onion, garlic, leek and chive belonging to the *Allium* genus are the oldest crops associated with medicinal and health related properties[22]. Some of these traits are thought to be related to the concentration and activity of organosulphur compounds in these vegetables. However, simply increasing the amount of these phytonutrients to improve the medicinal benefits of these vegetables can result in greater pungency[47]. Quantitative trait loci (QTL) for bulb pungency and sulphur

assimilation in onion have already been identified, which might facilitate better selection and breeding. On the other hand breeders have also attempted to breed onions with lower amounts of organosulphur compounds in order to make them more palatable in raw form, thus possibly delivering greater health benefits[48].

While research continues for enhancing *Brassica* isothiocyanates which are used as anti-microbial and anti-cancerous agents, high-glucosinolate broccoli germplasm has been developed that produce mainly isothiocyanates, compared with standard broccoli cultivars. Scientists and breeders have successfully introgressed chromosome segments from a wild ancestor, *Brassica villosa*, to enhance glucosinolate levels. Similarly, potato which usually accumulates lutein and violaxanthin has been genetically modified to accumulate zeaxanthin[49,50,51].

Another approach to improving the health functionality of vegetable crops is to reduce the concentration of anti-nutritional factors. These are naturally occurring compounds with inhibitory effects on the nutritive potential of plants. Faba bean (*Vicia faba* L.), for instance, contains condensed tannins that reduce the value of the inherently high protein levels of the crop. Tannins can be removed by the activity of two genes, *zt-1* and *zt-2*, which are pleiotropic for white-flowered plants. Gutierrez *et al* (2008) have identified a sequence characterized amplified repeat (SCAR) marker linked to the *zt-2* gene that is associated with increased protein levels and reduced fibre content of bean seeds, which should facilitate the development of tannin-free faba varieties[52]. Calcium oxalate is another common anti-nutritional factor in plants. There have been several attempts to reduce the amount of calcium oxalate in plant tissues using molecular approaches[53].

Plant metabolomics, or large-scale phytochemical analysis, is a new research discipline, which aims to develop a comprehensive approach to metabolite detection and identification. Mass spectrometry, nuclear magnetic resonance and infrared spectrometry are the most common metabolomics platforms[54,55]. Metabolite profiling and metabolite fingerprinting are fast growing technologies for phenotyping and diagnostic analysis of plants. They allow identification of the most important compounds, having nutraceutical qualities, underlying differences between genotypes or phenotypes[56].

New approaches are needed, to expand production of vegetables in order to improve food security and to meet the increasing demands at the local, national and regional levels. Increasing productivity requires implementation of modern agricultural practices and the development of new varieties rich in nutraceutics. In the past few years, emphasis has been laid on the use of nutraceuticals as anti-oxidants for the management of malnutrition and for prevention and treatment of diseases. More interdisciplinary work is required in the area of vegetable science that involves development of fast growing, highly productive new varieties of vegetables having high nutritional value.

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