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Review Article

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Biofortification of Vegetables

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ABSTRACT

Vitamin A, Iron and zinc mineral deficiency are the most common and widespread, afflicting more than half of the human population. Mineral malnutrition can be addressed through dietary diversification, mineral supplementation, food fortification and/or increasing mineral concentrations in edible crops. To overcome the hidden hunger, biofortification of vegetables is a most feasible and economical approach. The main daily food source is the staple crops especially in developing countries of the world, which mainly include vegetables i.e., cassava, beans, sweet potato, yam. These kinds of plants are often deficient in some of mineral elements. Thus, the increasing of bio available concentration of micronutrients in edible crop tissues via biofortification of vegetables has become a promising strategy in modern agriculture, providing more nutritious foods, to more people, with the use of fewer lands .However, Bio-fortification of vegetables is relatively new concept in India and to alleviate this malnutrition problem, it is the best option to improve the quality of the plants through the addition of the desired minerals to food stuffs.

Key words: *Malnutrition, Biofortified Vegetables, Nutrition*

INTRODUCTION

Deficiency of mineral is one of the main global challenges to human health. It is known as 'Hidden hunger', results in poor growth and compromised psychomotor development of children, reduced immunity, fatigue, irritability, weakness, hair loss, wasting of muscles, sterility, and death. Vitamin A and zinc deficiencies are estimated to cause 600,000 and 400,000 deaths annually, respectively [1.]Iron and zinc mineral deficiency are the most common and widespread, afflicting more than half of the human population. Bio fortification is the process of adding nutritional value to the crop. It refers to nutrient enrichment of crops to address them negative economic and health consequences of vitamin and mineral deficiencies in humans [2].

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Developing biofortified crops also improves their efficiency of growth in soils with depleted or unavailable mineral composition [3].India is one of the countries having problem of malnutrition As per India state hunger index, all the states are with serious to alarming indices with M.P. most alarming. To overcome the hidden hunger and it is the best option to improve the quality of the plants through the addition of the desired minerals to food stuffs.

BIOFORTIFICATION

Biofortification refers to increasing genetically the bio-available mineral content of food crops .It consists of breeding new varieties of staple foods that have higher mineral and vitamin content. it can be described as a complementary, rural- targeted micronutrient program strategy for better reaching remote regions, which often comprise the majority of the malnourished vulnerable populations .Developing bio-fortified crops also improves their efficiency of growth in soils with depleted or unavailable mineral composition. Bio-fortification differs from ordinary fortification because it focuses on making plant foods more nutritious as the plants are growing, rather than having nutrients added to the foods when they are being processed.Conventional breeding and genetic engineering techniques are the two approaches that may be used to bio-fortify the crops with minerals like iron and zinc[4] .This approach not only will lower the number of severely malnourished people who require treatment by complementary interventions, but also will help them maintain improved nutritional status. Moreover,it provides a feasible means of reaching malnourished rural populations who may have limited access to commercially marketed fortified foods and supplements.

Importance and goal of Biofortification

It is especially important for poor rural community with limited access to diversified diet, commercially marketed fortified foods, or supplements and also important for woman and children since they face greater risk of micronutrient malnutrition and the goal of biofortification is to help reduce the high prevalence of iron, zinc and vitamin A deficiencies by improving the micronutrient density of the staple food crops that are produced and consumed by low-income populations. Unlike traditional food fortification, biofortification does not require food to be processed centrally, as the micronutrients are already present in growing crops, making it more accessible to those who consume food that is grown locally, perhaps by themselves[5] .Biofortification is a long-term strategy aimed at increasing the micronutrient intake of large numbers of people throughout their lives, contributing to an overall reduction in micronutrient deficiencies in a population. However, it is not expected to treat severe micronutrient deficiencies or eliminate them in all population groups. Even so, the introduction of biofortified crops will provide a sustainable and low-cost way of reaching people with poor access to formal markets or healthcare systems.

Three things must happen for biofortification to be successful

In broad terms, three things must happen for biofortification to be successful. First, the breeding must be successful – high nutrient density must be combined with high yields and high profitability. Second, efficacy must be demonstrated – the micronutrient status of human subjects must be shown to improve when consuming the biofortified varieties as normally eaten. Thus, sufficient nutrients must be retained in processing and cooking and these nutrients must be sufficiently bio available. Third, the biofortified crops must be adopted by farmers and consumed by those suffering from micronutrient malnutrition in significant numbers. The pathway for bio-fortified crops" as suggested by HarvestPlus is divided into the following three stages 1) discovery 2) development and 3) dissemination of the newly developed plant variety

1. Discovery

The overlap of cropping patterns, consumption trends, and prevalence of micronutrient malnutrition, as well as *ex ante* cost-benefit analyses, determine target populations and focus crops. Nutritionists then work with breeders to establish nutritional breeding targets. These target levels take into account the average food intake and habitual food consumption patterns of target population groups, nutrient losses during storage and processing, and nutrient bioavailability.

Under Harvest Plus, breeding targets are set such that, for preschool children4-6 years old and for non-pregnant, non-lactating women of reproductive age, the incremental amount of iron will provide approximately30 percent of the Estimated Average Requirement (EAR), that incremental zinc will provide 40 percent of the EAR, and that incremental provitaminA will provide 50 percent of the EAR. Bioavailability of iron was originally assumed to be in vegetable 5 percent for beans, (10 percent for cassava, and sweet potato), that of zinc 25 percent for all staple crops, and for pro-vitamin A 8.5 percent for all staple crops (12 molecules of beta-carotene produce 1 molecule of retinol, the form of vitamin-A used by the body).

Plant breeders screen existing crop varieties and accessions in global germplasm banks to determine whether sufficient genetic variation exists to breed for a particular trait. Initial research indicated that selection of lines with diverse vitamin and mineral profiles could be exploited for genetic improvement [6]. Genetic transformation is an alternative method to incorporate specific genes that express nutritional density.

2. Development

Crop improvement includes all breeding activities. Initial product development is undertaken at international research institutes to develop varieties with improved nutrient content and high agronomic performance, as well as preferred consumer qualities. When promising high-yielding, high-nutrient lines emerge, they are tested by national research partners and the best-performing lines then selected to submit to national governments for release. The formal release process varies by country, but in general requires that a variety be grown and evaluated in several different locations (called multilocational trials) for at least two seasons, and its performance compared to other candidate and widely released varieties, before the national government approves the variety for dissemination. The breeding, testing, and release process can take 6 to 10 years to complete. Parallel to crop improvement, nutrition research measures retention and bioavailability of micronutrients in the target crop under typical processing, storage, and cooking practices. Initially, relative absorption is determined using in vitro and animal models and, with the most promising varieties, by direct study in humans in controlled experiments. Randomized, controlled efficacy trials demonstrating the impact of biofortified crops on micronutrient status and functional indicators of micronutrient status (i.e.visual adaptation to darkness for pro-vitamin A crops, physical activity for iron crops, etc.) provides evidence to support biofortified crops as alternative public health nutrition interventions. Economics research on consumer and farmer evaluation of biofortified varieties, as well as varietal adoption studies, further informs crop improvement research during the development phase.

3. Dissemination

Biofortified crops must be formally released in the target countries prior to their delivery to the target populations. Economists lead consumer acceptance, varietal adoption, and seed and grain value chain studies to inform effective, efficient, and targeted delivery and marketing strategies to maximize adoption and consumption of these crops

BIOFORTIFIED VEGETABLES

In the past, great efforts have focused only on increasing crop yields, but enhancing the concentrations of mineral micronutrients has become an urgent task. The main daily food source is the staple crops especially in developing countries of the world, which mainly include vegetables i.e., cassava, beans, sweet potato, yam. For example Cassava, an important crop in many developing countries, contains iron and zinc only in low concentrations. These kinds of plants are often deficient in some of mineral elements. Thus, the increasing of bioavailable concentration of micronutrients in edible crop tissues (via biofortification of vegetables) has become a promising strategy in modern agriculture, providing more nutritious foods, to more people, with the use of fewer lands .

Vegetable crops are important part of the daily diet. Therefore biofortifying vegetables can contribute alleviating the micronutrient deficiency. Bio fortification of vegetables for health benefit is a relatively recent phenomenon, and has been particularly highlighted by the effort and funds that have been put into alleviating human malnutrition deficiencies. Biofortification of vegetables is under the process of development in many parts of the world. However, it is relatively new concept in India.

Targeted vegetable crops for biofortification

- **Potato**
- **Cassava**
- **Sweet potato**
- **Cowpeas**
- **Yam**

Beans

Biofortified Nutrients Target in vegetables

Crop	**Target nutrients**
Cassava	β-Carotene
Sweet potato	β-Carotene
Beans	Iron
Potato	Iron

Strategies of biofortification of vegetables

In general, three complementary strategies can be employed to increase mineral concentrations in edible crops.

1. Agronomical biofortification
2. Conventional breeding
3. Genetic enginnering

1. Agronomical biofortification

One of the most important strategy is "agronomical" biofortification, employs the use of fertilizers containing the mineral elements lacking in human diets. A common limitation for agronomical biofortificationis the generally low phyto availability of mineral micronutrients in the soil. Thus, the agronomic efforts have been directed toward the application of mineral fertilizers and the improvement of the solubilisation and mobilization of mineral elements in the soil Principally Zn, Cu, Fe, I, Se, Mg, and Ca are the main micro and macro elements which are applied as soil inorganic fertilizer, amendments (such as composts and manures). The high pH of soil inhibits the minerals uptake therefore acidifying fertilizers (such as urea, ammonium nitrate, ammonium sulphate, ammonium phosphates, or elemental S) are useful to rectify soil alkalinity or lime. Appropriate crop rotations, intercropping, or the introduction of beneficial soil microorganisms to increase the phytoavailability of mineral elements could also be important tools of agronomical biofortification [7].Several authors have reviewed appropriate methods, infrastructural requirements, and practical benefits for food production, economic sustainability, and human health of agronomic biofortification of edible crops[8] .The agronomical biofortification by soil fertilizers are relatively simple with fast results but the success of it depends on several factors such as physical and chemical characterisation of soil, mineral mobility and soil microbial activities. Therefore this method cannot be seen as an universal approach for enhancing the micronutrient levels in edible crop tissues[9]. Several times mineral elements (such as Fe or Zn) become rapidly unavailable to roots, the use of foliar fertilizers, rather than soil fertilizers, is recommended[10] fertifortification (urea + iron + zinc) could be the potential strategy for attaining higher yield and nutritional security of the vegetarian population in India[11].

2. Conventional plant breeding

Traditional breeding mainly focused on yield attributes breeding from last four decades and lack of priority on nutritional aspects lead's to decreased amount of nutrient status in the existed varieties. Examples of minerals that their concentration in the dry matter has declined in several plant-based foods are Fe, Zn, Cu and Mg[12]. Recent progress in conventional plant breeding has given emphasis on fortification of important vitamins, antioxidants and micronutrients. The potential to increase the micronutrient density of staple foods by conventional breeding requires adequate genetic variation in concentrations of β-carotene, other functional carotenoids, iron, zinc, and other minerals exists among cultivars, making selection of nutritionally appropriate breeding materials possible[13]. Fe and Zn levels and up to a 6.6-fold variation has been reported in beans and peas. Apparently, this genotypic variation is generally more reduced in tubers White and and in fruits (e.g. Fe, Zn, Ca and Mg concentrations in strawberry differed less than 2-fold[14]. Steps in biofortification by breeding are: Discovery (1.Identify target populations, 2. Set nutrient target levels, 3. Screen germplasm and gene), Development (4. Breed biofortified crops, 5. Test performance of new crop varieties, Measure nutrient retention in crops/food, Evaluate nutrient absorption and impact) Dissemination (8. Develop strategies to disseminate seeds, 9. Promote marketing & consumption of biofortified food), (10. Improve nutritional status of target populations)

3. Genetic engineering

Lack of sufficient variation among the genotypes for the desired character/trait within the species or when the crop itself is not suitable for conventional plant breeding (due to lack of sexuality; e.g. banana) then genetic engineering offers a valid alternative for increasing the concentration and bioavailability of micro nutrients in the edible crop tissues. One of the main concerns is the so-called 'gene flow' environmental problem, i.e. the concern of transfer of foreign genes to non-target species[15].Targets for transgenes include, redistributing micronutrients between tissues, increasing the efficiency of biochemical pathways in edible tissues, or even the reconstruction of selected pathways. Some strategies involved in the removal of 'antinutrients'. For Instance, one of the first biofortified crops was golden rice, which was engineered to produce beta-carotene or provitamin A in the edible portion of the grain[16]. Since then, there have been similar successes with other crops, giving us a variety of carotenoid-enriched foods[17] as well as crops enriched with other micronutrients such as vitamin E .In the same way this approach is also being applied to other crops, including maize, orange cauliflower, tomato, yellow potatoes and golden canola. Feeding trials by [18] demonstrated that calcium absorption was significantly increased in both mice and humans by biofortified carrots. The genetic engineering has moved into a new phase that aims at (i.e. 'multigene transfer') ex: 'Multivitamin corn' which is engineered to produce higher levels of provitamin A, vitaminB9, and vitamin C (b -carotene, folate, and ascorbate). Promissing lines has been identified which contained 169-fold more b -carotene, 6.1-fold more ascorbate and double the amount of folate as found in endosperm. Micronutrient powders, popularly known under their original name of Sprinkles, are a form of 'home fortification that also provide several nutrients at once. In sachets for a single serving, they are sprinkled on top of normal foods. Beginning with just, encapsulated iron, they have now developed numerous varieties, with as many as 15 vitamins and minerals, appropriate for the nutritional problems of specific areas.

Target vegetable crops present status and future projects

Biofortification works have been practiced in most of the Vegetable crops like Cassava, Beans, Potato, Orange sweet potato (OSP), Cowpea, Pumpkin etc. Several conventional and transgenic varieties have been released.

Orange sweet potato (OSP)

To increase targeted level of 30 ppm of provitamin A in sweetpotato, International Potato Center (CIP) in south Africa and Uganda (Harvest plus) + National agriculture Research and Extension System (NARES) started project in 2002-2007 and the first variety released in 2002.This variety have ability to grater provitamin A retention more than 80% after boiling or steaming and at least 75% after solar or sun drying but also high yielding and drought tolerant. Harvest Plus and its partners distributed OSP to more than 24,000 households in Uganda and Mozambique. Biofortified varieties are now being introduced in many parts of Africa and South America, as well as China. In 2009, CIP launched its Sweet Potato for Profit and Health Initiative (SPHI), which seeks to deliver OSP to 10million households in Africa by 2020.

Bio Cassava+

Project on Bio Cassava Plus initiative started in 2009 by Donald Danforth Plant Science Center to target Nigeria, Kenya with 6 major objectives namely to increase the minerals zinc and iron, vitamins A and E, protein contents and decrease cyanogen content, delay postharvest deterioration, and develop virus-resistant varieties. The scientists of Nigeria have developed three new yellow colour varieties of cassava by and selective breeding methods. These varieties can produce higher amount of beta-carotene which helps to fight against vitamin A malnourishment in the region[19] and release of the varieties will be in 2017.

Potato

CIP (International centre for potato) started project on development of Fe rich potatoes by conventional biofortification method in 2009 and the varieties will be release in 2017.

Cow pea

Pioneer research on biofortifcation of cow pea has initiated G.B. Pant University of Agriculture and Technology, Pantnagar, India. Two early maturing high iron and zinc fortified varieties namely Pant Lobia-1 (82ppm Fe and 40ppmZn), Pant Lobia-2 (100ppm Fe and 37 ppm Zn) has been developed by conventional plant breeding and released in2008 and 2010.Pant Lobia-3 (67 ppm Fe and 38 ppm Zn), PantLobia-4 (51ppm Fe and 36 ppm Zn) released in 2013 and 2014respectively. Brazil also released three varieties of high-iron cowpeas, developed by Embrapa, in 2008 and 2009 and bio availability.

Beans

Iron (Fe) content in common bean is about 50 parts per million (ppm) and target in biofortification of bean by conventional breeding is 94 ppm, biofortified beans provide about 60% of the Estimated Average Requirement (EAR).Average bean yields in Rwanda. Non-biofortified beans produce approximately 0.8 tons/hectare (bush and climbers combined) but biofortified bush beans yield around 1.5 t/ha and biofortified climber beans 2–3 t/ha. Among the different varieties released in Rwanda in 2012 and 2014 MAC-42 from CIT contains 91 ppm iron and ability to resistance against anthracnose and bean common mosaic virus and ability to produce 3.5t/ha.

Table 1: Biofortified vegetables and countries-release schedule

Vegetables	Nutrient	Targeted country	Leading institutions	First release year
Sweet patato	Provitamin A Carotenoids	Uganda	CIP, NaCCRI	2007
		Mozambique	CIP	2002
		Brazil	Embrapa	2009
		China	Institute of Sweet Potato, CAAS	2010
Bean	Iron (Zinc)	Rwanda, DR Congo	CIAT, RAB, INERA	2012

		Brazil	Embrapa	2008
Cassava	Provitamin A Carotenoids	DR Congo Nigeria Brazil	CIAT	
	Provitamin A Carotenoids, Iron	Nigeria, Kenya	Donald Danforth Plant Science Cente	2017
Cowpea	Iron, Zinc	India, Brazil	G.B. Pant University Embrapa	2008 2008
Irish potato	Iron	Rwanda, Ethiopia	CIP	Unknown
Pumpkin	Provitamin A Carotenoids	Brazil	Embrapa	2015

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