***Review Article***

**Recent Approaches and Improvements in the Nutritional Status of Vegetable Crops**

**ABSTRACT**

An increasing global population, inadequate food and nutrition, malnutrition, and vitamin and micronutrient deficiencies plague most developing countries worldwide. Vegetables are the greatest and least expensive sources of nutrients, especially for vegetarians, and are an essential part of balanced diets that contribute to human growth and development. Concerns over health and nutrition have led vegetable breeders topay more attention to the quality of their vegetables and value-added products. Traditional agricultural practices can partially increase the nutritional value of plant products, but biofortification is the enrichment of food crops with nutrients using agronomic, conventional, and transgenic breeding methods to achieve a long-term sustainable strategy to eliminate the harmful effects of vitamins and nutrients. Many land races, historical varieties, pre-breeding lines, and wild relatives are excellent sources of nutrients. The ideal methods for increasing the nutritional concentration in vegetables would be appropriate poly-cross breeding techniques combined with population evaluation on a broad scale. In addition, a number of agronomic techniques like grafting and soilless culture, along with the application of biotechnological tools and molecular marker-assisted selection, would undoubtedly speed up the process and increase the probability of success in nutrient enhancement of vegetable crops.

**Keywords:** Vegetables, Nutrition, Breeding, Biofortification, Minerals

1. **INTRODUCTION**

The improvement in the nutritional status of vegetable crops is of extreme significance as it directly affects the quantity and quality of nutrients to be had for human consumption. Vegetable crops are rich sources of vitamins, minerals, and other essential nutrients that play a vital role in retaining good health and preventing numerous diseases. Therefore, improving the nutritional profile of vegetable crops is significant in areas of research and development in agriculture. One important component of enhancing the dietary status of vegetable plants is the selection of suitable types or cultivars with stronger nutritional attributes. Traditional breeding techniques have been used to develop varieties with increased levels of nutrients, including vitamins, minerals, and antioxidants. For example, breeders have focused on improving the Vitamin C content in vegetables like tomatoes and peppers, as well as boosting the iron and zinc levels in leafy greens including spinach and kale. By selecting and breeding plants with better nutrient contents, farmers can grow vegetable crops that provide greater nutritional value to consumers.

In recent years, genetic engineering has emerged as a powerful tool to improve the nutritional status of vegetable crops. This technique involves making targeted changes inside the plant's genome to introduce unique genes that promote the biosynthesis of desirable nutrients. Genetic engineering can be used to fortify vegetable crops with crucial nutrients and minerals, thereby significantly enhancing their nutritional high-quality. For example, the development of genetically changed (GM) crops like Golden Rice, which is enriched with vitamin A, has proven great promise in preventing Vitamin A deficiency, a major worldwide health issue. Other genetically engineered crops aim to increase the levels of positive antioxidants, consisting of lycopene or flavonoids, that have been related to numerous health advantages.

Furthermore, advances in agronomic practices also make a contribution to the improvement within the nutritional status of vegetable crops. Optimizing soil fertility control through the application of organic or inorganic fertilizers can influence the nutrient content of vegetables. Adequate and balanced nutrient supply to vegetables during their growth cycle is vital for obtaining crops with most appropriate nutrient levels. Additionally, the appropriate use of water, temperature manipulation, and pest control measures to minimize crop stress can definitely affect the nutrient composition of vegetable crops. To make sure the availability of nutritionally superior vegetable crops, efficient post-harvest handling and storage techniques are important. Proper harvesting, handling, and processing of vegetables can help preserve their nutritional content and prevent nutrient loss. Techniques like blanching, canning, freezing, and dehydration can help to retain vitamins and minerals. Furthermore, research on novel preservation methods, together with vacuum packaging or modified atmospheric packaging, aims to preserve the best and nutritional quality of vegetables for prolonged time.

* 1. **Government’s Initiatives to Reduce Undernutrition**

The Government of India recognized the importance of a program to address malnutrition and introduced Poshan Abhiyan in 2018, which encompasses various initiatives and policy measures aimed at reducing the high rates of undernutrition in the country. The success of Poshan Maah heavily relies on the level of community involvement in activities and programs throughout the month. Since its inception in India, different themes have been used to promote dietary knowledge. In 2023, the theme was "Suposhit Bharat, Sakshar Bharat, Sashakt Bharat," translating to Nutrition-rich India, Educated India, Empowered India, highlighting the integration of nutrition with education and empowerment for holistic development.

Government programs

1. Balwadi Nutrition Program
2. Special nutrition program
3. Integrated Child Development Services Program (ICDS)
4. Wheat-based nutrition program
5. Nutrition program for adolescent girls
6. National program for the prevention of nutritional anaemia
7. Weekly Iron and Folic Acid Supplementation Program for Adolescents
8. National Nutrition Blindness Prevention Program
9. The midday meal program
10. Chiranjivi Yojana
11. Antyodaya Anna Yojana
12. The WHO introduced the "Expended Programme of Immunization" (EPI) in 1974.

**1.2 Nutritional Quality of Vegetables**

Nutrients: the organic and inorganic compounds found in food that are necessary for life and health, giving us energy, acting as building blocks for growth, and controlling chemical reactions. Nutritional quality pertains to the inherent biological or health value of food, including the proportion of beneficial to harmful elements like flavour, aroma, freshness, and shelf life that influence consumer choices. Vegetables play an important role in maintaining health and preventing diseases as these are rich in vitamins, antioxidants and phytochemicals.

A number of vitamins such as A, C, E, as well as carotene are excellent antioxidants, which also contribute to good health through other mechanisms, such as being co-factors for certain enzymes, and their involvement in oxidation reduction reactions [1-2]. Increase in vegetable consumption reduces the risk of cancer by 15%, cardiovascular disease by 30% and mortality by 20% [3], by increasing the availability of antioxidants such as ascorbic acid, vitamin E, carotenoids, lycopene, polyphenols, and other phytochemicals [4]. A diet rich in fresh vegetables protects individuals from the risk of most common epithelial cancers. Selected antioxidants, β-carotene, vitamins C and E showed a significant inverse relation with the risk of oral, pharyngeal, oesophageal and breast cancers [5]. Moreover, Table 1 indicates some important vegetables with their nutritional value [6].

**Table 1. Nutrient-Rich Vegetables Categorized by Their Key Vitamins and Minerals**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Vegetable** | **Key nutrients** | **Major Vitamins** | **Major minerals** | **Health Benefits** |
| Spinach | Iron, Fiber, Protein | A, C, K, B, E | Iron, Calcium, Magnesium, Potassium | Boost immunity, supports bone health and improves vision. |
| Carrot | Beta-carotene, Fiber | A, C, K | Potassium | Eye health, Skin glow, helps in digestion. |
| Tomato | Lycopene, Fiber | A, C, K, B9 | Potassium, Magnesium | Reduces heart disease risk. |
| Cauliflower | Fiber, Choline | C, K, B6 | Potassium, Magnesium | Supports brain health and digestion. |
| Potato | Carbohydrates | C, B6 | Potassium, Magnesium | Provides energy and supports nerve function. |
| Pepper, Bell pepper, Sweet pepper | Antioxidant | C, A, B6, E | Potassium, iron | Skin health, strengthens immune system |
| Beet root, Sea beet, Swiss chard, sugar beet | Nitrates, Fiber | C, B9 | Iron, Magnesium, Potassium | Improves blood circulation and lowers blood pressure. |

**2. BREEDING APPROACHES FOR IMPROVED NUTRITIONAL QUALITY**

Biofortification is a term that combines the Greek word "bios" (meaning "life") with the Latin word "fortificare" (meaning "to make strong"). According to [7], it refers to the nutrient enrichment of crops as a means of mitigating the detrimental effects of vitamin and mineral deficiencies in humans and their health. Unlike ordinary fortification, which adds nutrients to meals after they are processed, bio-fortification concentrates on increasing the nutritional value of plant foods while the plants are still growing. Creating bio-fortified crops also increases the crop’s ability to thrive efficiently on soils with low or unavailable mineral content. It consists of breeding new **s**taple food varieties with a higher mineral and vitamin content. Developing biofortified crops also increases their ability to grow more efficiently on soils with scarce or low mineral content [8]. It can be described as a complementary rural micronutrient program strategy to better reach remote areas, which often constitute the majority of the malnourished vulnerable population. Conventional breeding and genetic techniques are two approaches used to biologically enrich crops with minerals such as iron and zinc [9]. This approach not only reduces the number of severely malnourished people who need treatment with additional interventions, but also helps them maintain a better nutritional status. Additionally, it is a viable way to reach malnourished rural populations that may have limited access to commercially available fortified foods and supplements [10]. For example, the World Health Organization (WHO) estimates that biofortification can help to treat two billion individuals suffering from anaemia due to iron deficiency [11].

**3. METHODS OF BIOFORTICATION**

**3.1** **Agronomic biofortification** - use of fertilizers to increase micronutrients in edible parts [7]. Foliar application is a quick and easy method. Several agronomic techniques such as seed treatment, foliar treatment, application of organic fertilizer are used to improve the nutritional value of various vegetable crops. These different agronomic approaches are relatively cheaper and faster as compared to other breeding methods as they are useful for increasing the mineral content of various vegetables. However, these methods cannot be used to fortify the contents of different phytochemicals such as terpenes, chlorophylls, polyphenols, and organo-sulphur compounds.

**3.1.1 Biofortification of crops with Iron**

Tomatoes are a good crop for iodine-biofortification projects because they can withstand high quantities of iodine, which is stored in both the vegetative tissues and fruits at concentrations that are more than sufficient for human consumption. The amount of iodine found in the fruit of plants treated with 5 mM iodide was more than sufficient to meet a 150 μg daily requirement for humans [12]. Using *Spirulina platensis* as a microbial inoculant increased the iron levels of *Amaranthus* plants when compared with control. He also reported that *Spirulina platensis* has been employed as a biofortifying agent to improve the iron status in *Amaranthus gangeticus* plants [13].

**3.1.2 Biofortification of crops with Zinc**

With foliar Zn application at a rate of 1.08 g /plant, the relationship between tuber Zn content and Zn application followed a saturation curve, peaking at about 30 mg Zn kg–1 DM. Even after applying 2.16 g of Zn per plant by foliar application, the concentration of Zn in the shoots increased 40 times more than in the unfertilized controls. Zinc enrichment is facilitated by the application of "Riverm" fertilizer when cultivating tomatoes, eggplants, and sweet peppers. Vegetables that have been biofortified had 6.60–8.59% more zinc than control.

**3.1.3 Biofortification of crops with Selenium**

Beneficial forms of organic-Se can be added to broccoli and carrots by using Se-enriched *S. pinnata* as a soil supplement. A solution of 77Se (IV) that was enriched to 99.7% as 77Se was applied by foliar application for biofortifying onions and carrots [14]. The application of selenium had no effect on the oil content or yield of brassica vegetables [15]. A high concentration of selenium (1.92–1.96 μg Se g−1) was found in the meal and seeds [16].

**3.2** **Conventional plant breeding** - Parental lines with high vitamin or mineral content can be crossed over several generations to produce plants with desired nutrients. Popular traditional breeding techniques including hybridization, selection, and introduction have been used to generate nutraceuticals in tuber crops and vegetables. This approach makes advantage of the inherent qualities of the crop, but it might take a very long time to generate new varieties as well as the success of the breeding programme depends upon the available variability [17]. Recent advances in conventional plant breeding have emphasized the enrichment of essential vitamins, antioxidants and trace elements. The possibility of increasing the density of micronutrients in the staple food with conventional breeding requires sufficient genetic variation in the concentrations of β-carotene, other functional carotenoids, iron, zinc and other minerals in the varieties, which makes it possible to choose nutritionally appropriate breeding materials [7].

The Indian Agricultural Research Institute (IARI) has increased efforts to develop nutritious vegetables, especiallyfor temperate vegetables. Several donor parents have been identified in different vegetables with nutraceutical properties (Table 2).

**Table 2: Donor parents in different vegetables with nutraceutical traits**

|  |  |  |
| --- | --- | --- |
| **CROP** | **TRAIT** | **DONOR(S)** |
|  | High Ascorbic acid | *S*. *pimpinellifolium,* Double Rich |
| Tomato | Pro-vitamin A (beta carotene) | Crimson and Caro Red |
| Potato | High protein content | *S phureja*, *S. vernei* |
| Pea | Protein | GC 195, Kinnauri, Laxton |
| Pumpkin | Carotene | Golden Delicious |
| Carrot | Vitamin A | Pusa Meghali |
| Pepper | Carotene | Douxed Alger |

**3.3 Genetic engineering** - allows breeders to add desired transgenes into elite varieties.

**4. GLOBAL STATUS OF BIOFORTIFIED CROPS**

Harvest plus is part of CGIAR's Research Program on Agriculture for Nutrition and Health which was launched in 2004, as a joint venture between CIAT and IFPRI [18]. By 2023, Harvest Plus and its partners have released a total of 443 biofortified varieties across 13 staple crops in 41 countries including Africa, Asia, and America. Additionally, candidate biofortified varieties across 12 crops are undergoing evaluation for release in an additional 20 countries.

**4.1 Biofortification And Zero Hunger Challenge:**

• Second Global Conference on biofortification recommends United Nations to celebrate 2018- 2020 as the International Year of Biofortified and Underutilized Crops.

• To meet the challenge of Zero Hunger by 2030.

**5. BIOFORTIFIED CROP VARIETIES RELEASED IN INDIA**

1. **Cauliflower:** **Pusa Betakesari**: It was introduced in 2016 as the country's first biofortified variety, boasting high levels of β-carotene (8.0-10.0 ppm) compared to other popular varieties with negligible amounts. With a curd yield of 40.0-50.0 t/ha, this cauliflower is specifically adapted for the National Capital Region of Delhi. Developed by the ICAR-Indian Agricultural Research Institute in New Delhi, this cauliflower variety offers a nutritious and high-yielding option for farmers in the region.

2. **Cabbage: Kinner Red**: It was released in 2016, is a cultivar that is rich in anthocyanin. Its heads are vibrant red in colour. This cabbage variety is tolerant to Diamond back moth and has a unique coat of wax. It takes approximately 90 days from transplanting to form a head, which typically weighs between 1-2 kg. The Kinner Red cabbage was developed by Dr. Y.S. Parmar University of Horticulture & Forestry.

3. **Potato: Kufri Neelkanth:** This variety was released in 2017, having purple ovoid tubers with shallow eyes and yellow flesh. It contains a high anthocyanin content, with a tuber yield of 38 t/ha after a 90-day duration. This variety is specifically adapted for the North Indian Plains and was developed by ICAR-CPRI in Shimla.

4. (i)The orange-fleshed **Sweet potato, Bhu Kanti,** is characterized by its composition: Dry matter content: 27%, Total sugar content: 2.3%, Starch content: 16.8% and B carotene content: 7.4 mg/100g.

(ii) **Bhu Krishna:** This variety was released in 2017 with a high anthocyanin content of 90.0 mg/100g. It has a tuber yield of 18.0 t/ha and a dry matter content of 24.0-25.5%. The starch content is 19.5% and the total sugar content ranges from 1.9-2.2%. It is also known for its tolerance to salinity stress and is well-adapted to the region of Odisha. This variety was developed by ICAR-Central Tuber Crops Research Institute in Thiruvananthapuram, Kerala.

(iii) **Bhu Sona:** This variety was released in 2017 having a high β-carotene content of 14.0 mg/100 g. It offers a tuber yield of 19.8 t/ha, with a dry matter content ranging from 27.0% to 29.0%, starch content of 20.0%, and total sugar content between 2.0% and 2.4%. It is well-suited for cultivation in Odisha and was developed by ICAR-Central Tuber Crops Research Institute in Thiruvananthapuram, Kerala.

|  |  |  |
| --- | --- | --- |
| **Pusa Betakesari** | **Kinner Red** | **Kufri Neelkanth** |
| **Bhu Kanti** | **Bhu Sona** | **Bhu Krishna** |

**Plate 1:** **Biofortified crop varieties introduced in India**

**5.1 Breeding Methods**

1. **Introduction** - This refers to the introduction of crops from their place of cultivation to areas where they have never been cultivated before. it means the process of bringing crops to new areas.
2. **Selection** - release of varieties from germplasm is one of the simplest breeding principles. Selections are used to develop and release several nutritious vegetables and colorful varieties.
3. **Hybridization** - The nutritional value of cucumber (*Cucumis sativus* L.) can be improved by introducing genes for β-carotene (i.e. provitamin A and/or orange flesh) from Xishuangbanna pumpkin (XIS; *Cucumis sativus* var.). *Xishuangbannanesis* Qi et Yuan) for US pickling cucumber (*Cucumis sativus* L. var. *sativus*). However, the genetics of β-carotene content in this US market type has not been clearly defined [19].
4. **Somaclonal Variation**- Tissue culture derived plants show variation termed soma clonal variation. A significant cause of this variance is chromosomal rearrangements. A sweet potato cultivar known as "Scarlet" that has a darker and more consistent skin tone than its parent cultivar while also producing more and exhibiting traits of disease resistance.
5. **Mutagenesis-** Mutagenesis is a process by which the genetic information of an organism is changed by the production of a mutation. It may occur spontaneously in nature, or due to exposure of mutagens.

**Table 3: Carotenoid pathway mutants in Tomato and Pepper**

|  |  |  |  |
| --- | --- | --- | --- |
| **Species** | **Mutant Name** | **Phenotype** | **References** |
| Tomato | R (yellow flesh) | Yellow fruit colour | [20] |
|  | Delta | Orange fruit colour | [21] |
| Tangerine | Orange fruit colour | [22] |
| Beta | Orange fruit colour | [23] |
| Pepper | y (yellow) | Yellow fruit colour | [24] |
| c2 | Yellow fruit colour | [25] |

1. **Polyploidy**- Polyploidy can be induced due to aberration in cell division. Polyploidy can be artificially induced by the application of colchicine.

**5.2 Use of transgenic techniques for nutraceutical biofortification**

Genetic engineering has allowed vegetable breeders to incorporate desired transgenes into elite varieties to improve their value, nutritional value and other health benefits [26]. Nutraceuticals in vegetable crops are being developed using a variety of transgenic techniques that are gaining popularity. This is a very quick procedure that works well with superior varieties. This method allows the breeder to transfer a favourable gene responsible for a specific nutritional value into a cultivated variety with a wider range of adaptability. Many vegetable crops have been genetically modified to improve characteristics such as higher nutritional value or better taste and to reduce bitterness, slow ripening, higher nutritional value, seedless fruits, increased sweetness and reduced nutritional factors. Many vegetable crops have been genetically modified by various transgenic techniques to achieve better taste, better nutritional value, seedless fruits, increased TSS, acidity, reduced nutritional factors, reduced bitterness, delayed ripening and extended shelf life.

**Potato-** To increase the total protein content of potato the AmA1 gene of Amaranthus seminal albumin was expressed in potato tubers [27]. The protein content of transgenic potato lines "Protato" increased by 48%.

**Tomato** – A transgenic tomato was developed to improve the carotenoid content and profile of tomato fruit by increasing the β-carotene content approximately threefold to 45% of the carotenoid content of cultivar 'Ailsa Cray' [28].

**Cauliflower -** The successful cloning of the Or gene in cauliflower demonstrates that carotenoid accumulation is significantly impacted by the manipulation of chromoplast formation to offer an efficient metabolic sink for carotenoid sequestration and deposition. An alternative new strategy to complement effects that depends on the expression of carotenogenic genes for raising carotenoid levels in food crops is demonstrated by the use of the Or gene to boost carotenoid content in transgenic potatoes [29].

**Cabbage -** Red cabbage has high antioxidant content and abundance of anthocyanins which can reduce the risk of cancer, cognitive problems and cardiovascular disease [30].

**Carrot -** A transgenic carrot with elevated Ca content may improve Ca uptake and lower the risk of calcium deficiencies like osteoporosis. Higher amounts of the plant Ca transporter SCAX1 were expressed in transgenic carrots [31].

**Pumpkin** - There was an increase in the amounts of β-carotene isomers and total carotenoids in pumpkin with several cooking techniques [32].

**Cyanogen-free cassava**- Linamarin, a cyanogenic glucoside, is present in cassava at potentially harmful quantities [33]. The maximum permitted cyanide level (10 mg CN equivalents/kg dry weight) in foods set by the FAO is lower than the cyanogen levels found in the leaves (200–1, 300 mg CN equivalents/kg dry weight) and roots (10–500 mg CN equivalents/kg dry weight) of several cassava varieties. Maceration, soaking, washing, and baking can lower the cyanogen concentration of cassava meals to acceptable levels; however, short-cut processing methods might result in toxic food items.

**6. PIGMENTS IN VEGETABLE CROPS**

Colourful vegetables have enormous nutritional and medicinal value.  Colour in vegetables contributes to photosynthesis, pollination by attracting pollinators, nutritional value and increases consumers. Pigments make nature colourful and pleasant. Plant pigments generally refer to four known classes: chlorophylls, carotenoids, flavonoids and betalains (Table 4). Each category may contain several chemical compounds that can be structurally classified into separate subgroups. Dark and strongly coloured vegetables usually contain more chemically active antioxidant pigments than light coloured. Eating a mix of different coloured vegetables nourishes our body with different nutritional compounds. Breeding for colour development improves the nutritional content of vegetable crops, which minimizes the risk of cancer, obesity and cardiovascular disease, and enables the development of a new generation of varieties with improved bioactive properties [34].

**Table 4: Pigments in vegetable crops: Types & Distribution**

|  |  |  |  |
| --- | --- | --- | --- |
| **Pigment class** | **Main subgroups** | **Typical colours** | **Examples** |
| **Carotenoids** | Carotenes, lycopene and xanthophylls | Orange, yellow, red | Carrot, tomato, water melon, pepper, Leafy Vegetables |
| **Flavonoids** | Anthocyanins;  Flavonols | Purple, blue, red | Eggplant, red  Cabbage, onion |
| **Betalains** | β-cyanins and  β-xanthins | Red, orange, yellow | Beet, Swiss  Chard |
| **Chlorophylls** | a and b | Green | Any green plants |

**7. VEGETABLES AS NUTRACEUTICALS**

Nutraceuticals are any substance that is a food or a component of a food that has health or medical advantages such as prevention and treatment of diseases. Any item that is a food or a component of a food that has health or medical advantages, such as illness prevention and treatment, is considered a nutraceutical. In 1989, Dr. Stephen De Felice, the Chairman of the Foundation for Innovation in Medicine, coined the terms "Nutrition" and "Pharmaceutical" to create the term "Nutraceutical" [35].These are the main source of biologically active nutraceuticals that are safe, efficient, and may have both therapeutic and nutritional benefits. Many nutraceuticals, such as vitamin C, E, and carotenoids, are antioxidants and may help prevent certain cancers and heart diseases [36].

**7.1 Anti-Nutritional Factors in Vegetables and Their Improvement**

Plants produce anti-nutritional factors as defense strategies to protect themselves which are primarily pathogen protective chemicals which have harmful effects on human health. So, these antinutrient compounds in plants need to be reduced by different methods like blanching, fermentation, soaking in hot water and cooking methods to enhance nutrient potential of vegetables.

**7.2 Nutritional Advantages of Less-Utilized Vegetables**

Underutilized crops are plant species with untapped potential that can significantly contribute to environmental sustainability, income generation, public health, and food security. These vegetables generally possess a superior nutritional profile compared to refined varieties with medicinal properties [37]. The Himalayan and sub-Himalayan regions of India are home to a wide array of underutilized vegetables, including crops from families like Brassicaceae, Cucurbitaceae, and Solanaceae, as well as various roots, beans, spices, tubers, and leafy greens [38]. Underused vegetables, being highly tolerant to various biotic and abiotic stresses, not only contribute to the diversity of diets and provide a better-balanced supply of micronutrients but can also be effectively utilized in plant breeding programs [39].

**8. CONCLUSION**

As vegetable crops are becoming more prevalent in consumer diets, their nutritional qualities and related health advantages becomes more crucial. Breeders are placing more emphasis on breeding programs aimed at enhancing the nutritional content, complex quality, attributes and shelf life of vegetables. Moreover, improving the nutritional quality of vegetables is the key to tackle malnutrition and ensure better health. Breeding, biofortification and modern farming techniques have helped boost essential nutrients in crop. With new, nutrient rich varieties and smarter farming methods, we can make healthy food more accessible. Let us work together to create a New India, where the diversity of our food can be restored and undernutrition and malnutrition can be eradicated by combining science with traditional knowledge, we move closer to a future where everyone has access to nutritious meals.

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