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Breeding and genomic investigations for quality and nutraceutical traits in vegetable crops-a review

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ABSTRACT

Globally, micronutrient malnutrition is a big burden in pubic health spread across the geopolitical regions and socio-economic strata. The efforts for challenging this 'hidden hunger' are dietary diversity, food supplementation, food fortification and biofortification of common food crops. Human body requires nearly 49 different dietary elements and maintaining their regular intake seems to more effective and sustainable through dietary diversity and biofortified crops, however, their accessibility and affordability in continuum remain issues. For this, vegetable crops have great promise to serve for dietary needs because these crops represent a group of more than thousand plants spread all across world and constituent of regular diets. Although, accounted vegetable production in the world is 1088.8 million tonnes but huge numbers of minor vegetables also serve for dietary minerals in poor or rural communities inhabiting in vulnerable regions. Vegetables are bulky in nature but they are the key sources of health protective dietary constituents such as minerals, vitamins and antioxidants in human diet. Their intake also provides dietary elements and antioxidants to protect body from various immune-related diseases by acting against free radicals. The complex matrix of various constituents and minerals influence consumer preference and absorption pattern also. However, the focus on breeding for yield traits affected quality attributes seriously, hence it become essential to breed varieties having high yield and better quality traits. For this, molecular tools and genome sequencing techniques showed effectiveness to speed up the classical breeding methods for these traits of complex pathways. Besides, genome editing techniques such as transgenics, RNA interference and CRISPR/cas have great prospect in vegetables for enriching health beneficial constituents and also for removal of antinutritional factors. The present review reports significant achievements from attempts on understanding genetic of quality traits and breeding vegetables for quality, nutraceutical, pharmaceutical and other industrial traits.

Key words: Anthocyanin, carotenoids, minerals, molecular markers, bioactive compounds, nutrient, medicinal properties.

INTRODUCTION

Nutrition is basic prerequisite to sustain human life and activity which depends on quality of food. Essentially, safe and nutritious food is inherent part of food security which means 'all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food that meets their *food* preferences and dietary needs for an active and healthy life (World Food Summit, 256). Further, rising awareness of environmental, nutritional and health concerns are leading to changes in consumer behaviour towards demand of quality nutritious foods. Quality food got promise to challenge different Sustainable Development Goals (SDGs), namely SDG-1 (No poverty), SDG-2 (Zero hunger and improved nutrition), SDG-3 (Good health & well being), SDG-4 (Quality education and cognitive development & learning), SDG-5 (Reduced inequalities and gender equality), SDG-7 (Improved work and productivity) and SDG-8 (decent work and economic growth). But, major concern is deficiency of micronutrients in children and vulnerable population because nearly 60% of the world's people are iron (Fe) deficient, over 30% are zinc (Zn) deficient, 30% are iodine (I) deficient and 15% are selenium (Se) deficient summarised by White and Broadley (250). Their deficiencies are occurring in the form of poor physical growth, intellectual impairments, perinatal complications and increased risk of morbidity and mortality and loss of productivity. Iron (microcytic anemia), iodine (goiter, mental retardation and cognitive function), folate, vitamin A, calcium and zinc are nutrients of major public health concern because around 2 billion people suffer from micronutrient deficiencies globally. In India, malnutrition accounts for 68.2% of total under-five deaths, 21.4% low birthweight, 39.3% stunting, 15.7% wasting and 32.7% underweight, 59.7% anaemia in children (Swaminathan *et al.,* 221). Dietary diversity, food supplementation, food fortification and biofortification are common approaches to handle micronutrient malnutrition. None of them appears as panacea to challenge the complexities of this hidden hunger in population, however their combination have added value to mitigate its incidence.

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Food quality is a multidimensional concept which not only depends on the property of the food but also on the consumer choice and preference. Consumer behaviour is mainly influenced by sensory attributes (shape, size, colour, flavour, aroma and taste) but, nutritive value and secondary metabolites determine health and nutritional benefits. The quality is defined as 'sum the all characteristics, properties and attributes of a product or commodity which is aimed at fulfilling the established or presumed customer requirement' (ISO 8402, 1989). This support the common view of 'the customer returns and the product does not'. Welch and Graham (249) listed 49 known essential nutrients for sustaining human life in six categories, namely (i) water and energy (water and carbohydrate), (ii) protein and amino acids (histidine, isoleucin, leucine, lycine, methionine, phenyl alanine, threonine, tryptophan and valine), (iii) macroelements (Na, K, Ca, Mg, S, P, Cl), (iv) microelements (Fe, Zn, Cu, Mn, I, Fe, B, Se, Mo, Ni, Cr, V, Si, As, Sn, Co), (v) fatty acids (lenoleic acid and α-linolenic acid), and (vi) vitamins (A, D, E, K, C, B_1, B_2, B_3, niacin, B_6, folate, biotin and B_{12}).To meet up this nutrient requirement, it is suggested to intake 400 g fruits and vegetables (excluding potato and starchy food) (FAO/WHO, 61) while ICMR (100) recommended for 300 g vegetables and 100g fruits per capita per day.

Vegetables are rich in dietary minerals and vitamins along with good amount of natural antioxidants. They are strong agent in improving fight against micronutrient malnutrition because (i) they are traditional part of every household diets, (ii) available worldwide with global production of 1088.8 million tonnes including India (128.2 million tonnes) (FAOSTAT, 62), (iii) successful examples of biofortification in vegetables such as sweet potato, cassava and beans, (iv) epidemiological studies shows association in intake of fruit and vegetables in risk of cancer, diabetes and cardiovascular diseases, (v) diverse vegetable species (1097) grows worldwide to add in dietary diversity, (vi) compound matrix in vegetables favours bioavailability of nutrients, (vii) great prospect for enriching further by use of diverse germplasm, and (viii) wealthier population is willing to include more fruits and vegetables in their daily diet and the regulations are coming from different agencies such as European Union Regulation No. 1151/2012 (Gragnani, 82). Human efficacy trials have shown that diets having biofortified rice (for Fe) and orange fleshed sweet potato (for Vit. A) and *sCAX1* carrot (for Ca) significantly improved respective micronutrient status in human.

Recommended dietary allowance (RDA) of dietary nutrients:

The RDAs are the levels of intake of essential nutrients that, on the basis of scientific knowledge, are judged by the Food and Nutrition Board to be adequate to meet the known nutrient needs (97-98%) of practically all healthy persons. The RDA must not be considered requirements but as levels of intake adequate for maintaining good health. The suggested intake of 300g of vegetables and 100g of fruits are almost enough to meet the RDA of most of nutrients of body as given in Table 1. However, the RDA is different from Dietary Reference Intake (DRI) which in addition to RDA, include maximum intake levels (ULs) and preferred because intake increases above the UL, the risk of adverse effects increases. The ULs have been prescribed for different compounds such as vitamin A (3000 µg/day), vitamin C (2000 mg/day), vitamin D (100 µg/day), vitamin E (1000 mg/day), niacin (35 mg/day) and folate (1000 µg/day).

Dietary minerals in vegetables

Minerals play a major role in the functioning of the physiological activities and reproduction. They are component of various body constituents such as (i) Calcium is the essential component of bones and teeth, (ii) Minerals present in blood as electrolytes like Na^+, K^+, Ca^{++}, Mg^{++}, Cl^{++}, HCO^-_3, HPO^-_4, $H2PO^=$ etc., (iii) Iron is the important component of haemoglobin. Iron content of crystalline human haemoglobin is 0.34 per cent, (iv) Phosphorus along with C, H, N and O are the components of the DNA. It is also constituent of phospholipids, and (v) Deficiency of iodine interferes with the function of thyroid gland resulting in swelling and cause goiter. Their deficiencies lead to different forms of ailments such as anemia (Iron), impaired gastrointestinal and immune functions and anemia (Zinc), osteoporosis (Calcium), goiter (Iodine). Leafy vegetables are rich source of these mineral elements, such as spinach, amaranth, *palak* or beet leaf, coriander, Indian spinach, drumstick leaves as reviewed by Natesh *et al*. (164). Interestingly, minerals have greater stability during kinds of food processing as compared to vitamins and proteins, hence, intake of prescribed quantity of leafy vegetables in daily diet is beneficial for health.

Health beneficial nutraceuticals in Vegetables

Certain secondary metabolites in vegetables have strong capacity for quenching free radicals or influencing certain biological processes and thus contribute in health promotion. These are bioactives or phytochemicals or nutraceuticals, of them, latter are certain compounds which have roles in providing nutrition *vis-a-vis* serve as medicines against ailments.

Table 1. Recommended nutrient intakes for adult males and females (data from FAO/WHO and ICMR).

Nutrient	Global (FAO/WHO)		Indian (ICMR)	
	Male	Female	Male	Female
Energy (kcal)	2900	2200	2730	2230
Protein (g)	63	50	60	55
Fat(g)	NA	NA	30	25
Vitamin A (µg retinol equivalent)	1000	800	600	600
Vitamin D (µg)	5.0	5.0	10	10
Vitamin E (mg α-tocopherol equivalent)	10	8	7.5	7.5
Vitamin K (µg)	80	65	55	55
Vitamin B_6	1.3	1.3	2.0	2.0
Vitamin B_{12} (µg)	2	2	1.0	1.0
Riboflavin (mg)	1.7	1.3	1.6	1.3
Niacin (mg niacin equivalent)	19	15	18	14
Thiamin (mg)	1.5	1.1	1.4	1.1
Vitamin C (mg)	90	60	40	40
Folate (µg)	200	180	200	200
Calcium (mg)	800	800	600	600
Phosphorus (mg)	800	800	600	600
Magnesium (mg)	350	280	340	310
Sodium (mg)	2000	2000	2100	1900
Potassium (mg)	2000	2000	3750	3225
Iron (mg)	10	15	17	21
Iodine (µg)	150	150	150	150
Zinc (mg)	10	15	12	10

NA- Not available.

Pandey *et al.* (168) classified nutraceuticals as potential and established nutraceutical compounds based on establishing their activity after clinical trials. It is to be noted that much of the nutraceutical products are still in the 'potential' category (Das *et al*., 42). The common nutraceuticals and their reported health functions are given in Fig. 1. Major attention of consumers is for carotenoids, anthocyanins, flavonoids, glucosinolates, capsaicin, oleoresins and terpenoids due to their potential health benefits. Although, vegetables are inherently rich in such compounds, but some of them lacks one or more dietary/health compounds despite their existence in respective crop germplasm. Hence, breeders explored these germplasm for potential nutraceuticals to enrich commercial varieties through classical or molecular based breeding approaches. Emphasis is towards enrichment of lycopene, vitamin C and anthocyanin in tomato, beta-carotene in cauliflower, anthocyanin and beta-carotene in carrot, glucosinolates and anthocyanin in broccoli, beta-carotene in melons and dietary minerals in leafy vegetables. Similarly, elimination/reduction of antinutritional factors also successfully attained in some of the legume and leafy vegetables.However, novel techniques in breeding and genomics have great promise in tailoring varieties for specific dietary nutrients.

Dietary nutrients for human health

Dietary fibers: Dietary fibers mostly include non-starch polysaccharides (NSP) such as celluloses, hemicelluloses, gums and pectins, lignin, resistant dextrins and resistant starches. Vegetables are rich source of dietary fibers. The soluble components of dietary fiber affect the rate of digestion and the uptake of nutrients, improve glucose tolerance, enhance insulin receptor binding and improve glycaemic response. Intake of high fiber food improves serum lipoprotein values, lowers blood pressure level, improves blood glucose control for diabetes, aids weight loss and promotes regularity. It is recommended that dietary fiber intake for adults generally fall in the range of 20–35 g/day (Pilch,

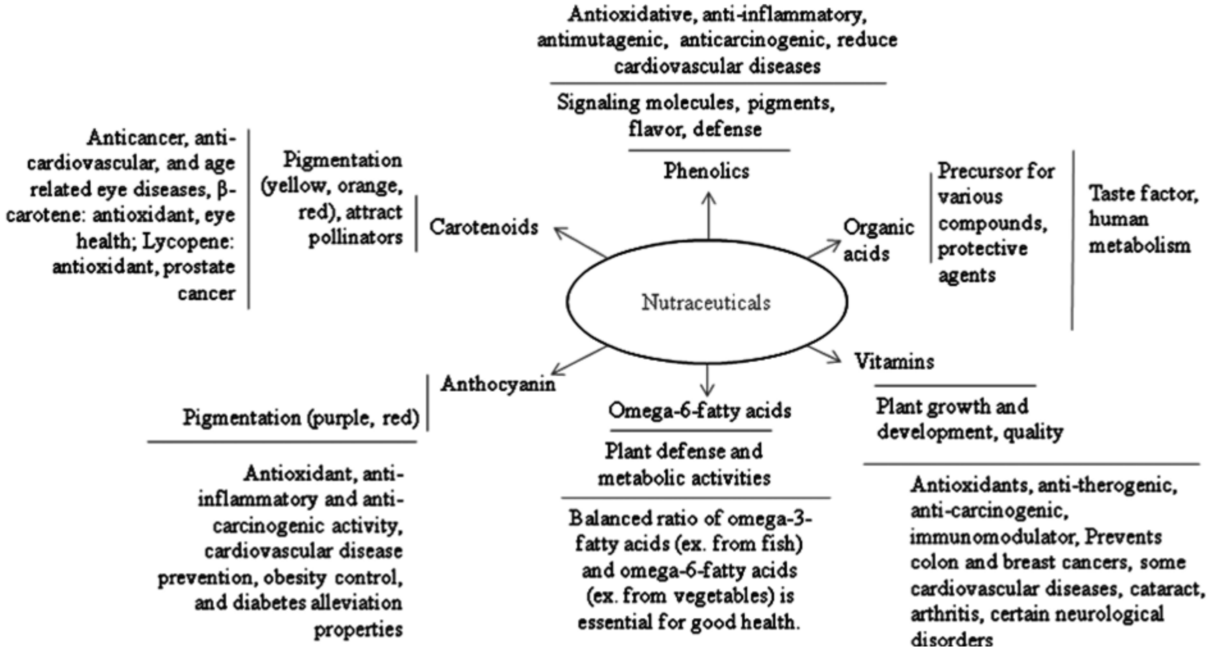

Fig. 1. Important nutraceuticals in plants (inner whorl) and their role in human health (outer whorl)

179). Curry leaves, drumstick leaves, amaranth and colocasia leaves are among the richest sources of dietary fiber in vegetable crops.

Polyunsaturated fatty acids (PUFAs): Although, all fats have important roles in the body but major concern is about those fatty acids which body cannot synthesize and depends on food. The essential fatty acids are linoleic acid (omega-6 group) and alpha-linolenic acid (omega-3 group). The FDA recommends a maximum of 3 g/day intake of EPA and DHA omega-3 fatty acids. Tender leaves of colocasia, drumstick, parsley, spinach, mustard, pumpkin, radish, Amaranth, beet leaf are good source of essential fatty acids. Further, cucurbit seeds, soybean seeds (green), leek, beans are also source for PUFAs.

Probiotics: Probiotics also represent a form of nutraceuticals which can be defined as 'live microorganisms which when administered in adequate amounts confer a health benefit on the host' (FAO/WHO, 60). They include *Lactobacilli* and *Bifidobacteria*. Savadogo *et al.* (205) found biofortification of cassava tubers with *Lb. rhamnosus*, *Lb. plantarum, Lb. acidophilus*, *Lb. reuteri*, *Lb. fermentum*, *Lb. brevis* and *Lb. salivarus* as promising option for contributing to folate intake in human body. Saubade *et al.* (203) reported that lactic acid fermentation can be explored as a tool for increasing the folate content of foods.

Most of the nutraceuticals are present across the plant families but there are specific nutraceuticals which occurs in particular groups of vegetables such as glucosinolates in *Brassicas*, Allylsulfides in *Alliums* and Silymarin in Compositae plants. The most commonly observed nutraceuticals in different vegetable groups are given in Table 2.

Vitamins in human health: Essential building block of certain coenzymes which are indispensable for the normal vital activities. All vitamins are essential for human body except vitamin D. Important source vegetables for different vitamin are given in Table 3.

Dietary antioxidants in human health

Antioxidants are basically phytochemicals or phytoceuticals naturally present in plant foods like vegetables which neutralize harmful free radicals generated in the body. These phytochemicals are secondary metabolites and formed due to the enzymatic reactions of primary metabolites (amino acids, sugars, vitamins etc.). A 'dietary antioxidant' is a substance in foods that significantly decreases the adverse effects of reactive oxygen species (ROS) and reactive nitrogen species (RNS) on normal physiological function in human beings and prevents from related health ailments. The ROS free radicals are super oxides, hydroxyperoxyl (HO_2), hydroxyl (OH), peroxyl (RO_2) and alkoxyl (RO) while common RNS are nitric oxide ($NO^•$) and peroxynitrite ($ONOO^•$). The free radicals are generated either from normal metabolic processes of body or from external sources (X-rays, ozone, smoking, air pollutants). They target

Table 2. Vegetable crops rich in nutraceuticals/bioactive compounds.

Nutraceuticals/ bioactive compounds	Vegetables
Allylsulfides, Fructan	Allium vegetables (garlic, onions, chives, leeks)
Glucosinolates	Brassica vegetables (broccoli, cauliflower, cabbage, Brussels sprouts, kale, turnips, kohlrabi)
Lycopene	Tomato, red carrot, water melon, seed aril of *Momordica* vegetables
Polyphenols	Potato, brinjal, okra, leafy vegetables, onion
Anthocyanin	Black carrot, beet root, red amaranth, red lettuce, red cabbage, brinjal
Carotenoids	Leafy vegetables, carrot, orange cauliflower, orange flesh sweet potato and cassava, muskmelon, pumpkin
Flavonoids, carotenoids, apigenin	Apiaceae (Celery, parsley carrot)
Silymarin	Compositae plants (artichoke)
Folate	Chenopodiaceae (spinach, swiss chard, beet greens)
Flavonoids (isoflavones)	Beans

Table 3. Functional/deficiencies of nutrients in human body and their potential source vegetables.

Dietary nutrients	Function/deficiency	Rich vegetable sources (per 100 g edible portion)
Carbohydrate	Source of energy Protein sparing food	Potato (22.6 g), sweet potato (27.0g), cassava (32.4g), elephant foot yam (18.4g), taro (21.1g), pea (15.8g), lima bean (23.5g)
Protein	Body building mainly for tissues, muscles and blood, deficiency leads to kwashiorkor disease.	Pea (7.2g), cowpea (4.3g), broad bean (4.5g), lima bean (7.5g), leaves of fenugreek (4.4g), drumstick (2.5g), Brussels sprout (4.4g)
Fat and oil	Source of energy, part of colloidal complex of cytoplasm	Chilli (0.6g), sweet pepper (0.3g), brinjal (0.3g), Brussels sprouts (0.5g), snake gourd (0.3g), pointed gourd (1.0g), sweet corn (0.3g), Bengal gram leaves (1.4g), bitter gourd (1.0g)
Vitamin A (xerophthol, retinol)	(i) Night blindness (nycalopia), (ii) xerophthalmia in infants and young children causing keratinisation in epithelial cells of eyes (iii) Dryness in skin	Carrot (12000 IU), amaranthus (9200 IU), *palak* or beet leaf (9770 IU), spinach (9300 IU), fenugreek leaves (3744 IU), mustard leaves (4195 IU), coriander leaves (11168 IU), broccoli (3500 IU), musk melon (3420 IU), kale (7540 IU)
Thiamine	Beri-beri, mascular weakness and loss of weight, neuritis, fluid in body cavities (oedema) and impaired function, dilation of heart and loss of appetite	Potato (0.40 mg), *Palak* or beet leaf (0.26 mg), pea (0.25 mg), tomato (0.19 mg), chilli (0.19 mg), muskmelon (0.11 mg), garlic (0.16 mg), leek (0.23 mg), coriander leaves (0.50 mg)
Riboflavin	Dark red inflamed tounge, dermatitis (inflammation of skin), loss of hair and dry scaly skin, diarrhoea, cracks in corners of mouths, ulcers in oral cavity, cracked lips	*Palak* or beet leaf (0.56 mg), chilli (0.19 mg), winged bean (0.12 mg), knol khol (0.10 mg), broccoli (0.12 mg), Brussels sprouts (0.13 mg)
Niacin	Pellagra, nervous breakdown, stomach and intestinal disorder	*Palak* or beet leaf (3.3 mg), amaranth (1 mg), bitter gourd, giant spine gourd, pointed gourd, bottle gourd, pumpkin (0.5-0.9 mg)
Ascorbic acid	Scurvy (dropsy, anaemia, bleeding gums, and mucus membranes), delayed healing of wounds, reduced resistance to diseases	Sweet potato, chilli, cabbage, broccoli, kale, drumstick, coriander leaves, cauliflower.
Folic acid	Anaemia (megaloblastic) more acute in pregnant women, impaired growth and nervous breakdown	*Palak* or beet leaf, lettuce, cabbage, spinach, cowpea, French bean

Contd...

Table 3 contd...

Dietary nutrients	Function/deficiency	Rich vegetable sources (per 100 g edible portion)
Tocopherol	Degeneration of kidney, necrosis of liver, reduction in capacity of reproduction	Zuccini (Green) (3.90 µg), Zuccini yellow (1.47 µg), Agathi leaves (1.48 µg), Spinach (1.27 µg), Onion (0.81 µg), Cluster bean (0.77 µg)
Phylloquinones (Vit K)	Delayed and faulty coagulation of blood cut wounds, hindrance in normal secretion of bile from liver	Drumstick leaves (479 µg), *Amaranths spinosus* (433 µg), Fenugreek leaves (428 µg), Drumstick (358 µg), Spinach (325 µg), Parsley (322 µg)
Ergocalciferol (Vit D_2)	Useful against hypoparathyroidism and rickets	Baby corn (31 µg), Drumstick leaves (14 µg), Cluster bean (13 µg), Tomato (12 µg), Pea (12 µg), Broad bean (11 µg)
Lutein	Maintaining eye health and reducing the risk of macular degeneration and cataracts	Agathi (12941 µg), Drumstick leaves (15580 µg), Spinach (3850µg), Parsley (3574 µg), Fenugreek leaves (2275 µg)
Zeaxanthin	Eye health	Agathi leaves (559 µg), *Amaranthus gangeticus* (164 µg), Sweet potato (146 µg), Fenugreek leaves (28 µg), Pumpkin (34 µg), Zuccini yellow (25 µg)
Lycopene	Antioxidant, protect against sunburns and certain types of cancers	Tomato hybrid (2481 µg), tomato green (35 µg), watermelon dark skin (1477 µg), watermelon pale green (1257 µg)

(Source: Longvah *et al*. 141; Hazra and Som, 215)

DNA, proteins, lipids and carbohydrate and contribute to the development of chronic diseases such as macular degeneration, antherosclerosis, cancer, coronary heart diseases and rheumatoid arthritis. Although, body has its own redox homeostasis mechanism to neutralize free radicals but to a certain extent, afterwards, it need antioxidants from external sources to assist scavenging process. The antioxidants neutralize free radicals through different mechanisms: (i) Decreasing ROS or RNS formation, (ii) binding metal ions needed for catalysis of ROS generation, (iii) scavenging ROS, RNS, or their precursors, (iv) up-regulating endogenous antioxidant enzymes defenses, (v) repairing oxidative damage to biomolecules such as glutathione peroxidases or specific DNA glycosylases, (vi) influencing and up-regulating repair enzymes, and (vii) reacting directly with free radical in a non-catalytic manner before the radicals react with other cell components. However, the effectiveness of each dietary antioxidant depends upon (i) which ROS or RNS is being scavenged (ii) how and where they are generated, (iii) the accessibility of antioxidants to this site, and (iv) what oxidizable substrate is involved.

The evidences showed that lycopene, beta-carotene, ascorbic acid, α-tocopherol, flavonoids and selenium are significantly associated with reduced cancer risk. Vitamin E, vitamin C, carotenoids, anthocyanins and phenolics are able to neutralize free radicals and inhibit LDL oxidation and potentially reduce the risk of coronary artery diseases.

Carotenoids: Carotenoids play an important role in plant reproduction, through their role in attracting pollinators and in seed dispersal, and are essential components of human diet. Lycopene, α-carotene, β-carotene and xanthophylls are common carotenoids from vegetables. Carotenoids provide protection to vision and eye function, and against macular degeneration and cataracts. They promote immune system response and presumed to be associated with inhibition of several types of cancers including cervical, oesophageal, pancreatic, lung, prostate, colorectal and stomach.

Phenols: Phenols or phenolics are secondary metabolites and often found in polymeric forms (polyphenols). Phenolics have role in human health due to antioxidant properties (reducing or metal chelating agents, hydrogen donors and singlet oxygen quenchers) and alternative mechanisms (cellular signaling, gene expression and modulation of enzymatic activity). Habauzit and Morand (91) reviewed the evidences for protective effect of phenolics. Besides, phenolics may also affect sensory characteristics of food with impacts on colour, flavour and astringency. Major polyphenols are flavonoids, phenolic acids, tannins (hydrolysable and condensed), stilbenes and lignans.

Flavonoids: The basic flavonoid structure is the flavan nucleus, which consists of 15 carbon atoms arranged in three rings (C6-C3-C6), labeled A, B, and C. Important flavonoids in vegetables are quercetin, kaempferol, myricetin and lutein. Onion, kale, broccoli, green beans and celery are rich in flavonoids while tomato, red pepper and broad beans are medium.

Anthocyanins: When the anthocyanidins are found in their glycoside form (bonded to a sugar moiety), they are known as anthocyanins (Castaneda-Ovando *et al.,* 23). There is a substantial variety of anthocyanins spread in nature. They are water-soluble pigments and impart red (in low pH), purple, and blue (in high pH) colour which are influenced by pH, light, temperature, and structure. Around 600 types of anthocyanin are reported in nature but cyanidin (magenta/purple - red sweet potato, purple corn), delphinidin (blue-reddish or purple; blue hue of flowers), pelargonidin (red to fruits and berries and orange hue to flowers), peonidin (magenta in berries, grapes, and red wines), malvidin (purple in blue-colored flowers, red to dusty red in wine), and petunidin (dark red or purple in blackcurrants) are the most common distributed in the plants. Cyanidin-3-glucoside is the major one found in most of the plants. They possess antioxidative and antimicrobial activities, improve visual and neurological health, and protect against various non-communicable diseases through different pathways i.e., free-radical scavenging pathway, cyclooxygenase pathway, mitogen-activated protein kinase pathway, and inflammatory cytokines signaling. Black carrot, red cabbage, purple broccoli, cauliflower, beet root, purple potato, purple amaranth and purple lettuce are rich source of anthocyanins. Improvement of anthocyanin through conventional breeding has been done in carrot (Pusa Asita), red cabbage (Kinner Red), purple heading broccoli (Palam Vichitra). Transgenic approach showed potential to enrich anthocyanin(70-100 fold) in tomato by the use of two transcription factors having fruit specific expression from *Delila* and *Rosea*1 isolated from *Antirrhinum majus* (Maligeppagol *et al*., 145). In tomato, *Aft* gene causes higher level of functional flavonoids quercetin and kaempferol in and *Ant1* gene encodes a *Myb* transcription factor and a DNA marker showed *Aft* trait is encoded by a single locus on chromosome 10 fully associated with *Ant1* (Sapir *et al*., 200).

Organosulphur compounds: Thiols are sulphur containing compounds in garlic and cruciferous vegetables. Allyl sulfides in onion and garlic are product of enzyme allicin activity on alliins and lowers bad LDL cholesterol and triglycerides and increase good HDL cholesterol in blood. They have antibacterial, antiviral, antifungal and antirheumatic properties and protect against asthma, pneumonia and gastrointestinal disorders. Allyl sulfides possess antimutagenic and anticarcinogenic properties and provide cardiovascular protection.

Chlorophylls: Chlorophyll is the most important plant pigment and a ‘real life force’ that nature uses to explode plants into greenery. The anti-mutagenic properties of chlorophylls have been demonstrated in various assays, and clearly intake of chlorophyll has potential to act as a chemo-preventive compound in humans. Green leafy vegetables, broccoli, cabbage and Brussels sprout are good source of chlorophyll.

Glucosinolates: Glucosinolates play an important role in plant defense for diseases and specialist insects (Agrawal and Kurashige, 2) and they also implicate strong influence on human health. Sulforaphane and iberin show stronger anti-carcinogenic activity than other isothiocynates (Faulkner *et al*., 64). But, few breakdown products such as cynogenic glucosinolates and progoitrin cause goitrogenic effect and reduce meal palatability (Chandra *et al.,* 26; Cartea *et al*., 22). High content of gluconapin, progoitrin, glucobrassicin and neoglucobrassicin produces bitter or pungent isothiocynates may affect consumer preference (Schonhof *et al.,* 206). Total glucosinolates content in leaves ranges from 46 to 87 µmol/g dw (Menard *et al.,* 151). They also reported wide variation in individual Glucosinolates, such as Sinigrin (5.7 – 12.9 µmol/g dw), Glucoiberin (0.5 – 6.6 mg/100 g fw), Glucoibervirin (0.6 – 2.9 mg/100 g fw) and Indole (15.2 – 24.9 mg/100 g fw), which are comparable with total glucosinolates (0.6 – 35.6 mg/100 g fw and Glucoraphanin (0.8 – 21.7 µmol/g dw) and Indole (0.4 – 6.2 µmol/g dw) in green broccoli (Kushad *et al.,* 127). Already, *CYP79* and *CYP83* gene families in *Arabidopsis* and *GS-ELONG*, *GS_OX*, *GS-ALK* and *GS-OH* loci in different Brassicas have been reported to be involved in glucosinolate biosynthesis. Accumulation of aliphatic glucosinolates is mainly regulated by genetic factors while environment and environment x genotype interaction affects indole glucosinolates in broccoli (Brown *et al.,* 15). Efforts were made to develop lines having high glucoraphanin along with agronomically acceptable traits through conventional breeding (Farnham *et al.,* 63*;* Sarikamis *et al.,* 201). Indoles also bind to chemical carcinogens and activate detoxification enzymes mostly of gastrointestinal tract.

Germplasm evaluation for nutritional traits

Germplasm screening for donor source is prerequisite for breeding programme which can be done by visual observation, organoleptic scoring, measurements and laboratory analyses. Visual in full daylight or incandescent light and organoleptic selection under optimal condition need expertise of breeder and feasible to improve quality up to certain extend as in case of carrot for carotenoids (up to 120 ppm) while measurement and laboratory analyses are main basis for quality traits. Similarly, selection for different situations such as fresh, processing/ canning items and storage life need specific traits and their measurements. Tomato germplasm ranged from 6.64 to 90.37 mg kg^{-1} and 25.7 to 329.9 mg kg^{-1}, respectively in Onam (Al Said *et al*., 3), total titrable acidity varied from 0.20 to 0.64%, whereas the TSS ranged from 3.4 to 9.0% (Panthee *et al.,* 170), β-carotene from 0.11 to7.79 µg g^{-1} FW), trans-lycopene (0.19 - 193.17 µg g^{-1} FW) (Ruggieri *et al.,* 195). In watermelon, lycopene ranges from 10 to 81 µg. g-1 fresh weight (Davis *et al.,* 44). Carrot germplasm also varied for carotenoids (1.25 - 254.3 mg/100g DW) and β-carotene (0.08 - 136.5 mg/100 g DW) (Jourdan *et al.,* 110). Brinjal fruits are good source of anthocyanin and whole fruit contained anthocyanins in the range of 0.55-88.24 mg/100g (Kumari *et al.,* 126). In Chilli, the pungency was ranged from 272897 to 1037305 SHU in *C. chinense*, 109508 to 487619 SHU in *C. frutescens* and 0 to 203731 SHU in *C. annuum* (Sarpras *et al.,* 202). Glucoraphanin is anti-cancer glucosiolates and its concentration was ranged from 0.8 to 21.7 micromol g^{-1} DW in broccoli (Kushad *et al.,* 127). In spinach, wide variation has been shown in germplasm for oxalic acid, nitrate, vitamin C, lutein, carotenoid and phenolic content. Oxalate content in spinach was ranged from 5.3% to 11.6% on dry weight basis (Mou, 161). Vegetable amaranth also had variation for nitrate (1.8 to 8.8 g kg^{-1}) and oxalate (5.1 to 19.2 g kg^{-1}).

Quality traits and their genetics in common vegetables

In vegetable crops, the quality attributes are grouped as (i) intrinsic quality attributes which are inherent to the product itself and provide stimuli to consumers such as sensory attributes (flavour, taste, appearance, colour, texture and smell) and health attributes which are concerned with nutritional and health-promoting values, and (ii) extrinsic quality attributes are linked to the production method but not a property of the food itself like pesticides, eco-and animal friendliness, packaging materials, processing technology which can influence the purchasing policy of some consumers. The extrinsic quality traits are not directly related to the product performance or core benefit of the product but contribute in general benefit of product and add value. Further, extrinsic quality can be grouped in narrower sense (characteristics that are perceptible through the product itself *i.e.,* packaging, colour, brand name, price, country of origin) and broader sense (characteristics which are conveyed through marketing instruments such as distribution, communication policies, advertising and pricing). The intrinsic quality traits are generally complex in nature, hence, modern high-throughput biochemical and molecular analytical tools and techniques have great potential to handle complex traits with shorten breeding cycles. The complete changes in the intrinsic traits in short period is because they are largely governed by genotypic factor and production manner. The breeding objectives for quality traits in major vegetable crops are given in Table 4. The quality attributes and their genetics have been summarized crop wise from available literature hereunder and details of genes involved, type of gene action in respect of quality traits in different vegetable crops are given in Table 5.

Tomato: High lycopene, high TSS (5.5°Brix or higher because high TSS gives mores cases of finished products per tonne of raw fruit and, thus, require less energy in concentrates), lower titrable acidity as percentage of citric acid (0.4-0.5 %), carotene, solid/acid ratio of 15, sugar /acid ratio of 8.5, pH value (for processing ≤ 4.35 because longer time required if pH increases) and flavour (2-isobutylthiazole, methyl salicylate and eugenol). Total acidity and pH are not always closely related due to difference in degree of buffering of unknown volatile constituents of pH by other fruit constituents of unknown volatile constituents). Vitamin C ranges from 10-120 mg/100g fw but high Vitamin C is pleotropic on small fruits. *Solanum cheesmanii* (15%) and *S. chmielewiskii* (10%) are sources for total solids while *S. peruvianum* is source of high sugar and vitamin C while *S. pimpinellifolium* for high acidity gene. Carotene in tomato is governed by og^c (old gold crimson gene) and *hp (*high pigment) gene. The og^c increase lycopene but reduce carotene by 25% while increases total carotenoids and vitamin A by 25-50%. The *B*-gene increases β-carotene at the expense of lycopene and result orange fruits with 8-10 times higher than red fruited ones. However, pleotropic effect of high ascorbic acid is pleotropic to size of fruit and of *hp* gene on slow germination and growth, premature defoliation, yield and fruit size.

Potato: Processing ability, uniformity of tuber shape (round long) and size, eye depth and distribution, incidence of growth cracks and growth irregularities, skin smoothness, appearance of final product, texture and flavour (glyalkaloids), flesh colour (white, yellow and cream).

Brinjal: Fruit colour (purple colour is dominant over green and cream fruit) is complex trait and monogenic, digenic and trigenic 3 complimentary genes (*Pfb*, *Pfb1* and *Pfb2*), shape (elongated over round and round over oval by 3 or 4 genes), flavour (glyalkaloids – solasonine and saponin). Tigchelaar *et al*. (229) identified nine genes that determine anthocyanin development and distribution in eggplant, three independent complementary factors *D (*four alleles *D* in order of dominance, *d* inhibits anthocyanin in fruit only, d^t in fruits and dilutes flower color and *dw* in all plant parts*)*, *P*, and *Y* cooperate to affect anthocyanin development in the corolla, hypocotyl

Table 4. Objectives specific to quality traits for use in breeding of vegetable crops.

Tomato	Fresh market - Appearance : fruit shape (oblong or square round), size or weight (80-90 g), smoothness (without ribs), stylar or blossom end rot smooth without any depression or scar; Fruit colour- uniform, red and deep red; Fruit firmness, a desirable trait for good transportability and long shelf life; Pericarp tissues has more sugars than the locular tissue. Acid content in locular tissue has predominant influence on fruit flavour. Processing traits: High TSS (5.5 °Brix or higher) because high TSS gives mores cases of finished products per tonnes of raw fruit and thus require less energy in concentrates). Acidity: pH (below 4.35; because longer time required if pH increases) and low titrable acidity (as percentage of citric acid) and 0.4-0.5 % Solid/acid ratio of 15, sugar /acid ratio of 8.5 Flavour (2-isobutylthiazole, methyl salicylate and eugenol); High vitamin C (but high vitamin C is pleiotropic on small fruits)
Chilli	Fresh market: Fruit shape, size, number of lobes (in sweet potato), colour, pungency, flavour, exocarp thickness, endocarp, seed ratio, vitamin A and C. Fresh processing (sauce, paste, canning, pickling): fruit colour, pungency, flavour, pericarp thickness, endocarp: seed ratio. Dried shape (whole fruit or powder): colour of dried fruits, pungency, flavour, dry weight recovery, low crude fibre, endocarp: seed ratio. Oleoresin extraction – essential oils (colour, pungency).
Brinjal	Fruit shape, size and colour (glossiness) Fruit quality: thickness, texture, flavour, seediness (less seeds), soft flesh and keeping quality. Lower solanine content (i.e. 400 mg is harmful), high anthocyanin, chlorogenic acid.
Potato	Physical – shape (round), size (medium), shallow eyes, colour Nutritional – dry matter content, reducing sugar, low glycoalkaloid content (20 mg/100g fw), high vitamin C and protein content Potato chips: long-term storage, round or oval shape, 40-75 mm in size. Dry matter (21-25%), starch (16-20%), reducing sugar (<0.25%) uniformly distributed in cross-section. French fries: Oblong, or oval in shape, size >70 mm. Dry matter 20-23%, 15-18% starch, reducing sugar (0.3%) distributed equally to avoid 'sugar end' effect in fries. Processing ability, uniformity of tuber shape (round long) and size, eye depth and distribution, incidence of growth cracks and growth irregularities, skin smoothness, appearance of final product, texture and flavour (glyalkaloids), flesh colour (white, yellow and cream). High specific gravity (dry matter content) suitable for French fries, chips and dehydrated products
Cabbage	Head shape spherical or round (polar and equatorial dia. ratio 0.8-1.0) and drum or flat head (p.e. 0.5-0.6), conical head (p.e. 1.0), medium size head (1.0 kg or 0.8-0.9 kg), head compactness, green heads for fresh market and white leaves are preferred for coleslaw. Short core (< 25% of head diameter). Narrow and soft core is desirable for processing. Reduced content of goitrogenic glucosinolates and higher content of desirable GLSs for good flavour and anti-carcinogenic effects
Cauliflower	Curd colour, curd compactness, curd depth, curd shape, self-blanching. Lowering of goitrogenic or adverse glusocinolates and increase of health beneficial Glucosinolates
Knol khol	Round, medium-sized knobs of desired colour-green or purple, low fibres and creamy white to greenish white flesh in tubers. Enriching vitamin A and anthocyanin content. Lowering of goitrogenic or adverse glusocinolates and increase of health beneficial glucosinolates
Broccoli	Fine buds, attractive green or purple heads, compact smooth heads, health beneficial Glucosinolates, increasing vitamin C, anthocyanin and vitamin A and minerals.
Carrot	Colour (red or orange), size, length and girth (diameter), shape (cylindrical, uniformly tapering or stump rooted, broad or narrow shoulder), non-branching and non-forking, smooth surface without fibrous in roots, thick flesh, thin self-coloured core, high carotene and high sugar and dry matter in roots, good flavour and taste.

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Table 4 contd...

Beet root	Uniform size, shape and colour, uniformly coloured roots without roots without internal zoning or white rings.
Turnip	Root shape, size, colour of skin and flesh and their uniformity
Radish	Root length, shape and colour, pungency, taste and edible quality, late pithiness, non-forking roots.
Onion	Fresh: Bulb size, shape, colour, pungency, firmness, single centre, rings per bulb, ring thickness, narrow neck, dormancy, dry matter (>15% for white onion for dehydration; 9-13% in onion for fresh consumption). Low solid/high water content is good for fresh use. Dehydration: Snow white colour, globe shaped bulbs, thick neck, free from greening and moulds, high pungency and high TSS (>18%) and low reducing sugar that reduces caking and deterioration of the colour during storage.
Garlic	Bulb size index, bulb colour, clove colour, clove shape (sickle), number of cloves, clove diameter, TSS, dry matter
Leafy vegetables	Attractive leaf colour, succulent stem, less fiborous, crispiness; Higher vitamin A content and folate, good flavour, taste; Plants with lower level of antinutrients (nitrate, oxalate); Optimum leaf/stem ratio (>1.0)
Okra	Pod quality – medium length, not much thick, dry matter and weight and pods, smooth pod surface without much pubescence, number of ridges- preferably five, pod colour – dark green or shining green, and longest keeping quality, Iodine content
Cucumber	Fruit colour – light green, green or white depending upon consumer's preference; Shape – uniformly cylindrical fruits without thin or crook neck or bulged blossom end; Size – depending upon consumers' preference and usage, preferably medium-long for slicing and small for pickling Spines- few or none, preferably white; Skin – smooth without warts; Seeds - few and immature at edible stage of fruits. Bitter free fruits Edible fruit without carpel separation
Pumpkin	Thick fruit flesh and small seed cavity; Round /oblong/flat round fruit shape; Small size fruits for nuclear families and big fruits for packing foods, orange flesh colour, rich in β-carotene.
Muskmelon	Fruit quality- shape, size, epicarp/skin colour and surface (smooth, sutures, netted); Flesh thick and attractive colour; Seed cavity, preferably small; Sweet taste, musky flavour, juiciness and high TSS (Not less than 10%; 11-13 %).Good keeping quality and transportability.
Watermelon	Fruit shape (round/oblong), size/weight (large, medium or small), Skin/rind: (tough, thickness, resistance to cracking, colour green, dark green or light green, striped or without stripes); Intermediate fruit shape advantageous because long fruits are prone to gourd neck fruits and round fruits to 'hollow-heart'; Flesh: firm, colour – attractive red, pink or yellow Seeds: smaller and fewer. TSS (more than 10%), Transportability and shelf-life.
Bitter gourd	Fruit size: ranges from 7-40 cm but medium size fruits (10-15 cm) are preferred; Fruit shape: uniformly medium thickness but thick fruits are required for stuffing; Surface: warty (with tubercles), or smooth or smooth with continuous or broken ridges. Fruits having smooth surface and continuous smooth ridges are preferred in many places. Fruit colour: White, light to dark green. White are preferred in Tamil Nadu, Karnataka and Maharashtra. Green or light green in Bihar, eastern Utter Pradesh and West Bengal and dark green that having long shelf-life/keeping quality are preferred in most places. Less number of mature seeds at the time of marketable stage; Bitterness: small fruited common in West Bengal and Bihar are very bitter. Medium-bitter fruits are more common in many parts of country. Increase antidiabetic constituents.
Sponge gourd and Ridge gourd	Shape: Uniformly cylindrical, medium-long fruits; Colour – whitish green, light green and dark green in sponge gourd and light to dark green in ridge gourd; Size: 25-30 cm in smooth gourd and 30-35 cm in ridge gourd Non-bitter fruits; Tender and non-fibrous fruits at marketable stage

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Table 4 contd...

Bottle gourd	Fruit shape varies as long, round, oval, club and dumble shaped; General preference for long, uniformly cylindrical, without neck and medium-long or spherical fruits are preferred; Surface : glossy green surface, pubescent with sparse hairs in immature fruits at marketable stage; Fruits should be non-bitter, non-fibrous flesh and less of immature soft seeds at marketable stage
Garden pea	Shelling percentage (30.7-56.4%); Pod colour, size, apex (blunt or pointed) and shape (straight or curved); Seed size (100 seed weight), seed colour (greenish white or yellowish), shape like round, dimpled or wrinkled (26-33% protein) or smooth (22-31% protein); Starch content in wrinkle seeded about 46.3%) and sweeter than smooth seeded (33.7%); Smooth seeded have hard texture and less flavour; Suitability for canning, dehydration (large sized wrinkled and dark green seeds) and freezing; Low content of antinutrients
Cowpea	Pods stringless, less fibrous, spongy inner pod walls with wide spaced seeds in the pods.
French bean	Fresh market: Pod shape- flat or round; Pod length/size, preferably smooth, stringless, straight, without curve, fleshy; Pod colour- light green, medium green or dark green; Pod wall fibre enough to retain its shape and fresh appearance for 7-10 days after harvest; Pods free from interlocular space and flat pods are preferred for fresh market, seed size/100 seed weight; Number of seeds per pod, seed colour, pod width (8.3-9.5 mm); Preference : High carbohydrate content, a pH of 8-8.5 and an alcohol insoluble solids content <8.5%; High protein content in seeds , Ca and Fe; Low content of antinutrients – tripsin inhibitor; Phytochemicals- L-3,4-dihydroxyphenylalanin (L-DOPA), C-DOPA, flavonoid quercetin, myrcetin, catechin, inositol hexaphosphate (IPC) and inositol pentakisphosphate. For canning – light or medium green, round fleshy, stringless pods with small white seeds, slogging free, short pods for whole pod processing. For freezing – Bright green, round or flat pods, stringless, small sized pods for freezing whole pod.

and fruit. Other genes *Ac* (convert delphinidin-3-rhamnoglucoside to nasunin), *Puc* (pigment under the calyx), *Sa* (anthocyanin stripe on the anthers), Dil_1 and Dil_2 (affect color intensity) and *R* (inhibits fruit pigmentation in certain genetic backgrounds) genes affects pigmentation in fruits and other parts.

Chilli: Fruit size (small>large; 30 genes), fruit shape (oval > elongated; polygenes), pungency (capsaicin by a single dominant gene *C* but degree is influenced by polygenes; high and dry temperature increases capaicin content) and fruit colour are red, brown and green (red > brown, single gene). Role of chlorophyll retainer gene [*cl(g)*] plays role in preventing complete degradation of chlorophyll. Chlorophyll and red pigment lycopene (genes y^+) produce brown fruits and genetic constitution of yellow colour ($yycl^+cl^+$), brown (y^+y^+clcl), red ($y^+y^+cl^+cl^+$) and green ($yyclcl$). Yellow or orange mature fruits colour is dominant trait and governed by *Y* gene. Beta-carotene in fruits is governed by *B* gene which interacts with *t* gene for higher levels.

Garden pea: Pea have two main classes of storage proteins as 11S (legumin) and 7S (vicilin, convicilin) in wrinkled (26-33%) and smooth (23-31%) seed types. Sugar is also high in wrinkle seeded (10-13%) (*RRrbrb*; *rrRbRb*) than round seeded (6-7%) (*RRRbRb*). But, they are low in methionine and also in cystine. *Pisum abyssinicum* and *P. fulvum* are good source of cystine. Inheritance of protein content is complex and polygenic governed trait.

Beans: In French bean, small seed size, dark pod colour, raw-pod quality, pod length, better holding capacity, percentage of pod fibre content and flesh firmness are important traits. Straight, smooth, round, uniform internal and external colour, flavour, texture, carpel separation, skin sloughing, interlocular cavitation, internal tissue breakdown. A single dominant gene is responsible for the inheritance of high Zn content in seeds (Cichy *et al.*, 31). In Faba bean, seed protein, amino acid composition and antinutritive factors are important attributes and they have additive effect with some partial dominance. Larger string free pods, attractive cooking and taste qualities are quality traits in vegetable cowpea. While in Lima bean, Agglutining activity and HCN production are of major concern.

Watermelon: Fruit shape is qualitatively inherited trait with one pair of alleles (round: elongated) with modifiers and elongate spherical. Fruit size is governed by polygenes (25 genes) and Poole and Grimbell (181) reported that 2-3 genes alongwith modifiers influence flesh colour. Red flesh colour (*YY*) is dominant over yellow (yy), white (*WY*) over canary yellow (*C*) and red, golden yellow flesh over red flesh. WR governed orange colour and white is epistatic to yellow. In *C. colosynthesis* x *C. lanatus*, white (*Wf*) colour is dominant over red flesh (*wf*) colour. Dark rind colour is dominant over light green or grey colour and stripped over solid light green colour. Total solids content is governed by three incompletely dominant genes. Bitterness in *C. colosyntheisis* is dominant over non-bitterness and governed by a single gene, however, Su^{Bi} acts suppresser of bitterness.

Muskmelon: Yield (earliness and concentration), fruit appearance (shape, size, colour, smoothness, flesh colour), flesh sweetness (TSS >9%), texture, aroma, firmness, colour and rind (hardness, thickness, netting).

Pointed gourd: Fruit colour, small seed content, greater pulp content and prolonged shelf-life are important quality traits. While in **bitter gourd** vitamin C, Iron, fruit colour, texture, tuberacles, taste and flavour are breeding targets.

Leafy vegetables: Attractive dark colour, high in nutrients such as iron, calcium, beta-carotene and anti-nutritive traits nitrate, oxalate, phytate and saponin. In coloured vegetables, high intensity of colour is a preferred trait.

Radish: Attractive colour, non-pithy, more in sugar and low in pungency (fresh – less; cooked/salted – high), elaboration of the cell, water content, pore extent. In turnip, two independent genes controls purple skin colour and flesh colour is monogenic and white is dominant over yellow.

Beet root: Colour is qualitative and quantitative and roots hypocotyls and petioles are red (*R_/Y_*), yellow (*rrY_*), white and red hypocotyls (*R_yy*), yellow hypocotyl and white root (*rryy*). The *R* locus has five alleles (*R*, R^t, *r*, R^p and R^h) and three alleles at *Y* locus (*Y*, Y^r and *y*). The red hypocotyl is R^HY and striped petiole is R^t without Y and Y^r for pigment only in roots. Quantitative differences in colour of red beet root are determined by the ratio of violet betacyanin to yellow beta-xanthin pigments which is governed by three alleles at *R* locus. High, medium and low ratio have violet, red and orange colour, respectively.

Cucumber: Skin colour, spine colour, presence or absence of warts and spines, fruit shape. Flesh firmness, skin tenderness and seed cavity. Bitter free (lacking cucurbitacin) is governed by *bi* gene. Parthenocarpy is governed by *Pc* and yellow green immature fruit colour and yellow flesh by *yg* and *yf* genes, respectively.

Squash: Single recessive allele (*n*) determines naked seed but modifying gene may influence it. Softness is due to inhibition of thickening and lignification of the cell walls of testa. Orange skin and deep orange flesh colour are preferred traits.

Onion: Five genes *C*, *R*, *G*, *L*, *I* governed onion bulb colour and of them are, red (*iiC_R_*), yellow (*iiC_rr*), homozygous recessive white (*iiccR_*, *iiccrr*), homozyhous dominant white (*II_ _*) and heterozygous dominant white or buff or off-white (*Ii_ _*). Pink colour occurs when cross is attempted between two homozygous yellow bulbs which creates bulb colour. Further, two additional genes G (golden bulb) and L also causes variation in onion bulb colour. Golden colour bulbs developed during presence of a dominant allele at *G* locus. Three loci on chromosomes 3, 5 and 8 govern amount of fructans, fructose, glucose and sucrose and *Frc* on chromosome 8 is responsible for fructan content.

Cabbage: Red colour in cabbage is governed by several factors and quantitatively inherited. The F_1 cross between green × dark red resulted pink plants. The gene *M* produces magenta and *S* gives purple on upper side of the leaf. Savoy leaf texture is high yielding, contains more dry matter, better flavoured and less gas producing and controlled by three or more genes. Storability and eating are contrasting traits because very late cultivars storage leaves are very hard and tough. Dry matter in early type (6%) is positively correlated with later maturity (10%) and is a quantitatively inherited trait.

Carrot: Important quality attributes are carotenoids, anthocyanins, lutein, fibre, texture, sugars, flavour, minerals and toxicants. Carrots have xylem, phloem and vascular cambium and their colouration is governed by different genes. Predominant colours are orange, red, black and pale for xylem. However, self-core roots are preferred but different colour combinations are made by combining gene combinations. Genes responsible for xylem colour were reported to be *O* for orange, *P-1* and *P-2* for purple and *y* for yellow. *Y-1* and *Y-2* governed differential xylem/phloem levels. Sugar quantity, total dissolved solids and dry matter content are quantitatively governed traits. A dominant locus *Rs* controls the ratio of reducing sugar (glucose and fructose) to sucrose, independent of total sugar. Harsh flavour is due to volatile terpenoids and quantitative trait, but mild flavour is dominant.

High throughput techniques for quality assessment

Measurement of most of the quality traits is laborious, time consuming and costly practice. However, recent developments in tools and techniques in food analysis have opened new arena having high throughput capacity for such analysis which are rapid, cost effective and relatively easy or automated.

Table 5. Classical studies on Genetics of quality traits in different vegetable crops.

	Quality traits	Number of genes	Type of Gene action	References
Potato	Skin colour	Digenic (D-R-)	Complementary *D_R_* Red; *D_rr,* White *dd R_* White; *dd rr* White	De Jong (45)
		Three independent loci	*D* (red), *R* (tuber-specific regulation) and *P* (purple)	Van Eck *et al*. (239)
		Single dominant gene	*S. tuberosum* anthocyanin 2 (*Stan2*) is an R_2R_3 MYB domain gene in the anthocyanin pathway that co-segregates with the D locus and is associated with the synthesis of red and purple anthocyanin pigments	Jung *et al*. (112)
		Single recessive gene	Dihydroflavonol 4-reductase (*dfr*) co-segregates with the *R* locus for red pigmentation	Zhang *et al*. (268)
		Single recessive gene	Flavonoid 3′,5′-hydroxylase (f3′5′h), co-segregates with the *P* locus	Jung *et al*. (111)
	Flesh colour	Monogenic	Colour is incompletely dominant to white, the intermediate is pale yellow	Jung *et al*. (112)
		Single dominant	Zeaxanthin accumulation (yellow flesh) *Chy2* gene	Wolters *et al*. (255)
	Tuber shape		Long tuber axis is dominant to short axis	De Jong (45)
Brinjal	Fruit colour	3 genes (*P, X, Puc*)	Purple dominant to green	Thakur *et al*. (226)
			Green (*Gm*) incompletely dominant over white (*gm*)	Choudhury (30)
			Green streaked purple > greenish white	More *et al*. (158)
		Three complementary genes	Pfa, Pfb_1 and Pfb_2; purple > green	Patil and More (175)
	Fruit shape	Monogenic	Round shape partially dominant to long (*Ofa, Ofb1, Ofb2* and *Ofb3*)	Patidar (173)
	Fruit size	Monogenic	Large fruit size partially dominant to small fruit size	Patil and Moore (174)
Tomato	High B-carotene; low lycopene	Monogenic	*B (*high concentrations of b-carotene in orange-pigmented*) but* subject to influence by a modifier gene, *MoB*, which segregated independently of *B*	Tomes *et al*. (231)
Chilli	Fruit colour	Three independent genes	$yy\ cl^+cl^+$ yellow; $y^+y^+cl^+cl^+$ Red; y^+y^+clcl brown; $yy\ clcl$ green	Kormos and Kormos (124)
		Partial dominance	Bright red colour and purple colour over green	Ahmed *et al*. (1984)
	Capsanthin content	Monogenic dominant	*C*	Lippert (138)
	Pungency	Monogenic	Pungency dominant to non	Dempsey (49)
Garden Pea	Pod colour	Monogenic	Yellow (*Gp*); Blue-green (*Dp*); Purple (*Pu, Pur*)	Swarup (222)

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Table 5 contd...

	Quality traits	Number of genes	Type of Gene action	References
Turnip	Flesh colour	Monogenic	White dominant to yellow	Davey (43)
	Skin colour	Two independent loci	Both dominant genes give purple colours	Brar *et al*. (14)
Beetroot	Root colour	Digenic	Red is dominant to yellow or white. Intensity of red colour is influenced by minor genes. Further, 5 alleles at R locus: *R, Rt, r, Rp* and *Rh 3* alleles at *Y* locus: *Y, Yr* and *y* *R_Y_* : Red roots, hypocotyls and petioles *RrY –* : Yellow roots, petioles and hypocotyl *R_yy* : White roots with red hypocotyls *Rryy* : White roots and yellow hypocotyls	Watson and Gabelman (246); Keller (115); Pederson (176)
Carrot	Root colour	Digenic *P-Y-* and two modified *E_*& *I_*	Deep purple : *iiPPYYEE*; Purple : *iiPPYYee* Diffused purple : *iiPPyyee*; Yellow : *IippYYee* Red : *iiPPyyEE*; Light red / orange : *iippyyee*	Kust (128); Buishand and Gabelman (17)
	Nutritional	Monogenic dominant	*A* (α-carotene accumulation), *Io* (intense orange xylem, which may be an allelic form of A), L_1 and L_2 (lycopene accumulation), *O* (orange xylem, which may also be an allelic form of A)	Buishand and Gabelman (16)
	Root shape	Three gene (*D,N,P*)	1.Long or Desi : Long and tapay, *D-N-P* 2.Cylindrical type : Cylindrical, *dd, nn, p* 3.Chantenay type : Obvate / cuneate root, d*d, N-P-* 4.Round type : Round root, *dd,N-, Pp*	Frimmel (72)
Radish	Root colour	3 genes and complimentary gene action	Red : $R_2r_2/R_3r_3/cc$ White : $r_2r_2/r_3r_3/CC$ Purple : $r_2r_2/R_3r_3/cc$ $R_2r_2/r_3r_3/Cc$ $R_2R_2/R_3R_3/CC$ *:* lethal and can not survive $R_2r_2/r_3r_3/cc$ *:* double recessive could be lethal	Yi *et al*. (260); Tatsuzawa *et al*., (225); Tatebe (224); Uphof (238)
	Root shape	Quantitative genes	Many genes	Tsuro *et al*. (234); Iwata *et al*. (103); Zaki *et al*. (261)
Beetroot	Root colour	Two independent loci	*R* locus has five alleles, viz., *R, Rt, r, Rp*, and *Rh,* whereas Y locus had three alleles, viz., *Y, Yr*, and *y*	Kellar (147); Watson and Gableman (246), Pederson (176)
Cauliflower	Curd colour	Monogenic	Orange (beta-carotene) dominant over white curd	Li *et al*. (134)
Cabbage	Leaf colour	Monogenic	Anthocyanin (*A*) development several alleles	Kwan (129); Magruder and Myers (144)
Cucumber	Fruit colour (ripe)	Digenic (R-C-)	*R-C-* (9) Red; *R-cc* (3) Orange; *rrC-* (3) Yellow; *rrcc* (1) Creamy	Hutchins (99)
	Flesh colour (ripe)	Digenic (V-W-)	*V-W- (9)* Diggy White; *V-ww (3)* Intense White *vv W-(3)* Intense Yellow; *vvww (1)* Orange	Kooistra (122)

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Table 5 contd...

	Quality traits	Number of genes	Type of Gene action	References
Muskmelon	Flesh colour	Digenic	*gf::* Green flesh colour wf:: white flesh	Hughes(96); Clayberg (33); Imam *et al*. (101)
	Carotenoids	Monogenic	*CmOr*	Tzuri *et al*. (235)
Watermelon	Flesh colour	Monogenic	*Wf* – *Y* – White flesh *Wfwfy* – Red flesh *Wfwfyy* – Ref flesh *C*-Canary yellow *B*-Yellow flesh *Y*-coral red flesh y^O- orange flesh *y*-salmon yellow	Wehner (247); Bang *et al*. (7)
Okra	Pod colour	Monogenic	White dominant to green	Jasim (104); Kolhe and D'Cruz (1121)
	Pod shape	Oligogenic	Angular dominant over round	Jasim and Fontenot (105)
Onion	Bulb colour	Three loci	*II* – Inhibitory gene – white colour *Ii* – Off white or buff coloured bulb *ii* – Other colour genes express *iicc* – White *iiC-R-* : Red colour *iiC-rr* –: Yellow colour	Rieman (190) Clarke *et al*. (32); El-Shafie and Davis (57); Jones and Peterson (109)

Few of them for phytochemicals/nutraceuticals are High performance liquid chromatography (HPLC) for non-volatile samples, Ultra Performance Convergence Chromatography (UPC^2) for both qualitative and quantitative analysis of gas-phase, Ultra-performance convergence chromatography with a quadrupole time-of-flight mass spectrometry (UPCC-QTOF MS), Waters ACQUITY UPC^2 System for hydrophobic and chiral compounds, lipids, thermally-labile samples and polymers, Spin trapping technique for detection of short-lived free radicals, Gas chromatography (GC) for analyzing volatile compounds which vaporize without decomposition, Gas Chromatography-Mass Spectrometry (GC-MS) for identification and quantification of organic substances in compound matrices, Ultra-high performance liquid chromatography-triple quadrupole/ linear ion trap tandem mass spectrometry (UHPLC-QTRAP/MS/MS) for both small and large molecule analyses. Similarly for minerals, flame photometer, atomic absorption spectroscopy (AAS) for minerals, synchrotron radiation X-ray fluorescence (SXRF) for trace elements, chemical states and surface analyses, inductively coupled plasma-mass-spectrometry (ICP-MS) for low to ultra-los concentration of elements are useful developments. However, these instruments are costly and technical demanding.

Breeding vegetables for quality traits

While designing breeding for quality traits, the following points are necessary to consider: (i) source germplasm must have high density of target nutrient(s), (ii) biofortified variety must have wider adaptability with high content of target nutrients, (iii) processed forms of variety/hybrid must retain sufficient quality attribute i.e., nutrients, antoxidants, (iv) bioavailability of nutrients in human body must be high, and (v) acceptance of biofortified crops by target groups i.e., farmers, consumers. The flow chart for quality breeding is given in Fig. 2. Through conventional breeding, large numbers of varieties have been developed in different vegetable crops and some of them are rich in dietary minerals and nutraceuticals. Pigments present in vegetable varieties can be extracted and used as natural dyes, edible food colour and also for functional food development. A comprehensive breeding programme for quality improvement of vegetable need to involve evaluation of germplasm and identification of potential donors, pre-breeding and product enhancement to develop germplasm combining one or more micronutrients, transgressive segregation or heterosis for quality traits, search for promoters for increased bioavailability and reduced anti-nutrients in biofortified varieties, enhancing the density of desirable nutrients, bioactives, molecular breeding for handling complex quality traits and exploring gene editing approaches such as transgenics, RNA interference and CRISPR/Cas9.

Biofortification for quality traits

It is a process of enrichment of health beneficial dietary nutrients in crop through conventional and molecular breeding, genetic and agronomic measures. Biofortification gives opportunity for on-site production of nutrient dense perishable

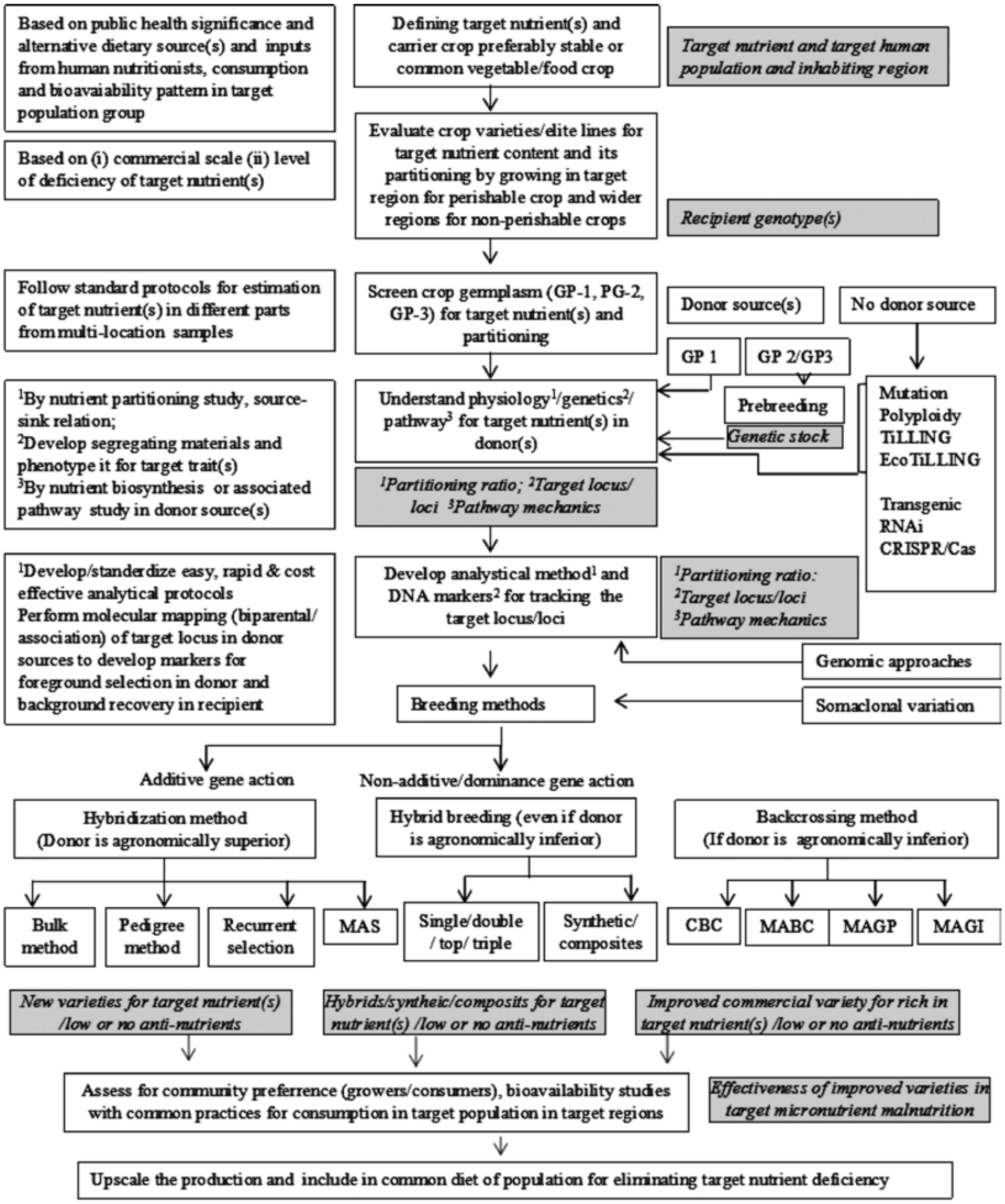

Fig. 1. Important steps in breeding for quality traits in vegetable crops. MAS- Marker assisted breeding, CBC- Conventional backcrossing, MABC –Marker assisted backcrossing, MAGP- Marker assisted gene pyramiding, MAGI- Marker assisted gene introgression.

Fig. 2. Important steps in breeding for quality traits in vegetable crops. MAS- Marker assisted breeding, CBC- Conventional backcrossing, MABC –Marker assisted backcrossing, MAGP- Marker assisted gene pyramiding, MAGI- Marker assisted gene introgression.

vegetables to serve target population in sustainable manner and to use the extra produce for extraction of desirable compound in industry related to pharmaceutical, cosmeceutical etc. Since 2003, HarvestPlus and its partners have demonstrated that this agriculture-based method of addressing micronutrient deficiency through plant breeding works well. Biofortification has been successfully attempted for vitamin A in vegetables such as sweet potato, cassava, sweet corn, tomato and cauliflower; for iron, millions of people in developing countries are now growing and consuming biofortified crops (Bouis and Saltzman, 13). They suggested three key challenges to reach one billion people by 2030: 1) Mainstreaming biofortified traits into public plant breeding programmes; 2) Building consumer demand, and 3) Integrating biofortification into public and private policies, programmes, and investments. However, long-term cost-effectiveness and its ability to reach rural population make it preferred choice to fight against micronutrient malnutrition.

a) Biofortification for minerals in crops

Agronomic biofortification for minerals is effective through optimizing the application of mineral fertilizers and/or improving the solubilisation and mobilization of mineral elements in soil (Golubkina *et al.,* 77). But, the extent of increase in mineral content varies with crop variety, soil and climatic condition and amount of nutrient supplied. Genetic biofortification is more stable and acceptable which can be attained through targeting genotypes and plant tissues. Thereby, enrichment of minerals in plants is possible by overcoming genetic barriers for metal accumulation in edible portion. Additionally, increase in concentrations of ‘promoter’ substances (vitamin C, β-carotene, cysteine-rich polypeptides and certain organic and amino acids which stimulate the absorption of minerals by the gut) and eliminate antinutrients (oxalate, tannins, phytate) which interfere with their absorption. The barriers for metal accumulation largely regulate absorption, transportation (xylem/phloem loading) and redistribution to sink. In rhizosphere, absorption factors need changes in root morphology (i.e., primary root length and angle; lateral root length, number, density and diameter and root hairs length and density) to increase surface area and root-cell processes to augment solubility and movement of minerals (Welch, 248). Here, root-cell efflux of H^+, metal-complexes and redox potential are crucial factors. Active and specific transporters and ion channels in root-cell plasma membrane also regulates absorption pattern of minerals once they enter the apoplasm of root cells. Phloem/xylem loading and translocation factor their accumulation in edible plant organ. It is essential to decipher the molecular and physiological processes for minerals such as proteins for metal homeostasis and hyperaccumulation, transporters and candidates for cytoplasmic metal influx in roots, ATP powered ion pumps (H^+-ATPases genes), ion channel proteins (aquaporins) and cotransporters in crop plants (Dunlop and Phung, 55; Grennan, 85), particularly vegetable crops where most of the crops have non-seed tissues as edible portion. This can be done through characterization and exploitation of genetic variation or gene discovery and directed gene modification. Genetic engineering led to overexpression of Ca2+/H+ antiporters (cation exchanger 1 antiporter- sCAX1) located in the vacuolar membrane to increase Ca content of transgenic crops like potato (Park *et al.,* 172), carrots (Jeong and Guerinot, 107) and lettuce leaves (Park *et al.,* 171). Besides, retention during processing and bioavailability in target population are important considerations.

b) Advanced approaches for quality improvement

To intensify the biofortification process in vegetables, the available opportunities in molecular breeding and related techniques such as genomics by sequencing (GBS), Genome Wide Association Study (GWAS) and single nucleotide polymorphism (SNPs) and techniques targeting genomic sequences such as RNA interference (RNAi), DNA-directed RNA interference (ddRNAi), *CRISPR*-associated protein-9 nuclease (CRISPR/*Cas9*), Targeting Induced Local Lesions in Genomes *(TILLING)* etc. can be explored. Use of TILLING for quality improvement in different vegetables is listed in Table 6. Okabe *et al.* (166) developed Micro-Tom TILLING platform and identified two allelic mutants of *SlETR1* (*Sletr-1-1* and *Sletr-2*) for reduced ethylene responses in tomato.

Molecular breeding for quality traits

Molecular markers enable unambiguous identification of lines/individuals in segregating population for handling of quality traits which otherwise difficult to phenotype due to want of technical expertise and sophisticated equipment. Generally, quality traits are outcome of different complex pathways and governed by quantitative traits with environmental influence. A number of genes governing quality attributes in vegetables are mapped using molecular markers (Table 7). A spontaneous *‘Or’* mutant gene accumulates β-carotene in cauliflower (Li *et al.,*

Table 6. TILLING approaches for different vegetable quality traits.

Crop	Trait	Allele/Locus/Candidate gene	Method	Author
Tomato	Fruit shelf life	*PG*	TILLING	McCallum *et al.* (147)
	Fruit quality	*Exp1*	CSCE	Gady *et al.* (73)
	Fruit quality	*PG, RIN, Gr, Rab11a, Exp1, Lcy-b, Lcy-e*	TILLING	Minoia *et al.* (153)
	Fruit quality	*PSY, Sus2*	HRM	Gady *et al.* (74)
	Fruit quality	*Exp1*	TILLING	Colbert *et al.* (36)
	Fruit quality	*10 genes*	TILLING	Okabe *et al.* (208)
	Fruit quality	*TBG4*	TILLING	Hurst *et al.* (98)
	β-carotene synthase	*Psy1*	TILLING	Gady *et al.* (89)
Potato	Starch quality	*Waxy*	Sequencing	Muth *et al.* (163)
	Tuber colour	*bch, dfr, f3'5'h*	HRM	De Koeyer *et al.* (48)
Cassava	Starch quality	*Waxy*	TILLING	Tofino *et al.* (230)
French bean	Storage defense proteins	*Lectin locus*	TILLING	Lioi *et al.* (137)
Pea	Trypsin inhibitors	*TI1*	TILLING	Sonnante *et al.* (216)
Melon	Fruit quality	ACO1,PDS, DET, DHS	TILLING	Gonzalez *et al.* (78)
	Fruit shelf life	ACO1	TILLING	Dahmani-Mardas *et al.* (41)

169). The introgression of this *'Or'* gene into Indian cauliflower will lead to development of β-carotene rich cauliflower. Kalia *et al.* (114) developed Pusa KesariVitA-1 and promising introgression lines in cauliflower rich in beta-carotene content (8-20 ppm) in Indian cauliflower. Zhang *et al.* (263) found SCAR markers linked to "*or*" gene inducing beta-carotene accumulation in Chinese cabbage. Zou *et al.* (272) performed fine mapping of *or* gene and identified *BrPro1* molecular marker in the promoter region of Bra031539 (predicted to encode CRTISO, a carotenoid isomerase specifically required for carotenoid biosynthesis) that can be used for early identification of orange head materials. The eye-appealing orange cauliflower was first discovered in Bradford Marsh, Ontario, Canada in 1970. The orange cauliflower results from a spontaneous mutation of a single dominant gene designated as '*Or'* for orange gene. This *Or* mutant was originally found in white curded autumn crop cv. Extra Early snowball. This trait is absent in Indian cauliflower where large population is suffering from carotene deficiency, however, biofortification of Indian cauliflower with beta-carotene enhancing native '*Or*' gene to benefit Indian population.

Genomics by sequencing (GBS): The GBS is a simple, affordable and robust procedure for SNP discovery and mapping. This approach is suitable for population studies, germplasm characterization, breeding, and trait mapping in diverse organisms. This procedure, which can be generalized to any species at a low per-sample cost, is based on high-throughput, next-generation sequencing of genomic subsets targeted by restriction enzymes (Elshire *et al.,* 58). Pereira *et al.* (177) identified 33 QTLs controlling fruit quality traits such as sugar and carotenoid content, fruit and seed morphology and major loci controlling external colour of immature fruit and mottled rind in melon using a RIL population and a GBS-based genetic map.

Genome Wide Association Study (GWAS): GWAS is also known as whole genome association study in which genetic variants in the entire genome are investigated in different individuals to see if any variant is associated with a particular trait. GWAS typically focuses on associations between single-nucleotide polymorphisms (SNPs) and traits. The GWAS have developed into a valuable approach for identifying the genetic basis of phenotypic variation. It has been used for understanding association between genetic variation and target trait. Sauvage *et al.* (204) performed GWAS using core collection of 163 tomato accessions composed of *S. lycopersicum*, *S. lycopersicum* var. *cerasiforme*, and *Solanum pimpinellifolium* to map loci controlling variation in fruit metabolites. They reported a total of 44 loci which were significantly associated with a total of 19 traits, including sucrose, ascorbate, malate, and citrate levels. The GWAS also found helpful in studying the evolution of different fruit quality traits (fruit shape, sweetness, flesh colour) in watermelon

Table 7. Gene and QTL mapping for improving vegetable quality.

Quality	Traits	Gene/QTL	References
Tomato	Fruit weight	*Fw2.2*	Cong and Tanksley (38)
	Fruit shape	*fas* (fasciated)	Cong *et al*. (39)
	Fruit shape	*o* (ovate)	Liu *et al*. (139)
	Fruit shape	*SUN*	Xiao *et al*. (258)
	Sugar content	*Lin5* (increased sugar content)	Fridman *et al*. (71)
	Vitamin C	*Vtc9.1* (Higher vitamin C)	Stevens *et al*. (217)
	Shelf life	*Rin*-inhibited ripening (semi-dominant)	Vrebalov *et al*. (241)
		nor (non ripening)- -inhibited ripening (semi-dominant)	Moore *et al*. (157)
		Nr (Never-ripe)- inhibited ripening (dominant)	Wilkinson *et al*. (252)
		Cnr (Colorless non-ripening)- inhibited ripening (dominant)	Thompson *et al*. (227); Seymour *et al*. (207)
	Fruit colour/Carotenoids	*B (Beta)*-Yellow fruits	Ronen *et al*. (193)
		og^c (old gold-crimson)- higher lycopene content	Ronen *et al*. (193)
		Del (Delta)-Orange fruits	Ronen *et al*. (194)
		r (yellow flesh)-Yellow fruits	Fray and Grierson (70)
		t (tangerine)-Orange fruits	Isaacson *et al*. (102)
		hp-2 (high pigment)- higher lycopene content	Mustilli *et al*. (162)
		Dg (dark green)-Higher lycopene content	Levin *et al*. (132)
		y-Uncoloured epidermis	Adato *et al*. (1)
		Apricot (at)	Jenkins and McKinney (106)
	Anthocyanins	*Anthocyanin fruit (Aft)*- anthocyanin in skin and outer pericarp	Giorgiev (76); Jones *et al*. (108)
		Atroviolacium (atv)	Clayberg (34)
		Aubergine (Abg)	Rick *et al*. (189)
Chilli	Pungency (capsaicin)	*Cap, cap3.1, cap4.2, cap7.1, cap7.2*	Ben Chaim *et al*. (9)
		Pun1	Stewart *et al*. (219)
		C	Blum *et al*. (10)
	Fruit shape	*fs3.1, fs8.1, fs10.1* *fs1.1, fs3.1, fs4.1* *fs10.1*	Rao *et al*. (186)
	Fruit weight	*fw2.1, fw3.1, fw3.2, fw4.1, fw8.1, fw1.1, fw2.1, fw3.1, fw4.1, fw8.1, fw10.1, fw11.2*	Rao *et al*. (186)
	Pericarp thickness	*pt 3.1, pt4.1, pt8.1, pt10.1* *perwd1.1, perwd3.1, perwd3.2, perwd6.1, perwd8.1, perwd11.1*	Rao *et al*. (186)

Contd...

Table 7 contd...

Quality	Traits	Gene/QTL	References
	Fruit Colour	*Y*-Yellow fruit colour	Lefebvre *et al*. (131)
		C2-Orange fruit colour	Huh *et al*. (97)
		Chlorophyll retainer (*cl*) –Brown fruits	Borovsky and Paran (12)
		A-Purple fruit colour	Borovsky *et al*. (11)
	Soft flesh and deciduous fruit	*S*	Rao and Paran (185)
Brinjal	Fruit weight	*fw2.1, fw9.1, fw11.1*	Frary *et al*. (68)
	Fruit shape	*fl2.1-Ovate*	Ku *et al*. (125)
		fs7.1, ovs4.1	Grandillo *et al*. (83)
	Anthocyanin	*fap10.1*	De Jong *et al*. (47)
	Fruit stripe	*fst4.1*	Grandillo and Tanksley (84)
	Fruit glossiness	*fglo1.1, fglo6.1, fglo8.1, fglo9.1, fglo12.1*	Frary *et al*. (68)
	Parthenocarpy	*Cop3.1*, *Cop8.1*	Miyatake *et al*. (155)
Onion	Carbohydrate	*Frc 8* (Fructan content)	McCallum *et al*. (147)
	Bulb color	*P* (Pink colour)	Kim *et al*. (117)
		crb7-complementry recessive red	King *et al*. (118)
Cauliflower	Curd colour	*β*-carotene accumulation/*Or* gene	Li and Garvin (133)
		Pr-High anthocyanin content	Chiu *et al*. (32)
Cabbage	Head type	*Glossy foliage (gl-1)*	Kianian and Quiros (116)
	Head shape	*Htd* 3.1, *Htd* 8.1	Pang *et al*.(169)
Kale	Leaf colour	*BoPr*-Purple leaf	Liu *et al.* (140)
Beetroot	Sucrose content	*13QTL*	Trebbi (233)
Carrot	β-carotene	*8QTL*	Santos and Simon (198)
	ŏ-carotene	*4QTL*	Santos and Simon (199)
	Carotenoids	*PSY*	Santos *et al*. (199)
Watermelon	Lycopene	LCYB	Bang *et al*. (8)

(Gou *et al.,* 81) and draft genome sequence also open new area for molecular studies (Gou *et al*., 88). Colonna *et al*. (37) analyzed genomic diversity and novel genome wide association in *Capsicum* and identified four novel loci associated with the phenotypes determining the fruit shape, including a non-synonymous mutation in the gene *Longifolia 1-like* (CA03g16080). In tomato, Zhao *et al.* (269) performed GWAS using 775 tomato accessions and discovered 305 significant associations for sugars, acids, amino acids, and flavour-related volatiles. The potential of GWAS and genomic prediction for improving curd-related traits in cauliflower was explored by Thorwarth *et al.* (228) using 174 accessions and identified 24 significant associations for curd-related traits. Accumulated capsaicinoid content and increased fruit size are important quality traits in *Capsicum annuum*. Nimmakayala *et al.* (165) identified genomic segments linked to various fruit traits and capsaicin accumulation in *C. annuum* and generated 66,960 SNPs using GBS and reported SNPs in Ankyrin-like protein, IKI3 family protein, ABC transporter G family and pentatricopeptide repeat protein as markers for capsaicinoids.

Transgenic approach: Transgenic crops, commonly known as genetically modified (GM) crops enable plant breeders to bring favourable genes, often previously inaccessible, into elite cultivars, improving their value considerably. With the development of genetics and molecular biology, a large number of quality related genes such as those involved in pigmentation, biosynthesis of vitamins, minerals and flavour compounds, soluble carbohydrate metabolism, fruit colour, shape, size and position, cell wall metabolism, shelf life have been identified in different vegetable crops. Genetic engineering enabled vegetable breeders to incorporate desired transgenes into elite cultivars, thereby improving their value, nutritional quality and other health benefits. Dias and Ortiz (52) reviewed recent advances in transgenic vegetable crops. This approach is more efficient and precise to incorporate genomic region which manifest desired improvement in target quality traits. Zinc fortified transgenic lettuce can be used to overcome its deficiency that severely impairs organ function. Transgenic lettuce with improved tocopherol and resveratrol composition and transgenic tomatoes with high folate levels are promising developments against deficiencies (Dias and Ortiz, 51; Diaz de la Garza *et al*. 53). Further, cyanide-free transgenic cultivars of cassava can be promising option to provide safe cassava (Siritunga and Sayre, 214). Romer *et al.* (192) developed transgenic tomato to enhance the carotenoid content and profile of tomato fruit. It has contributed to increase in β-carotene content about threefold, up to 45% of the total carotenoid content in cultivar "Ailsa Cray". Park *et al*. (171) demonstrated that lettuce expressing the deregulated *Arabidopsis* H^+/Ca^{2+} transporter *sCAX1* (cation exchanger 1) contained 25–32% more calcium than controls. Lu *et al.* (143) suggested that transgenic cauliflower with *Or* transgenesis associated with acellular process that triggers the differentiation of proplastids or other noncoloured plastids into chromoplasts **for** carotenoids accumulation. Wahlroos *et al.* (242) produced oilseed *Brassica rapa* with increased histidine content. Transgenic approach also helped in extending the shelf-life of vegetable crops. For example, cytokinins are known to delay floral yellowing of plants and Chan *et al.* (25) used a transgene construct pSG766A to increase expression of isopentenyl transferase (key enzyme for cytokinin synthesis) in broccoli. The *ipt* transgene is triggered by the senescence-associated gene promoter (SAG-13) and this resulted into extending shelf-life to 7.5 - 8.5 d compared with 5.6 d for the non-transgenic line.

RNA interference (RNAi) in quality breeding: The RNA silencing is a gene regulatory mechanism that limits the transcript level by either suppressing transcription (TGS) or by activating a sequence-specific RNA degradation process [PTGS/RNA interference (RNAi)].This approach was effectively used to alter the gene expressions for improving quality traits by increasing antioxidants in tomatoes or suppressing over expression of negative traits such as sinapate esters in canola and alpha-linolenic acid in soybean. Eady *et al.* (56) suppressed the lachrymatory factor synthase gene using RNAi silencing and reduced lachrymatory synthase activity manifold. This silencing had shifted the trans-S-1-propenyl-l-cysteine sulfoxide breakdown pathway so that more 1-propenyl sulfenic acid was converted into di-1-propenyl thiosulfinate which resulted into a marked increase in usually trace or non-detectable non-enzymatically produced zwiebelane isomer and other volatile sulfur compounds, di-1-propenyl disulfide and 2-mercapto-3,4-dimethyl-2,3-dihydrothiophene.Further, Meli *et al.* (149) also used RNAi approach to extend shelf-life of tomato by blocking the expression of ACC oxidase gene and suppression of two ripening specific N-glycoprotein modifying enzymes, α-mannosidase and β-D-*N*-acytlhexosaminidase (β-Hex). Targeting of three homologs of ripening genes 1-aminocyclopropane-1-carboxylate synthase (ACS) using chimeric RNAi-ACS construct also resulted into delayed ripening of fruits up to 45 days (Gupta *et al.,* 89). Peters *et al.* (178) used RNAi technology to develop Dau c 1.01 and Dau c 1.02-silenced transgenic carrot plants show reduced allergenicity to patients with carrot allergy. The RNAi-mediated suppression of DET1 expression under fruit-specific promoters has recently shown to improve carotenoid and flavonoid levels in tomato fruits with minimal effects on plant growth (Williams *et al*., 253). Seedlessness is desirable factor and auxin and gibberellins are associated with parthenocarpy and suppression of auxin response factor 8 using RNAi resulted parthenocarpic fruits in tomato (De Jong *et al.,* 46). Such fruits were also obtained by suppression of genes of the AUCSIA family coding for 53-amino-acid-long (protein or peptide) by RNAi (Molesini *et al.,* 156).

CRISPR/Cas system in quality breeding

Clustered regularly interspaced short palindromic repeats (CRISPR)/CRISPR-associated protein 9 (*Cas9*) system is an efficient genome editing tool. It allows easy alteration in DNA sequences to modify gene function for obtaining desirable traits in crop plants as well. Wang *et al*. (244) reviewed use of CRISPR/cas in improvement of tomato attempted by different researchers through targeting a number of genes such as *CLV3 and lc* (Fruits with increasing locule numbers) (Rodriguez-Leal *et al.,* 199), *PSY1* (yellow coloured fruits) (Filler *et al.,* 66), *MYB12* (pink colour fruits) and *ANT2* (gene insertion) (purple colour fruits) (Deng *et al.,* 50), *Pl* and *ALC* (long shelf life) (Uluisik *et al.,* 237), *MPK20* (Repression of genes controlling sugar metabolism) (Chen *et al.,* 27) and *SGR1, LCY-E, Blc, LCY-B1, LCY-B2* for increase in lycopene content (Li *et al.,* 136).

Different genes of anthocyanin and carotenoid biosynthetic pathways including *Anthocyanin 1*

(*ANT1*) (Cermak *et al.,* 24), *Phytoene desaturase* (*SlPDS*), *Phytochrome interacting factor* (*SlPIF4*) (Pan *et al.,* 167), and *Phytoene synthase* (*PSY1*) (Hayut *et al.,* 92) have also been edited by CRISPR/Cas9 in tomato. Parthenocarpy is an important trait in tomato with huge potential in processing industry and the trait has been obtained by editing two different genes namely knocking down *Slagamous-like 6* (*SlAGL6*) gene (Klap *et al.* (119) and by mutating *SlIAA9* gene (Ueta *et al.,* 236). These reports in tomato open new opportunities for developing parthenocarpic fruits in other horticultural crops like watermelon, pointed gourd, bitter gourd, etc. where seedless or less seeded fruits are in demand.

There are few reports in potato which establish that CRISPR/Cas9 can be effectively utilized for multi-allelic mutagenesis in polyploid crops. Starch quality of potato is an important trait. Hexaploid potato containing only amylopectin was developed by mutating *granule bound starch synthase* (*GBSS*) gene using CRSIPR/Cas9 by Andersson *et al.* (5). Similarly *ACETOLACTATE SYNTHASE1* (*StALS1*) gene has also been mutated in potato (Butler *et al.,* 18).

Multiplexed CRISPR/Cas9 system has also been attempted to obtain knockout lines of multiple genes in a single transformation experiment, such experiments have application in metabolic engineering of vegetables. Li *et al.* (135) simultaneously targeted five key genes of γ-aminobutyric acid (GABA) shunt in tomato and significantly enhanced GABA accumulation in both the leaves and fruits.

Biosynthetic pathway analysis in vegetable crops

In different vegetable crops various studies have been carried out on the expression profiling of genes involved in different nutrient biosynthetic pathways. These studies carried out on different tissues under various conditions or in different genotypes or in the comparison of mutants and wild-type have led to the identification of candidate genes linked to various nutritional traits.

Glucosinolates (GSL) are the most studied secondary metabolites in brassica crops (Ramchiary *et al.,* 183; Feng *et al.,* 65). Twenty five putative GSL biosynthetic and degradation genes have been identified in broccoli through Transcriptome RNA-seq analysis (Gao *et al.*, 75). In a separate study by Guo *et al.* (87) transcriptomes of high-GSL and low-GSL *Brassica alboglabra* sprouts were compared by RNA-seq analysis which revealed that level of myrosinase in high-GSL material was significantly lower than that of lower-GSL one. Such studies have also shown that the GSL profile of *B. oleracea* has undergone extensive variations compared with that of *B. rapa* as the type of major GSL vary in both these spp. As gluconapin and glucobrassicanapin are the major GSLs in *B. rapa* (Cartea *et al.,* 24; Wiesner *et al.,* 251), glucoraphanin, gluconapin, progoitrin, and sinigrin in *B. oleracea* whereas broccoli (*B. oleracea* var. *italica*) has a higher level of the anticancer precursor glucoraphanin compared with the other vegetable Brassicas (Sarikamis *et al*. 201).

Vegetables get their red, orange, and yellow colour due to the presence of phytonutrients called carotenoids. Vegetables contain different carotenoids such as beta-carotene, lutein, zeaxanthin, neoxanthin, violaxanthin, and folate, which have important antioxidant, anticancer and pro-vitaminA properties (Kopsell and Kopsell, 126).

The *Or* gene that is responsible for the orange colour has been extensively studied in relation to its function in the carotenoid biosynthesis pathway in *Brassicas* (Lu *et al*., 143; Zhou *et al.,* 270; Zhang *et al.,* 265). Zhang *et al.* (267) reported that the orange head phenotype of the *Br-or* mutant is attributable to the insertion of a large genomic fragment at the 3′ end of the *BrCRTISO* gene and the differential expression of a number of transcription factor genes. In cauliflower (*B. oleracea* var. *botrytis*), the semi-dominant *Or* gene mutant induces carotenoid (dominant beta-carotene) accumulation in the leaf bases and curd shoot meristems but not in the leaves (Li *et al.,* 134). The relationship between carotenoid accumulation and the expression of biosynthesis genes was investigated in different tissues (Jung *et al.,* 113). The *BrPSY*, *BrPDS*, *BrZDS*, *BrLCYE*, *BrCHXB*, and *BrZEP* genes were upregulated in the flowers and leaves in which lutein and beta-carotene were abundant. Additionally, Br300K microarray analysis has indicated that the downregulation of three carotene degradation genes, *BrNCED3*, *BrNCED4*, and *BrNCED6*, are associated with the carotenoid content in Chinese cabbage yellow leaves (Jung *et al.,* 113).

Clotault *et al.* (35) investigated the expression of eight genes (phytoene synthase -*PSY1* and *PSY2*, phytoene desaturase -*PDS*, ζ-carotene desaturase-*ZDS1* and *ZDS2*, lycopene ε-cyclase-*LCYE*, lycopene β-cyclase -*LCYB1*, and zeaxanthin epoxidase-*ZEP*) encoding carotenoid biosynthesis enzymes during the development of white, yellow, orange, and red carrot roots. All eight genes were expressed in the white cultivar even though it did not contain carotenoids. The high expression of genes encoding *LCYE* and *ZDS* noted in yellow and red cultivars, respectively was found to be consistent with the accumulation of lutein and lycopene, respectively. Campos *et al.* (20) characterized and established role of plastid terminal oxidase gene *DcPTOX* during growth and development stages in different colour roots. Carotenoids are produced in both carrot (*Daucus carota*) leaves and reserve roots, and high amounts of α-carotene and β-carotene accumulate in the latter. In some plant models, the presence of different isoforms of carotenogenic genes is associated with an organ-specific function. Carrot has also been reported to harbour two *Lcyb* genes, of which *DcLcyb1* is expressed in leaves and storage roots during carrot development, correlating with an increase in carotenoid levels. Moreno *et al*. (159) indicated that *DcLcyb1* does not possess an organ specific function and modulate carotenoid gene expression and accumulation in carrot leaves and storage roots.

Phytoene synthase catalyzes the first committed step in the carotenoid biosynthesis pathway, and its overexpression is the main driving force in the orange phenotype. Promoter analysis showed that *DcPSY* genes have diverged substantially in their regulatory sequences after gene duplication. Expression levels of *DcPSY1* and *DcPSY2* were generally positively correlated with carotenoid content during root development. Wang *et al*. (245) reported that *DcPSY1* makes an important contribution to carotenoid accumulation in the leaves and is important for photosynthesis and photoprotection, but they are not the determining factors of root colour. Fraser *et al*. (69) analysed tomato fruit, at five stages of development, for their carotenoid and chlorophyll (Chl) contents, *in vitro* activities of phytoene synthase, phytoene desaturase, and lycopene cyclase, as well as expression of the phytoene synthase (*Psy*) and phytoene desaturase (*Pds*) genes. They reported highest carotenoid in ripe fruit while carotenogenic enzymic activities in green fruit. Of these enzymes, *Psy* was located in the plastid stroma whereas metabolism of phytoene was associated with plastid membranes during fruit development stages. Transcription of *Psy* and *Pds* is regulated developmentally, with expression being considerably elevated in chromoplast-containing tissues. The absence of detectable *Psy* and *Pds mRNA* in green tissues despite their high enzyme activities support the hypothesis of divergent genes encoding these enzymes. Enfissi *et al*. (59) performed expression analysis of 4, 4′ carotenoid oxygenase (*crtW*) and 3, 3′ hydroxylase (*crtZ*) from marine bacteria in tomato which showed low level production of ketocarotenoids in ripe fruit but over production of lycopene (~3.5 mg/g DW) along with delayed ripening. Su *et al*. (220) demonstrated that Carotenoid accumulation during tomato fruit ripening is modulated by the auxin-ethylene balance.

Anthocyanins are flavonoid pigments that are responsible for the red, purple and blue colours in plants. These provide antioxidant and anti-cancer benefits to humans, as well as protection of plant DNA from UV light damage. Several vegetable crops including purple cauliflower, red cabbage, purple heading Chinese cabbage, purple capsicum and carrots are rich in anthocyanin in their stems, curds, heading leaves, fruits or roots (Chiu *et al.,* 29; Lorizzo *et al.,* 142; Sankhari *et al.,* 196; Singh *et al.,* 254; Stommel *et al.,* 218).

Genes involved in anthocyanin biosynthesis have been identified and characterized in *A. thaliana* and include 24 structure genes, 16 transcription factor genes, and one transport gene, as well as some miRNAs that participate in anthocyanin synthesis, regulation, and transport (Walker *et al.,* 243; Matsui *et al.,* 146; Gou *et al.,* 80). 73 genes orthologous to these 41 *A. thaliana* anthocyanin biosynthesis genes have been identified in *B. rapa*, (Guo *et al.,* 86). Differentially expressed genes that are involved in anthocyanin synthesis have been identified through comparative transcriptional analysis of green and purple lines/cultivars/mutants of *Brassica* vegetables. Almost all anthocyanin biosynthesis-related genes are upregulated in purple cultivars such compared with white ones (Zhang *et al.,*264). A very high upregulation of *BoPAP1* gene, which encodes a *R2R3 MYB* transcription factor is believed to induce extensive anthocyanin accumulation in purple kale by activating structural genes under low temperature stress (Zhang *et al.,* 262). *BoMYB2*, an ortholog of *AtPAP2* or *MYB113*, together with *BobHLHs* has been associated with anthocyanin synthesis in purple cauliflower (*B. oleracea* var. *botrytis*) mutant (Chiu and Li, 28), however, a different pattern of expression of these genes was reported in Sicilian purple by Singh *et al*. (Singh *et al*., 209). The *BrMYB2* and *BrTT8* are two regulatory factors of anthocyanin accumulation in purple heading Chinese cabbage line rich in anthocyanin (He *et al.,* 93; Zhang *et al.,* 264).

A wide array of tissue-specific anthocyanin pigmentation is observed in *Capsicum annuum* L. (pepper). In order to determine the genetic basis for tissue-specific pigmentation, Stommel *et al.* (262) studied the expression of anthocyanin biosynthetic (*Chs, Dfr*, and *Ans*) and regulatory (*Myc*, Myb_A, and *Wd*) genes in flower, fruit, and foliar tissue from pigmented and nonpigmented *C. annuum* genotypes. Biosynthetic gene transcript levels were significantly higher in anthocyanin-pigmented tissue than in nonpigmented tissues. Myb_A and *Myc* transcript levels were also substantially higher in anthocyanin-pigmented floral and fruit tissues. They demonstrated that differential expression of *C. annuum* Myb_A as well as *Myc* occurs was coincident with anthocyanin accumulation in *C. annuum* flower and fruit tissues. In contrast to the situation in flowers and fruit, differential expression of Myb_A and *Myc* was not observed in foliar tissue, suggesting that different mechanisms contribute to the regulation of anthocyanin biosynthesis in different parts of the *C. annuum* plant.

Purple carrots can accumulate large quantities of anthocyanins in their roots. Lorizzo *et al.* (180) performed fine mapping combined with gene expression analyses to identify candidate genes controlling anthocyanin pigmentation in the carrot root and petiole. They identified a cluster of six *MYB* transcription factors, denominated *DcMYB6* to *DcMYB11*, associated with the regulation of anthocyanin biosynthesis. No anthocyanin biosynthetic genes were present in this region. Comparative transcriptome analysis indicated that upregulation of *DcMYB7* was always associated with anthocyanin pigmentation in both root and petiole tissues, whereas *DcMYB11* was only upregulated with pigmentation in petioles.

In addition to the pigments and secondary metabolites biosynthetic pathways of vitamins have also been studied in vegetable crops. The expression profiles of vitamin C synthetic pathway-related genes have been investigated in various studies. In non-heading Chinese cabbage, the upregulation of three *d*-mannose/*l*-galactose pathway genes (*PMI*, *GME*, and *GGP*) and downregulation of ascorbate oxidase (*AAO*) was correlated with the high vitamin C contents (Ren *et al.,* 187). Additionally, the overexpression of a monodehydroascorbate reductase gene (*MDHA*) in non-heading Chinese cabbage and tobacco reduces its ascorbate level, thereby indicating its negative regulatory function (Ren *et al.,* 188).

Pre-breeding and introgressiomics for nutraceutical enrichment

The pre-breeding is transferring useful gene(s) from exotics/wild (unadapted sources) types into agronomically acceptable background/breeding materials. It aims to generate conventionally usable new base population/genetic stock which is/are expected to have merit to be included in ordinary breeding programme. It is a bridge between gene pool and crop improvement. There are different approaches to pre-breeding, namely Introgression, Incorporation, wide crossing, somatic hybridization, genetic transformation and others. The germplasm of vegetable crops useful for biofortification/quality traits is given in Table 8. Introgressiomics is a related term to pre-breeding and Prohens *et al.* (182) defined it as a mass scale systematic development of plant materials and populations carrying introgressions of genome fragments obtained from (mostly wild) crop relatives into the genetic background of crops that may allow developing new generations of cultivars with improved properties'. They described five clear steps: (i) Identification of CWRs to be used in the programme; (ii) Hybridization and backcrossing of the crop with a number (as large as possible) of crop wild relatives from different genepools using special techniques when needed; (iii) Development of multiple special introgression populations containing introgressed fragments from one or several CWRs using genomic tools; (iv) Creating repositories of the introgressiomics populations and materials and databases with phenotypic and genomic information; and lastly, and (v) Moving the materials into breeding pipelines. Traka *et al.* (232) developed three high-glucoraphanin F_1 broccoli hybrids through genome introgression from the wild species *Brassica villosa*. The high-glucoraphanin broccoli hybrids contained 2.5–3 times the glucoraphanin content of standard hybrids due to enhanced sulphate assimilation and modifications in sulphur partitioning between sulphur-containing metabolites. All of the high-glucoraphanin hybrids possessed an introgressed *B.villosa* segment which contained *B.villosa Myb28* allele. *Xishuangbanna* gourd (*C. sativus* L. var. *xishuangbannanesis*) is a potential donor source of beta-carotene (700 µg/100 g fresh weight) for use in enrichment of commercial cucumber (*Cucumis sativus* L) which contains beta-carotene in range of 22–48 µg/100 g fresh weight. Endocarp quantity of β-carotene (QbC) in cucumber was governed by a single recessive gene *ore* on chromosome 3 (Cuevas *et al.,* 40). But, this need further investigation for some commercially undesirable traits (e.g., poor fruit quality including fruit shape, length, and spine colour). Orange colour intensity (hue; QbC) and dispersion (uniform colour) in endocarp/mesocarp tissue are likely under polygenic control.

Glucosinolates are functional compounds which affect health due the activities by degradation products such as sulphoraphane which acts against tumor inhibition through different mechanisms such as induction of phase 2 response, anti-inflammatory activity, antibiotic against *H. pylori*, cell cycle arrest and apoptosis and variable effects on phase I. Hence, development of broccoli rich in health beneficial glucoiberin (3- MSP) and glucoraphanin (4-MSB) was attained by Faulkner *et al.* (64) and Mithen *et al.* (154) using *Brassica villosa*. They identified two QTLs having major effect on glucosinolate content alongwith linked microsatellite marker O112-F02 for QTL-2. Glucosinolates content was high when

QTL1 was from *B. villosa*, although it was highest (10 μmol/g dry weight) when both QTL1 and QTL2 were from *B. villosa* followed by QTL1 from *B. villosa* and QTL2 in heterozygous state. Interestingly, MSB content and sulforaphane content of soup after 90 s cooking was increased 89% in 48/13 × BR9 (*B. villosa* based hybrid).

Wild species are used to enhance bioavailability of antioxidants in vegetables such as Willits *et al*. (254) enhanced quercetin in fruit flesh and peel in tomato using *S. pennellii* and anthocyanin from *S. chilense* (dominant allele Anthocyanin fruit, *AFT*) and *S. cheesmanie* (recessive allele Atroviolacium, *atv*) and *S. lycopersicoides* (dominant allele Aubergine, *ABG*). Fruits of either AFT-/atvatv and ABG-/atvatv hybrids showed high production of anthocyanins in the peel (Mes *et al.,* 152; Gonzali *et al*., 79). Similarly, flavonoids content increased in *Allium sativum* using *A. ursinum* and *A. victorialis* (Wu *et al*., 257). However, classical breeding has limitation therefore molecular markers are ideal to handle such complex to measure traits and provide quick tool that allows breeders to accelerate and reduce the costs of selection programmes. In onion, Kim *et al*. (117) developed a codominant PCR-based marker linked to the DFR-A gene, known to be involved in the last steps of anthocyanin biosynthesis. They proposed the use of this marker to expedite the screening of heterozygous red onions in segregating populations, thereby eliminating the need for time-consuming progeny tests. Further, specific biochemical pathways can be modified through the activation or repression of specific genes.

Omics approaches in biofortification: Omics represents collective technologies used to understand the roles, relationships, and actions of the various types of molecules that make up the cells of an organism. This leads to the development of new breeding tools including precise cross breeding and genetic engineering. The use of omics tools is in infancy for nutraceutical research in vegetable crop. Xiaonan *et al.* (259) reviewed the use of omics technologies to analyze the genome sequence, transcripts, proteins, and metabolites involved in phytonutrient biosynthesis/degradation for nutritional enrichment.

Minor vegetable crops as source of dietary nutrients and nutraceuticals

Minor vegetables are important source of food and dietary needs of tribal and vulnerable communities in remote forest and rural areas (Vijay Bhaskar *et al*., 240; Singh *et al*. 211). Although, no attempt have been made except few of these underexplored crops for yield or quality traits they are inherently found to be rich in various minerals (Ca, Fe, Zn) and dietary microelements such as vitamins and amino acids

Table 8. Crop wild relatives rich in quality traits useful for breeding.

Crops	Wild relatives/ accessions/ landraces/ varieties	Nutrients
Tomato	*S. pimpinellifolium*, Caro Red (Rugers x *S. hirsutum*)	Vitamin A
	Caro Rich, F-7045, VRT-35, CGT, VRT-5	Beta carotene
	High pigment mutants (hp), Crimpson (og), Pusa Rohini	Lycopene
	S. pennellii IL6-2, IL7-2	Phenolics
	S. pennellii IL12-4	Ascorbic acid
	S. chilense and atroviolacium (atv) from *S. cheesmaniae*	Anthocyanin
Chilli	*C. annuum* var. IC: 119262(CA2), Bayadaggi kaddi	Ascorbic acid
Paprika	KTPL-19	Capsanthin
Cucumber	*Xishuangbanna* gourd (C. sativus var. Xishuangbananesis)	Beta carotene
Muskmelon	Honey dew32	Ascorbic acid
	Canary yellow	Flavons (Naringenin chalcone)
Spine gourd	*Momordica dioca*	Protein
	M. chochinchinenesis	Lycopene
Bitter gourd	DRAR-1, DVBTH-5	Beta carotene
	DRAR-1, DVBTG-5	Ascorbic acid
Sweet potato	Resisto, Zambezi, Chiwoko	Beta carotene
Cassava	UMUCASS 44, UMUCASS 45 and UMUCASS 46	Vitamin A
Broccoli	*Brassica villosa*	Glucosinolates

(Singh *et al.*, 210). They are hardy for biotic and abiotc stresses, require less care and low inputs, easily accessible in natural habitats or home gardens and are a rich source of micronutrients (Flyman and Afolayan, 67). Despite their resilience to climate change factors and first line of foods for primitive and indigenous tribes still they are neglected vegetables. Certain antinutrients like nitrate, phytate and oxalate content in these vegetables is a matter of concern, however, they can be removed by common cooking practices (Aletor and Adeugun, 4; Singh *et al*., 213) but still the breeding genotypes hacing low values of antinutrients and high content of nutritional content could be preferred option. Underutilized vegetables also have potential for nutraceuticals such as gac (*Momordica cochinchinensis*) contain very high lycopene 380 (µg g^{-1} fresh fruit) than commonly known sources like tomato (31 µg g^{-1}), watermelon (41 µg g^{-1}) (Aoki *et al*. 6). Similarly, aril fraction of teasel gourd (an underutilized cucurbitaceous vegetable) also contain high amount of lycopene and have potential for commercial extraction (Singh *et al*. 212) from arils. Hence, they could make an important contribution to combating micronutrient malnutrition as well as providing food security.

Antinutritional factors and their elimination

Some of the vegetables contain chemical compounds which are: (i) fatal/toxic to human, and (ii) interfering agents to dietary nutrients and enzymes and called as 'anti-nutritional factors'. Some of them are oxalates, nitrate, phytate, saponin, tannins, glycosides which affect human health. It is important for consumers and researchers to understand the importance of these chemicals and their impacts on human health and available methods for their assessments. Anti-nutritional compounds in vegetables are given in Table 9. In faba bean, condensed vicine, convicine and condensed tannins are major antinutrients and two recessive genes, *zt-1* and *zt-2* interrupt the anthocyanin biosynthetic pathway and cause zero-tannin content and promote white-flowered plants. The removal through marker assisted breeding was attempted by Gutierrez *et al.* (90) by developing SCAR markers for *zt-2* and *VfTTG1* gene for a loss of pigmentation in flowers and absence of tannins. Vicine-convicine content may decrease up to 20 times due to presence of the *vc*-allele that is linked to colourless hilum in the seeds. Another gene *vcr* is also reported to reuduce 20-fold reduction in vicine-convicine concentration with respect to wild-type faba bean similar to *vc*⁻ (Ramsay *et al.,* 184). Phytate is another antinutrient in plant but, low phytate affects germination, emergence, stress tolerance and yield. Hence, biotechnological approaches have been suggested to remedy this problem, including embryo-specific silencing of an ABC transporter responsible for phytic acid

Table 9. Antinutrients in plant foods that reduce nutrient bioavailability impairing health.

Antinutrients	Effect	Dietary source
Phytic acid	Binds minerals K, Mg, Ca, Fe, Zn	Legumes and cereals
Trypsin inhibitor	Reduces the activity of the enzyme trypsin and other closely related enzymes that help digest protein	Legumes, cereals and potato
Hemaglutinin, eg. Lectin	Interfere with cells lining the gastrointestinal tract causing acute symptoms, can bind metals and some vitamins	Legumes
Polyphenolics, tannins	Form complexes with iron, zinc, copper that reduces mineral absorption	Beans, tea, coffee, sorghum
Cyanogens or glycoalkaloids	Inhibit acetylcholinestrase activity which impair nerve transmission, can damage cell membranes	Cassava, peas, beans
Oxalic acid	Binds calcium to prevent its absorption	Spinach leaf, amaranth, rhubarb, portulaca, colocasia, elephant foot yam
Solanine	Can be toxic, affect gastro intestinal and nervous system	Green parts of potato tubers
Saponins	May irritate the gastrointestinal tract and interfere with nutrient absorption	Soybeans, peas, sugar beets, pea nuts
Goitrogens	Suppress thyroids function	Brassica, alliums foods
Cadmium, mercury, lead	May have toxic effects, e.g.. High levels of Hg impair brain development	Contaminated leafy vegetables
Glycosides	Liberate toxic hydrocynic acid with enzymic action	Tapioca leaves
Dioscorine	Toxic alkaloid	Yam

accumulation (Shi *et al*., 208) or by Silencing of a key phytate transporter and engineering of increased phytase activity in seeds (Campion *et al.,* 19). Tripsin inhibitor content in pea seeds is governed by QTL closely linked to *TI* genes at the *Tri* locus (Domoney *et al.,* 54). Zivanov *et al.* (271) used *Pisum elatius* to reduce low trypsin inhibitor and found a marker At13/At5 for use in breeding.

Bioavailability studies

Horvitz *et al*. (95) investigated higher level of serum lycopene and beta-carotene concentrations in human beings while fed with red carrot in comparison to white carrot, tomato paste and white carrot+tomato paste. Morris *et al.* (160) reported that fractional absorption of calcium from control carrots was 48.8% for females and 56.9% for males, compared with 42.1% for females and 43.8% for males for the sCAX1-expressing carrots. However, fractional Ca absorption is lower in the sCAX1-expressing carrots, the total Ca absorbed per 100 g of fresh carrots is 45.9% higher for females and 38.7% higher for males from the sCAX1-expressing carrots. Therefore, the *sCAX1*-expressing carrots contain more bioavailable Ca in both the mouse and human models. Bioavailability studies on beta-carotene biofortified cassava in Kenyan children showed increased level of serum retinol concentration over the control and serum beta-carotene concentration over both control and beta-carotene supplement. Further, prevalence of vitamin A deficiency was reduced to 29% with yellow cassava while it was still at higher levels in control (34%) and beta-carotene supplement (33%) (Talsma *et al.,* 223). The mineral absorption increases from food plant alongwith increase in 'mineral promoters' such as ascorbic acid and vitamin A and also by reducing antinutritional compounds namely oxalate, nitrate, phytate, saponin, tannins and tripsin inhibotors in vegetables such as leafy vegetables, legume and tuber crops (Platel and Srinivasan, 180).

CONCLUSION

Promoting a nutrient rich crop fitting to growing conditions in target communities is relatively less time demanding compared to developing varieties and challenging the deficiencies. Fortification of non-perishable public food is option but its affordability and mass availability to masses at reasonable prices (on consumer side) will remain a challenge. Except 'iodised salt' we hardly found a big breakthrough showing larger implication on public health. Biofortification using classical breeding or new breeding approaches always face challenges from traditional food culture point of view, so participatory mode is always a preferred mode.

Biofortified crops have potential to increase delivery of minerals to vulnerable communities *pro rata* to their contribution to the diet, without a change in behaviour. However, before planning biofortification programme, it is essential to understand the issues related to, such as (i) feasibility of breeding nutrient/nutraceutical/pharmaceutical/bioactive compounds dense varieties, (ii) chances of adoption of new genotypes by farmers, (iii) target nutrient content for breeding, (iv) impact on nutritional status, (v) cost-effectiveness of new genotypes, and (vi) consumers acceptance of biofortified foods (Nestel *et al*., 2006). Breeding vegetable for quality traits needs adequate attention to meet the diverse need of consumers' taste, health and nutrition. Identify vegetables for target nutraceuticals, other industrial compounds and develop holistic programme by PPP mode with breeder and health expert's participation. Adequate focus should be given to explore the nutritional and health potential of underutilized vegetables particularly in the areas/communities of their preference. Exploit wild species and land races for genes/QTLs for nutraceuticals and other bioactive compounds. Molecular tools have great potential to support conventional breeding in developing vegetable varieties high in nutraceuticals/pharmaceuticals/ bioactive compounds. Use of '*omics*' approaches to understand complexities of biosynthetic pathway is also emerging option to use for tailoring the genotypes for plan vaccine, nutraceutical and aromatic compounds.

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