Development and Dissemination of Biofortified Varieties of Different Crops in SAARC Member States

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SAARC Agriculture Centre (SAC)

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Abbreviations

AIP	Agricultural Innovation Programme
ARD	Agriculture and Rural Development
ARI	Agricultural Research Institute
ARID	Agricultural Research and Innovation Division
ARDCs	Agricultural Research and Development Centres
BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BIMSTEC	Bay of Bengal Initiative for Multi Sectoral Technical and Economic Cooperation
BINA	Bangladesh Institute of Nuclear Agriculture
BWMRI	Bangladesh Wheat and Maize Research Institute
BRRI	Bangladesh Rice Research Institute
CGIAR	Consultative Group on International Agricultural Research
GLS	Grey Leaf Spot
GOP	Government of Pakistan
GPC	Germplasm Centre
CIMMYT	International Maize and Wheat Improvement Centre
CIP	International Potato Center
DAE	Department of Agricultural Extension
DOA	Department of Agriculture
EGS	Early Generation Seed System
FAO	Food and Agriculture Organization of the United Nations
GABA	Gamma aminobutyric acid
GAIN	Global Alliance for Improved Nutrition
GDP	Gross Domestic Product
GHI	Global Hunger Index
G.I	Glycemic Index
GMOs	Genetically Modified Organisms
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
INGO's	International Non-Government Organizations
IRRI	International Rice Research Institute
IMIC	International Medical Information Centre
IARCS	International Agricultural Research Centers

QPM	Quality Protein Maize
MOA	Ministry of Agriculture
MOALD	Ministry of Agriculture and Livestock Development
MOFA	Ministry of Foreign Affairs
MOFMRA	Ministry of Fisheries Marine Resources and Agriculture
MSP	Minimum Support Price
MT	Metric tons
NARC	Nepal Agricultural Research Council
NARP	National Agricultural Research Policy
NARS	National Agricultural Research System
NCDs	Non-Communicable Diseases
NCVT	National Coordinated Varietal Test
NDHS	National Demographic and Health Survey
NGO	Non-Governmental Organization
NNS	National Nutrition Survey
NMRP	National Maize Research Program
NSB	National Bureau Statistics
OFSP	Orange – fleshed Sweet Potato
OPVs	Open – Pollinated Varieties
PARC	Pakistan Agricultural Research Council
PDS	Public Distribution Systems
PPPs	Public – private Partnerships
PVA	Provitamin A
QPM	Quality Protein Maize
R&D	Research and Development
SAARC	South Asian Association for Regional Cooperation
SAC	SAARC Agriculture Centre
SIDS	Small Island Development State
SDF	SAARC Development Fund
SDG	Sustainable Development Goal
USAID	United States Agency for International Development
UNICEF	United Nations Children's Emergency Fund
UNFA	United Nations Fund for Agriculture
UNFPA	United National Population Fund
WHO	World Health Organization
WFP	World Food Program
WRI	Wheat Research Institute

Foreword

South Asia is the home of more than 1.90 billion people, while the land mass of the region is 6.4 million square kilometers. It is the most densely populated region of the world. It extends from the highlands of the Himalayas to the atolls of the Indian Ocean. Burgeoning population, decereasing land holdings and changing climatic conditions are the main issues of this region. Soil of this region is continously over exploited, quality of land bearing crop, fodder or forest has undergone drastic and critical changes. Most of the population of this region is living below poverty line and world's largest share of poverty and malnutrition is in this region. One - third of the world's poor (earning less than 1.9 $/day) people live in this region. This region constitutes smallholder producers having less than 2 ha of land for cultivation and is facing food insecurity, malnutrition, and climate challenge on agriculture.This region has made a great progress in food production, transforming the region from a food-deficit to a food self-sufficient region. Despite significant improvements in last two decades the rates of under nourished still remain high in South Asia. High consumption of cereal based foods with low contents of micronutrients is causing health hazards in humans.

Micronutrients deficiency is a leading global concern of public health importance. This micronutrient deficiencies can impair physical and cognitive development, weaken the immune system and impacting on health.The root cause of this peoblem is the non-availability of a balanced diet in resource-poor communities. Resource poor people relay on staple food for their energy requirement and these staple food crops are low in micronutrient concentration. Among the micronutrients, zinc, iron and vitamin A are the most common deficiencies and it is a global issue. Bioforification of staple crops is essential to restrict malnutriton and diseases and to promote the well-being of the target population. Biofortified varieties of different crops have been developed in the world and as well as in maximum SAARC Member States offer sustainable solution to the problem. However further research and development work as well as promotion and extension of these biofortied varieties of different crops is needed on large scale. Governments as well as, different international research centres. INGO,s , NGOs and media should play their roles for the promotion of biofortified varieries on large scale in all countries. I hope this book will be helpful for scientists, extension service providers, policy makers, academia and other related stakeholders for the development and promotion of biofortified varieties of all crops in this region.

In the end I congratulate all the SAC technical members, especially Dr Sikander Khan Tanveer, Senior Program Specialist (Crops) for arranging the regional consultation meeting on the “Development and Dissemination of Biofortified varieties of different crops in the SAARC Member States” compiling it in the form of book.

(Dr. Md. Harunur Rashid)
Director, SAC

Chapter 1

Status of Development and Dissemination of Biofortified Varieties of Different Crops in SAARC Member States

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South Asia accounts for about 25% of the global population which is presently more than 1.9 billion. Total landmass of this region is 6.4 million square km which is about 3.5% of the Earth's land areas. Resource poor people of this region mainly rely on staple food for their calorie and nutrients requirement. One-third of the world's poor (earning less than 1.9$/day) people live in this region. This region constitutes smallholder producers (having less than 2.0 ha of land for cultivation). This region is also facing food, insecurity, malnutrition and climate challenges issues in the forms of droughts, floods and heat shocks etc. Despite significant improvements in last two decades the rates of undernourishment still remain high in South Asia. High consumption of cereal-based foods with low contents of micronutrients is causing health hazards in humans. According to FAO 2023 data, out of total 1949.4 million people of Asia, who were unable to afford a healthy diet in 2021, of this, maximum (1408.5 million) was from South Asia. In 2022, 15.6% of the people of Southern Asia were under nourished and their number was 313.6 million. According to WHO, malnutrition means imbalances of vital nutrients, deficits or excess in nutritional intake, or impaired nutrient utilization (www.who.int.2020).

Micronutrients deficiency is a leading global concern of public health importance and the root cause of this problem is the non-availability of a balanced diet in the resource poor communities. Deficiencies of minerals and vitamins affects a high population of the world's population, particularly in the developing world (Stein., 2010). Nutrients in the human diet ultimately come from plants but all our major food crops lack certain essential micronutrients (vitamins and minerals) (Zhu C *et al*., 2007). Zinc and Iron deficiencies affect more than 50% of the human population, resulting poor growth and development, an impaired immune system, fatigue, muscle wasting, sterility and even death (Rawat N *et al*., 2013 and Gómez-Galera S *et al*., 2010). Strategies to address micronutrient deficiency include dietary diversification, nutritional supplements, fortification and biofortification (Zhu C *et al*., 2007 and Gómez-Galera S. *et al*., 2010) and Biofortification is the process of naturally enhancing food crops with vital nutrients which offers a sustainable and enduring solution to nourish both agricultural and non-agricultural communities with essential micronutrients (Ghimire *et al.*, 2019; Yadava *et al.*, 2020).

Biofortification of staple crops is essential to prevent malnutrition, resist diseases and to promote the well-being of the target population. It is an invention strategy currently being researched and developed to increase the absorbable content of micronutrients in edible portions of staple food crops. Its main goal is to contribute to reducing the high prevalence of specific nutritional deficiencies, which commonly occurs in low-income population. It could be achieved by improving the micronutrients density of the staple food crops that are produced and consumed by large populations.

Research and development work on Biofortified varieties of different crops are in progress in most of the SAARC Member States. Different activities related to the development and dissemination of Biofortified varieties currently going on in SAARC Member States are given below.

In Bangladesh, malnutrition, particularly micronutrient deficiencies, continues to be a major public health concern and it affects one in every three children under five, with half of the women suffering from zinc deficiency. Improving the health conditions and nutritional status of women, adolescents and children under five in Bangladesh by promoting the cultivation, development and dissemination of biofortified crops and its consumption specially biofortified zinc rice is important.

Agriculture in Bangladesh is primarily centered around rice production, largely managed by smallholder farmers. Rice is grown year round, with different varieties suited to Boro, Aus, and Aman, growing seasons. About 80% of arable land is dedicated to rice cultivation in different agroecological zones. However, there has been a noticeable shift toward crop diversification with high value crops. In Bangladesh, many people suffer from zinc deficiency. This problem can be solved by increasing cultivation and consumption of zinc biofortified rice.

In Bangladesh, biofortified varieties of crops such as rice, wheat, sweet potato and lentils have been developed to increase their essential nutrients content like zinc, iron, and vitamin A. Bangladesh Rice Research Institute (BRRI) developed and released the world's first biofortified zinc rice variety (BRRI dhan62) in 2013 with support from Harvest Plus. Other biofortified rice varieties developed by BRRI are BRRI dhan62, BRRI dhan64, BRRI dhan72, BRRI dhan74, BRRI dhan84, Bangabandhu dhan100 (BRRI dhan100), and BRRI dhan102. In addition to BRRI, several zinc-enriched biofortified rice varieties have been developed by BINA which are specifically bred for their higher zinc contents. In addition to zinc biofortified rice, BRRI has also developed high protein content rice varieties (containing 10.0-10.8% protein), rice varieties enriched with both iron and zinc, as well as varieties with a low glycemic index (Low GI), antioxidant rich, and GABA (gamma aminobutyric acid) enriched rice. The institute developed

Vitamin A-enriched GR2-E BRRI dhan29 (golden rice), containing 12 ppm beta-carotenoids which is awaiting approval for commercial release to farmers.

Wheat is another staple crop in Bangladesh. Bangladesh Agricultural Research Institute (BARI) and Bangladesh Wheat and Maize Research Institute (BWMRI) have developed zinc enriched wheat varieties named BARI Gom 33 and BWMRI Gom 3, having zinc content ranging from 50 to 60 ppm. These varieties are widely cultivated across the country. Biofortified sweet potato varieties rich in beta-carotene, a precursor of vitamin A have been developed by BARI and Bangladesh Agricultural University (BAU). The orange and yellow-fleshed sweet potatoes varieties introduced in various regions, have been well received by the growers due to their nutritional benefits and adaptability to local growing conditions. BARI has developed biofortified lentil varieties which are enriched with iron and zinc.

Demand for maize crop is steadily increasing in Bangladesh, and scientists are working to introduce biofortified varieties enriched with multiple micronutrients, including vitamin A, zinc, and iron.

BARI has developed a biofortified potato variety named BARI Alu-101, enriched with iron, zinc, and a high level of anthocyanin (93.7 mg per 100g). Over 15 sweet potato varieties developed by BARI are also biofortified. BARI has developed several biofortified tomato varieties. BAU Germplasm Centre (GPC) has released seven antioxidant rich coloured flesh potato varieties and four sweet potato varieties.

The development and dissemination of biofortified rice varieties are essential to Bangladesh to achieve food and nutrition security, and for improving the overall health of its population. These varieties are promoted at farm level through awareness campaigns, training to the farmers, distribution of seed of biofortified crop varieties and integration of biofortified varieties of different crops in the national nutrition programs by building partnerships with the international organizations like HarvestPlus, World Food Program (WFP) and IRRI. However there are some challenges in the promotion of biofortified varieties of different crops on large scale. Among them less awareness of the farmers and consumers about the benefit of biofortified varieties, seed availability and market demand are important.

Major crops of Bhutan are rice, maize, potatoes and wheat. About 27% of households in Bhutan can not afford a nutritious diet. Over 40% of the population, including 43.8% of the young children are suffering from anemia. They also face micronutrient deficiencies (vitamin, iron, zinc). Work is in progress for the development of biofortified crops by using breeding and other genetic techniques to improve nutritional quality of crop varieties to address nutrition problem by aligning with Bhutan’s GNH.

Bhutan started biofortification crop breeding work in 2012 with the introduction of quality protein maize and nutrient dense potatoes. The National Maize Program of Bhutan received 100 GLS-tolerant maize varieties from CIMMYT and after evaluation two GLS-tolerant varieties from CIMMYT Colombia, named Shafangma ashom were officially released in 2012. It is GLS tolerant, high in protein and widely grown in eastern Bhutan and it's seed is available with the National Seed Centre. Research work is in progress on the development of biofortified wheat varieties. The country is actively advancing in the development of biofortified varieties of different crops through international collaboration.

Potato is the staple crop of Bhutan. It is also important for food security and economy. The country currently lacks sufficient number of biofortified potato varieties except Yusimap (Red potato) and NKK (White) having VC 59-89.7/Zn >16.5/Fe >18.45mg /100 gm DW).

Wheat is the third most important crop of Bhutan after rice. Currently, four varieties are being cultivated and these are not biofortified. A promising line with high zinc and yield potential is in advanced stage of approval. Some promising lines are also in advance evaluation stage.

Rice is the major staple diet of Bhutan but no biofortified rice variety rice is available in Bhutan. Rising neuropathy cases were linked to micronutrient deficiencies especially with the deficiency of vitamin B, during 2012-14. To address the nutritional problem, fortified rice with (B1, B3, B6, B9, B12, Fe, Zn) blended domestically and supplied to school feeding programs, to combat the beriberi neuropathy problem among students.

On-going value addition & biofortification efforts in Bhutan include research for the development of varieties of different crops in collaboration with the different international centers, and fortification of rice for school feeding programs. Future efforts will be expanded through collaborative research through partnerships development. Research and Development work will be continued for the development of Golden rice.

Challenges in this sector include lack of awareness of the people, hesitation of farmers, limited research and development work on biofortified crops and clarity between GMOs and biofortified crops. Rugged terrain, smallholder farming is complicated and its seed distribution and access system, and poor market infrastructure limits the commercial viability of biofortified crops.

For promotion of biofortified crops in Bhutan , thrust is needed on capacity building of different stakeholders, farmers participation, R & D collaboration and integration of biofortified seeds into national policies and programs.

Maldives consists of 1200 coral islands, 6 natural atolls, 8 provinces /20 atolls for administration. It covers an area of 895,000 Km^2. Islands are 1-1.5 meters above sea level. Economy depends on tourism and fisheries. Share of agriculture in

GDP is 1.6%. Population of the country is 520,000 scattered over 190 inhabited islands.

Traditionally root crops, millet, sorghum and maize are the staple crops of the country and the country mainly relies on imported food (rice, wheat flour); and is net importer since 1980s. There are basically 2 types of production system; home based / semi commercial and commercial level in leased uninhabited islands. Total area suitable for cultivation is approximately 2670 hectares. More than 50 islands are leased for agriculture, (30-60 ha). Apart from coconut, horticulture remains as the prominent industry in Maldivian agriculture sector. Tropical fruits such as mango, banana, passion fruit, cucurbits, chilli and papaya are the major crops targeted to produce and achieve self-sufficiency. Availability of land and land allocation schemes differ from island to island. Lack of crop farming knowledge among youth,limited labour resources – high expatriate labour number, limited & unreliable transportation system, competition with cheaper imported products in the market are the major problem in agriculture. Moreover, crop production already negatively impacted by climate change due to reduced water availability and salinization of aquifers, further loss of land through sea-level rise, heat stress on plants, new pests & diseases and changes in rainfall patterns.

In Maldives, Iron and other micronutrients deficiency is prevailing among the pregnant women and children especially in the rural population. So cultivation of biofortified varieties of different crops with good agronomic practices and their marketing can be helpful in the reduction of micronutrients deficiency problem. Regional exchange of seeds of biofortified crop varieties which are suitable for cultivation in Maldives can be helpful in addressing the problem. Maldives put emphasis on adaptation research on biofortified varieties .

Agriculture in Nepal is mainly dominated by small scale farming and fragmented land holdings. About 50.8% labor force is engaged in agriculture and this sector contributes 25% in GDP. There is diverse agro-ecology in Nepal which includes lowland Terai/plains, hills and mountains and it is also driven more by culture than entrepreneurship. Deficiencies of different nutrients among the people include iron, vitamin A, Iodine, Vitamin D and Zinc, however, the percentage of children under age of 5 who are malnourished decreased over time. According to National Demographic and Health Survey (NDHS), 2022 the percentage of stunted children which was (57%), underweight (43%) and wasted (11%) in 2001, has reduced to 25%, 19% and 8% respectively.

Different interventions to cope with the Nutritional insecurity in Nepal are being used which include fortification, biofortification and agronomic biofortification. With the support of WFP, 159 MT fortified harvests distributed to 97,988 people in the hard -to-reach Hills and Mountains of Karnali province in January to July, 2024. Breeding or Genetic Engineering tools have been used for incorporation of Opaque-2, Floury-2 genes for enhancing the Tryptophan and Lycine in QPM.

Similarly agronomic biofortification is also being used and practiced to increase the concentration of minerals like zinc, iron and selenium in edible parts of crops.

Fortification interventions in Nepal includes Iodized Salt Act (1992), Nutritional Nutrition Policy and Strategy (2004), Nutritional Nutrition Strategy (2020) and Strategic plan i.e. Multi sector Nutrition Plan (2018-2022). Through all these above mentioned act and strategies, different fortified recommended commercial products that includes wheat flour with iron, folic acid and vitamin A, rice fortification with micronutrients and fortification of salt with Iodine were made for consumption .

As far as Agronomic biofortification of different crops is concerned, it has been found that foliar application of zinc found to be more efficient for zinc biofortification (up to 20-30% over control) in rice, wheat and maize compared to zinc priming, seed coating, and soil application.

Eleven (11) Biofortified varieties of different crops i.e., wheat (6), maize (2) and lentil (3) have been developed. It has been found that many local varieties / land races are also found to be nutrient dense and highly versatile for adaptation in local environment. So biofortified and local varieties can be combined and complement for each other's in Nepalese context.

Seed of biofortified varieties is also produced every year. During 2023-24, 13902 kg Breeder seed of different varieties of maize, wheat and lentil was produced by concerned research Centers of Nepal.

There are various issues related to adoption and marketing of biofortified varieties of different crops. In case of maize crop there is difficulty in maintaining the quality of seed and grain at farm level because of cross pollination and recessive nature of gene of QPM. When QPM varieties are grown near conventional maize, cross-pollination gradually diminishes the QPM traits, ultimately reducing the bioavailability of lysine and tryptophan. These characteristics forces farmer to seek isolated areas for cultivating QPM, and they must purchase new seeds each season to ensure genetic purity like hybrid seeds.

In case of wheat crop issues include i.e. least priority for biofortified products in market as compared to taste, flour quality and cooking quality of wheat. Biofortified varieties are only targeted in small holder farming communities where they grow and mill their own product. However urban population prefers biofortified flour with good packaging advertisement and taste. Presently only one biofortified lentil variety is available in the market and its price is more than the traditional lentil. However in case of lentil, varietal adulteration is the main issue, which is the hurdle in the promotion of biofortified lentil on large scale. Other factors include, limited awareness of the people regarding biofortified crops, lack of consumer sensitization, inadequate extension of biofortified crops on large scale.

For promotion of biofortification varieties on large scale in the country, there is need to strengthen research and development system in the country, improving seed access and distribution of biofortified varieties of different crops awareness building and education among the farming communities about biofortified varieties, product certification and market linkages and promotion of public, private partnership, packing of products of different biofortified varieties of different crops and biofortified products of different crops need to be linked with the markets and school meal programs. Emphasis should also be given on the development of supportive policies and incentives to the growers and processors.

In Pakistan, the essential minerals and vitamins deficiencies cost about US$ 3 billion in GDP (World Bank). To enhance nutritional value and improve public health in Pakistan, NARS system in collaboration with the international centres like CIMMYT and HarvestPlus is working for the development and dissemination of biofortified varieties of wheat crop in the country. National Agricultural Research System (NARS) has developed five biofortified wheat varieties named Zincol-2016, Akbar-2019, Nawab-21, Tarnab Gandhum-1, Tarnab Rehbar-23 containing 34-37 ppm zinc and yield potentials of these varieties ranges from 6-8 t/ha).

Pakistan has also developed two biofortified varieties of rice named Vital Basmati and G.M Ali-5. Pakistan Agricultural Research Council (PARC) has evaluated provitamin A biofortified maize crop hybrids across diverse maize growing regions under the umbrella of CIMMYT -led and USAID –funded AIP for Pakistan and further work is in progress for the development of biofortified maize crop varieties / hybrids.

Biofortified varieties of wheat crop are getting popularity in Pakistan and the variety Akbar-2019 is widely cultivated in Punjab and covered lot of hectares in Punjab and it has got a great share in the total production of wheat in the country, however, further awareness and efforts are needed for the development and promotion of biofortified varieties of different crops in the country.

In Sri Lanka the share of agriculture in the GDP is 7.5% mainly from different crops including rice, tea, rubber, coconut and spices. About 34% of cultivated land area is under paddy crops and it provides livelihood for 1.8 million farmers. Annual rice requirement in the country is 2.54 million metric tons, while rice availability for consumption is 2.76 million metric tons. In Sri Lanka, focus for development of rice varieties are on higher yields and better grain quality such as higher antioxidant, low glycemic index, enrich in micronutrients and tolerant against biotic and a biotic stresses.

More than 33% of children in Sri Lanka are iron deficient and rice fortification has a great potential to reduce the prevalence of iron deficiency and other micronutrients deficiencies. Currently few commercially fortified rice products are available and recently the government has taken steps to launch a rice fortification program to address the malnutrition of school children. The Ministry of Agriculture and Plantation Industries, the Ministry of Education, the World Food Program and the National Food Promotion Board are working together for this purpose.

Work is in progress for the development of biofortified varieties of rice. Maize is also a very important crop for human consumption and it is also a source of animal feed in the country. Demand for maize crop is increasing in the country with the passage of time and exotic maize hybrids have also become popular among farmers due to their high yield potential. The quality protein maize (QPM) hybrid M1, Maize hybrid Hy 01 was released in 2013 by using QPM in bred lines developed by CIMMYT. Further research work is in progress for the development of QPM hybrids. In future, work will be continued to develop biofortified varieties of different crops according to environmental conditions of the country. Rice branding will also be developed for the popularization of biofortified rice varieties in the country.

SAARC Members States need to strengthen research and development work for the development of Biofortified crop varieties. Regional cooperation in the form of exchange of germplasm, seeds of different biofortified varieties, partnership development, training of the scientists, farmers and other stake holders can further support these countries in the rapid development of Biofortified varieties of different crops. Priority on biofortified crop variety development research, government policy support, better marketing and awareness of the farming community and consumers are also very important for the development and dissemination of biofortified varieties of crops in the SAARC Member States.

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Chapter 2

Development and Dissemination of Biofortified Varieties of Different Crops in Bangladesh

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Abstract

Biofortification is the process of enhancing the nutritional content of crops through agronomic practices, conventional plant breeding, or modern biotechnological approaches such as genetic engineering and genome editing. This approach offers a sustainable solution to micronutrient deficiencies, particularly in developing countries like Bangladesh. This paper highlights Bangladesh's efforts to combat malnutrition through biofortification, focusing on zinc enriched rice and wheat, vitamin A enriched sweet potato, and iron & zinc enriched lentils. These crops have been developed through rigorous breeding programs to increase their nutritional value without compromising yield or adaptability. Despite progress in disseminating biofortified crops in Bangladesh, challenges such as limited seed availability, infrastructure gaps, and low consumers, and public awareness persist. Overcoming these challenges is essential to maximize biofortification's potential to reduce hidden hunger, contribute to healthier populations, and improve or strengthen the country's long-term food and nutritional security.

1. Introduction

Humans require food and nutrients in the right proportions to ensure proper growth and development (Jha and Warkentin, 2020). The United Nations Second Sustainable Development Goal (SDG) aims to eradicate extreme hunger and malnutrition while promoting food security (Dias *et al.*, 2018; Saint Ville *et al.*, 2019; Olson *et al.*, 2021). However, rapid population growth, combined with the effects of global climate change, has led to severe hunger in some regions of the world, where there is not enough food or nutrients to meet the needs of the entire population (Wakeel *et al.*, 2018).

Agriculture in Bangladesh is primarily centered around rice production, largely managed by smallholder farmers. Rice is grown year round, with different varieties, Boro, Aus, and Aman, suited to the country's three main growing seasons (Sarker *et al.*, 2012). Approximately 80% of arable land used for crop production is dedicated to rice in the agroecological zones. However, there has been a noticeable shift toward crop diversification and the cultivation of high value crops. The production of high value crops such as fruits and vegetables, typically grown in flood free regions, as well as livestock and fisheries, has increased significantly over the last decade due to rising market demand. Despite this growth, rice remains dominant in overall production (Mainuddin *et al.*, 2021). In Bangladesh, many people suffer from zinc deficiency. One of the most proven and effective ways to address this issue is by increasing the production and consumption of zinc biofortified rice.

Malnutrition, particularly micronutrient deficiencies, continues to be a major public health concern in Bangladesh. It affects one in every three children under five, with half of the women suffering from zinc deficiency. This micronutrient deficiency can impair physical and cognitive development, weaken the immune system, and negatively impact fertility and reproductive health (Wessells and Brown, 2012; Black *et al.*, 2013). Biofortification, which involves breeding crops to enhance their nutritional value, offers a sustainable solution to this problem (Bouis *et. al.*, 2011). In Bangladesh, biofortified varieties of staple crops such as rice, wheat, sweet potato and lentils have been developed to increase their content of essential nutrients like zinc, iron, and vitamin A (Bashar *et al.*, 2022). According to International Centre for Diarrheal Disease Research, Bangladesh (ICDDRB) report in 2022, the prevalence of deficiencies among children under five years in Bangladesh stands at 31% for zinc, 15% for iron, 49% for vitamin A, and 78% for vitamin D.

Biofortified crops signify a ground breaking approach in the global fight to combat malnutrition, particularly in developing countries like Bangladesh. These crops are specifically bred to contain higher levels of essential vitamins and minerals, such as zinc, iron, and vitamin A, addressing the widespread issue of micronutrient deficiencies, often referred to as "*hidden hunger*". In many countries, where a significant portion of the population depends on staple crops for their daily nutrition, biofortification provides a sustainable and cost effective solution to improve the nutritional quality of these foods. Biofortified crops play a vital role in advancing food security and public health (Avnee *et al.*, 2023). Bangladesh Rice Research Institute (BRRI) developed and released the world's first biofortified zinc rice variety (BRRI dhan62) in 2013 and the institute is further releasing the biofortified rice varieties. As rice is the staple food and a key source of protein and minerals in the Bangladeshi diet, consuming zinc enriched rice regularly can provide up to 70% of the daily zinc requirement.

Therefore, promoting the cultivation, development and dissemination of biofortified crops and its consumption for public health benefits specially for women, adolescents and children underage of five in Bangladesh is important.

2. Biofortification

Fortification refers to the intentional enhancement of one or more micronutrients (such as vitamins and minerals) in a food or condiment to improve its nutritional quality and provide public health benefits with minimal health risks. It is a proven intervention that helps prevent, reduce, and control micronutrient deficiencies. Fortification can be implemented on a large scale to address nutrient deficiencies in the general population (mass fortification) or targeted to specific groups, such as children, pregnant women, or recipients of social protection programs (targeted or market driven fortification).

Mass fortification involves adding one or more essential nutrients to staple foods or condiments that are widely consumed by the general population at risk of deficiencies that pose a public health concern. Examples include fortifying flour with iron and folic acid or adding iodine to salt. Targeted fortification, on the other hand, focuses on providing fortified foods specifically designed for certain population groups. These groups often include infants and young children but can also encompass adolescents, young women, pregnant women, or even displaced populations receiving food aid. Unlike mass fortification, targeted fortification typically includes a broad range of critical nutrients, addressing specific deficiencies prevalent in the intended group (Mannar and Hurrell, 2018).

Biofortification, on the other hand, involves increasing the nutritional value of food crops through biological methods, with the aim of addressing micronutrient deficiencies and improving public health (Datta and Bouis, 2000). This is done by enhancing the levels of essential vitamins and minerals in the edible parts of crops, such as grains, roots, or tubers, during the plant growth and development. Biofortification can be achieved through conventional plant breeding, agronomic practices, or modern biotechnology, including genetic modification (Ofori *et al.*, 2022). Dr. Howarth Bouis, the founder of HarvestPlus, introduced the term “Biofortification”. HarvestPlus, a part of Consultative Group for International Agricultural Research (CGIAR), is based at International Food Policy Research Institute (IFPRI), a CGIAR research center. HarvestPlus took the first initiative in Bangladesh to enhance nutritional security by promoting the production of biofortified crops and connecting value chain actors and policymakers (HarvestPlus, 2014).

Biofortification meets the nutritional needs of both urban and rural populations and can be implemented at a low cost. Multiple nutrients can be added to crops through biofortification without affecting food prices. Since it does not require advanced infrastructure, it is relatively easy to implement and does not rely on consumer compliance. The HarvestPlus program, launched in 2003, targets countries in Asia and Africa to ensure the availability and accessibility of nutrient rich biofortified staple crops. Notable examples of biofortified crops from this program include orange-fleshed sweet potatoes (OFSP), golden rice, vitamin A enriched yellow and orange maize, as well as wheat and rice biofortified with zinc, iron, and beans biofortified with iron (Ofori *et al.*, 2022).

2.1. Biofortification: The Development Process

The development process of biofortified crop varieties involves a multi-step process that includes:

a. Research and Breeding: Scientists identify existing varieties of crops that naturally contain higher levels of the desired nutrients. Through conventional breeding techniques, these traits are combined with those of high yielding, disease resistant varieties to create biofortified crops.

b. Field Trials and Testing: New biofortified varieties undergo rigorous field trials to ensure they are suitable for local growing conditions, meet yield demands or expectations, and maintain their enhanced nutritional content. These trials also test for resistance to pests and diseases.

c. Seed Multiplication and Distribution: Once a biofortified variety is developed and approved, the next step is to multiply the seeds and distribute them to farmers. This phase often involves collaboration with government agencies, non-governmental organizations, and international partners to ensure widespread adoption.

d. Farmer Training and Awareness: Educating farmers about the benefits of biofortified crops and the best practices for growing them is crucial for the success of these varieties. Extension services and training programs help farmers understand the nutritional advantages and agronomic benefits of biofortified crops.

3. Development of Biofortified Crop Varieties in Bangladesh

Biofortification is emerging as a powerful strategy to combat micronutrient deficiencies in Bangladesh, where large segments of the population suffer from malnutrition. By enhancing the nutritional content of staple crops, biofortification aims to address deficiencies in essential vitamins and minerals, such as zinc, iron, and vitamin A, through everyday diets. In Bangladesh, several biofortified crop varieties have been developed to improve public health and nutrition, particularly among vulnerable populations.

a) Zinc Enriched Rice

Zinc (Zn) deficiency is a widespread issue in Bangladesh, leading to stunted growth and increased susceptibility to infections (Bhowmik *et al.*, 2010; Prasad, 2013; Gammoh and Rink, 2017; Calayugan *et al.*, 2021). A proven and effective way to address this problem is by scaling up the production and consumption of zinc biofortified rice. As the staple food in Bangladesh, rice serves as the primary source of protein and minerals in the diet, and zinc enriched varieties can provide up to 70% of the daily zinc requirement when consumed regularly.

Bangladesh Rice Research Institute (BRRI) pioneered the development of zinc biofortified rice through conventional breeding, releasing world’s first variety named as BRRI dhan62 in 2013 with support from HarvestPlus (BRRI, 2014). The other Zn enriched varieties developed are BRRI dhan62, BRRI dhan64, BRRI dhan72, BRRI dhan74, BRRI dhan84, Bangabandhu dhan100 (BRRI dhan100), and BRRI dhan102 (Table 1). In addition to BRRI, several zinc-enriched biofortified rice varieties have also been developed by other institutions (Table 2). These varieties are specifically bred for their higher zinc, which is essential for immune function, growth, and cognitive development. In addition to their nutritional benefits, these zinc enriched rice varieties also offer desirable agronomic traits such as high yields, disease resistant and adaptability to different growing conditions, making them attractive or popular to the farmers. These varieties have been widely promoted by the government and non-governmental organizations as part of a broader strategy to combat malnutrition.

In addition to zinc biofortified rice, BRRI has also developed high protein varieties (containing 10.0-10.8% protein), rice enriched with both iron and zinc, varieties with low glycemic index (Low GI), antioxidant rich, and GABA (gamma aminobutyric acid) enriched rice (Table 3).

Vitamin A-enriched GR2-E BRRI dhan29 (golden rice), containing 12 ppm beta-carotenoids, has also been developed by BRRI and is awaiting approval for commercial release to farmers. The development and dissemination of these biofortified rice varieties are essential to Bangladesh’s efforts to achieve food and nutritional security, and improve the overall health of its population.

Table 1: Features of zinc (Zn) enriched rice varieties developed by BRRI (BRRI, 2023).

Variety Name	Season	Growth Duration (Days)	Zn (ppm)	Yield (t/ha)	Year of Release
BRRI dhan62	T. Aman	100	20	4.5	2013
BRRI dhan64	Boro	152	24	6.5	2014
BRRI dhan72	T. Aman	125	23	6.0	2015
BRRI dhan74	Boro	147	24	7.0	2015
BRRI dhan84	Boro	141	28	6.5	2017
BRRI dhan100	Boro	148	25	7.7	2021
BRRI dhan102	Boro	150	26	8.1	2022

Table 2: Zinc enriched rice varieties developed by BSMRAU and BINA

Variety Name	Season	Growth Duration (Days)	Zinc (ppm)	Grain Type	Yield (t/ha)
BU Aromatic Hybrid Dhan-1	T. Aman	112-115	22	Aromatic long slender	5.0 - 5.5
BU Aromatic Dhan-2	Aus T. Aman Boro	115 (Aus) 120 (T. Aman) 145 (Boro)	22	Aromatic long slender	4.5 (Aus) 5.0 (T. Aman) 6.0 (Boro)
BINA dhan20 (Both Zn & Fe)	T. Aman	125-130	28 (Fe-31 ppm)	Long slender	4.5 - 5.5

Table 3: Nutritional and Nutraceutical rice varieties developed by BRRI

Items	Rice Varieties	Remarks
High protein enriched	BRRI dhan34, BRRI dhan36, BRRI dhan37, BRRI dhan66, BRRI dhan81, BRRI dhan86, BRRI dhan90, BRRI dhan91, BRRI dhan96, BRRI Hybrid dhan4 and BRRI Hybrid dhan7	10.0-10.8 %
Zinc and Iron enriched	BRRI dhan84	Fe: 10-12 ppm Zn: 26.5-27.6 ppm
Low glycemic index (Low GI)	BR16, BRRI dhan46, BRRI dhan69, BRRI dhan105	52.4-55.0 (for diabetic patient)
Antioxidant enriched	BR5, BRRI dhan84	Anti-cancer
GABA enriched	BRRI dhan31	Anti depressive (GABA 12.50 $mg100g^{-1}$)

b) Zinc Enriched Wheat

Wheat is another staple food crop in Bangladesh, and biofortification efforts have been extended to it as well. Bangladesh Agricultural Research Institute (BARI) and Bangladesh Wheat and Maize Research Institute (BWMRI) have developed zinc enriched wheat varieties, BARI Gom 33 and BWMRI Gom 3, with zinc levels ranging from 50 to 60 ppm. These varieties are now being cultivated across the country to address food security and widespread zinc deficiency. In addition to enhancing the nutritional value of bread and other wheat based foods, biofortified wheat supports the agricultural economy by providing farmers with resilient, high yielding crop.

c) Vitamin A Enriched Sweet Potato

To address vitamin A deficiency, which can cause blindness and other serious health issues, Bangladesh introduced biofortified sweet potato varieties rich in beta-carotene, a precursor to vitamin A. These varieties were developed by BARI and Bangladesh Agricultural University (BAU). The orange and yellow-fleshed sweet potatoes, introduced in various regions of the country, have been well received by the farmers due to their nutritional benefits and adaptability to local growing conditions. This initiative is part of a broader public health effort to increase vitamin A intake, particularly among children and pregnant women.

d) Iron Biofortified Lentil

Iron (Fe) deficiency is a major concern in Bangladesh, contributing to widespread anemia, particularly among women and children. Pulses like lentils, mung beans, and chickpeas, are important sources of protein and micronutrients in the Bangladeshi diet. To address anemia, BARI developed biofortified lentil varieties enriched with iron and zinc (Table 4). These lentils are specifically bred to contain higher levels of iron, making them an essential part of the diet The biofortified lentils help increase iron intake, reducing the risk of anemia and promoting overall health.

Table 4: Features of some iron (Fe) enriched lentil varieties developed by BARI (Azad *et al.*, 2020).

Variety Name	Growth Duration (Days)	Fe (ppm)	Zinc (ppm)	Yield (t/ha)
BARI Masur-4	105-110	75.40	52.24	1.9-2.0
BARI Masur-6	105-110	87.42	65.15	2.0-2.2
BARI Masur-7	105-110	77.78	61.57	2.1-2.3
BARI Masur-8	110-115	75.40	56.50	2.2-2.3
BARI Masur-9	85-90	79.60	60.30	1.2-1.5

e) Nutrient Enriched Maize

Although maize is not yet a staple food cereal in Bangladesh, it currently ranks second after rice in terms of production (produced 6.42 million tons in 2022-23: requirement is around 7.0 million tons). The national average yield of maize in Bangladesh surpasses the global average, primarily due to the introduction of hybrid varieties and the adoption of good agronomic practices. Demand for maize is steadily increasing, and scientists are working to introduce biofortified varieties enriched with multiple micronutrients, including vitamin A, zinc, and iron. These varieties are especially beneficial in regions where vitamin A deficiency is a significant health concern and are being integrated into both subsistence and commercial farming practices.

f) Other Crops

BARI has developed a biofortified potato variety named as BARI Alu-101, enriched with iron, zinc, and a high level of anthocyanin (93.7 mg per 100g). Over 15 sweet potato varieties developed by BARI are also biofortified, enriched with beta carotene and anthocyanin, respectively. Additionally, BARI has developed several biofortified tomato varieties: BARI Tomato 18, which has a high lycopene content with the crimson gene inserted; BARI Tomato 19, a processing variety with a viscosity of 3200 cp; and BARI Tomato 20, rich in beta carotene, providing 227 µg of vitamin A per 100g for table tomatoes and 170 µg of vitamin A per 100g for regular consumption. Meanwhile, BAU Germplasm Centre (GPC) (the largest germplasm repository for fruits, medicinal plants, and agroforestry species in Bangladesh, and the second largest globally after Miami, USA) has released seven antioxidant rich coloured flesh potato varieties and four sweet potato varieties for cultivation.

4. Dissemination of Biofortified Crop Varieties in Bangladesh

The dissemination of biofortified crops in Bangladesh is a critical step toward addressing the widespread issue of micronutrient deficiencies, commonly referred to as "*hidden hunger*". With a significant portion of the population suffering from a lack of essential vitamins and minerals despite sufficient caloric intake, biofortified crops offer a sustainable and cost-effective solution. The success of these crops, however, hinges on their widespread adoption and integration into the farming systems and diets of the population.

4.1. Key Strategies for Dissemination

a) **Awareness Campaigns:** Raising awareness among farmers, consumers, and key stakeholders about the benefits of biofortified crops is essential. Government agencies, non-governmental organizations (NGOs), and international partners have been actively involved in conducting awareness campaigns that highlight the nutritional benefits of biofortified varieties, such as zinc enriched rice, iron and zinc enriched lentils, and vitamin A fortified sweet potatoes. These campaigns use various platforms, including community meetings, agricultural fairs, radio, television, and social media, to reach a larger audience.

b) **Farmer Training and Extension Services:** Effective dissemination relies heavily on educating farmers about the cultivation practices of biofortified crops. Department of Agricultural Extension, some selected NGOs, and agricultural research institutes are playing a crucial role in this regard. These organizations impart training to farmers about the agronomic benefits of biofortified crops, such as yield & nutrition benefit, pest and disease management, cultivation practices and the specific nutritional advantages they provide. Demonstration plots are often establish at farmer's field to showcase the performance of these crops under local conditions, encouraging adoption by neighbouring farmers.

c) **Seed Distribution Networks:** High quality seeds of biofortified varieties are readily available to farmers is a fundamental aspect of dissemination. Government agencies like Bangladesh Agricultural Development Corporation (BADC), Department of Agricultural Extension (DAE), BRRI, BARI and many private seed companies, and NGOs, facilitated the dissemination and distribution of biofortified seeds. This seed distribution networks often takes place through established channels, including local seed dealers, agricultural extension offices, and then finally to the farmers. In some cases, seeds are provided at subsidized rates or even for free to encourage the initial adoption. Over 15,000 metric tons (MT) of biofortified crop seeds have been made available and accessible to farmers, and their use continues to increase gradually (Figure1). In 2022, approximately 3 million households cultivated biofortified zinc rice across the country, and more than 15 million people consumed it (Bashar *et al*., 2022; Amin *et al*., 2023).

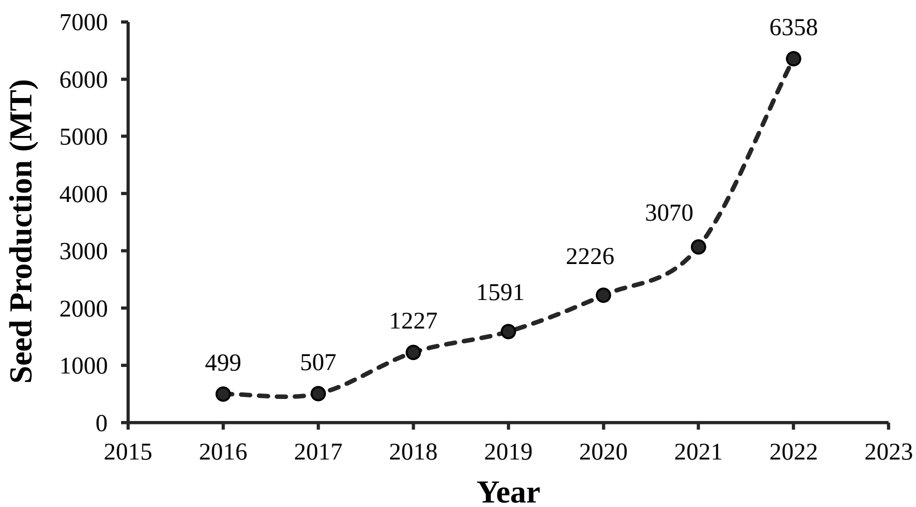

Figure 1: Seed production trend (2016-2022) of zinc enriched biofortified rice varieties in Bangladesh (Source: Amin *et al.*, 2023). MT = Metric ton.

d) **Integration into National Nutrition Programs:** To maximize the impact of biofortified crops, Bangladesh has integrated them into national nutrition programs. For example, biofortified rice and other nutrient rich crops have been included in school feeding programs, targeting vulnerable groups such as children and pregnant women. These programs help to ensure that biofortified foods reach those people most in need of improved nutrition, thereby amplifying the public health benefits.

e) **Partnerships with NGOs and International Organizations:** The dissemination of biofortified crops in Bangladesh has been significantly supported by partnerships with international organizations such as HarvestPlus, World Food Programme (WFP), and International Rice Research Institute (IRRI). These organizations provide technical assistance, funding, and expertise in biofortification. HarvestPlus works in Bangladesh to develop and deliver biofortified rice seeds to farmers through partnerships with National Agricultural Research Systems (NARS), DAE, BADC, NGOs, and private seed companies. Public organization and private seed companies produce and market zinc rice seeds nationwide, supported by DAE and private seed retailors, driving rapid adoption. NGOs, both local and international, play a crucial role in mobilizing communities, distributing seeds, and conducting awareness campaigns, thereby complementing government efforts.

f) **Research and Feedback Mechanisms:** Ongoing research and feedback from farmers and consumers are vital for the improvement and dissemination of biofortified crops. Agricultural research institutions like BRRI and BARI conducted field trials and gathered data on the performance of biofortified varieties. This research helps refined the crops and ensures they meet the nutritional needs and preferences of the population.

4.2. Challenges in Dissemination

Despite the significant progress in disseminating biofortified crops, several challenges remain:

a) ***Awareness and Acceptance*:** While awareness is growing, some farmers and consumers remain sceptical about the benefits of biofortified crops. Overcoming these perceptions requires continuous education and demonstration of the tangible health and economic benefits.

b) ***Seed Supply and Distribution*:** Ensuring a consistent and widespread supply of biofortified seeds is a logistical challenge. Infrastructure limitations and the need for efficient distribution networks can hinder the availability of seeds, particularly in remote areas.

c) ***Market Integration*:** For biofortified crops to be widely adopted, they must be integrated into local markets. Farmers need to be assured of a market for their biofortified produce, which requires efforts to increase consumer demand and the establishment of value chains that support the sale and distribution of these crops.

5. Way Forward

The future of biofortified crops holds immense potential in addressing Bangladesh malnutrition, but realizing this potential requires strategic actions and sustained efforts. To fully integrate biofortified crops into agricultural systems and diets, needs to take several key steps:

a) **Scaling Up Production and Distribution:** Expanding the cultivation of biofortified crops is crucial. This involves increasing seed production, enhancing distribution networks, and ensuring that farmers, especially those in remote areas, have access to high quality biofortified seeds. Governments, NGOs, and private sector partners need to work together to create efficient supply chains that reach all regions.

b) **Increasing Farmer Adoption:** To encourage widespread adoption, it is important to provide farmers with the necessary knowledge and resources to grow biofortified crops effectively. This includes offering training programs, establishing demonstration trials, and providing financial incentives or subsidies where needed. Extension services should play a central role in educating farmers about the agronomic benefits and nutritional advantages of biofortified crops.

c) **Consumer Awareness and Demand Creation:** For biofortified crops to succeed, consumers must recognize and value their nutritional benefits. Public awareness campaigns, nutritional education programs, and marketing strategies can help build demand for biofortified foods. By creating consumer demand, farmers are more likely to grow these crops, knowing there is a market for their produce.

d) ***Integration into National Policies and Programs:*** Governments should integrate biofortified crops into national food and nutrition security strategies. This could include incorporating biofortified foods into public procurement systems, such as school feeding programs and food aid initiatives. Policies that support the research, development, and dissemination of biofortified crops should be prioritized.

e) ***Continued Research and Innovation*:** Ongoing research is essential to improve the nutrient content, yield, and adaptability of biofortified crops. Scientists should continue to explore new crop varieties and biofortification methods, including both conventional breeding and biotechnology. Research should also focus on understanding consumer preferences and addressing any barriers to the acceptance of biofortified foods.

f) ***Strengthening Partnerships*:** Collaboration between governments, research institutions, international organizations, NGOs, and the private sector is key to scaling up biofortification efforts. Strong partnerships can help mobilize resources, share knowledge, and implement coordinated strategies that enhance the reach and impact of biofortified crops.

g) ***Monitoring and Evaluation*:** To ensure the effectiveness of biofortification programs, robust monitoring and evaluation systems should be in place. This involves tracking the adoption rates of biofortified crops, assessing their impact on nutritional outcomes, and gathering feedback from farmers and consumers. Data driven insights will guide future improvements and help sustain the momentum of biofortification initiatives.

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Chapter 3

Development and Dissemination of Biofortified Crop Varieties of different crops in Bhutan

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1. Introduction:

Bhutan is a small, landlocked country located in the southern slopes of the Eastern Himalayas. It is bordered by China to the north and India to the south, east, and west. The country spans a total geographical area of 38,394 square kilometres and has a population of 763,249 people (UNFPA, 2024). Despite 2.93% of land being arable, farming continues to be the primary occupation of 42.1% of its population (NSB, 2023). As reported in the 2022 Labor Force Survey.

Bhutan's 43.5% population rely on agriculture for their livelihood (NSB, 2022). The majority of Bhutanese farmers are smallholders with an average farm size of 3.7 acres engaging in self-sustaining subsistence integrated farming systems (RNR Census 2019). Major crops cultivated in Bhutan are rice, maize, potatoes, and wheat. Bhutan's unique topography and climatic conditions create a diverse range of agro-ecological zones, making it ideal for cultivating various crops.

Despite all these potentials agricultural diversity, the country faces challenges in ensuring food and nutritional security for its population. To address these challenges, developing and disseminating biofortified crop varieties offers a promising solution. Biofortification focuses on enhancing the concentration of essential vitamins and minerals in crops through methods such as traditional plant breeding, genetic engineering, or agronomic techniques. This strategy seeks to offer more nutritious food choices, contributing to the reduction of micronutrient deficiencies in a sustainable and cost-efficient way.

Given Bhutan's dedication to Gross National Happiness (GNH) and sustainable development, the country is ideally suited to adopt biofortification as a means to enhance the nutritional well-being of its people. Introducing biofortified crop varieties can significantly enhance the dietary quality of Bhutanese households, particularly in rural areas where access to diverse and nutrient-rich foods is limited. This paper explores the development and dissemination of biofortified crop varieties in Bhutan, focusing on the progress made, the challenges encountered, and future prospects. It discusses the importance of biofortification in addressing micronutrient deficiencies, the role of government and international organizations, and the impact on local communities.

1.1 Nutritional Challenges in Bhutan:

Picture 2: Primary school students growing vegetables

Despite Bhutan's significant progress in reducing poverty, malnutrition remains a persistent challenge. A substantial portion of the population does not have access to nutritious diet. The World Food Programme's 2022 report revealed that 27% of households cannot afford nutritious diet. Therefore, further emphasizes has been given on the access to nutritious foods, such as fruits, vegetables, and animal-based products. Bhutan faces a "triple burden" of malnutrition, which includes over nutrition, under nutrition, and micronutrient deficiencies, as noted by the Department of Public Health (2021). Undernutrition, particularly stunting and micronutrient deficiencies, is a critical issue, especially in rural area. Child stunting in Bhutan is considered to be of moderate public health significance, with approximately 21.2% of children affected (National Nutrition Survey, 2015). In addition to stunting, anemia poses a serious public health concern, affecting over 40% of the population (National Nutrition Strategy and Action Plan 2021-2025, 2021). The National Nutrition Survey 2015 indicates that anemia affects 43.8% of children aged 6-59 months, 31.3% of adolescent girls aged 10-19 years, 34.9% of non-pregnant women aged 15-49 years, and 27.3% of pregnant women. On a positive note, the annual report by the Ministry of Health (2012) highlights that Vitamin - A deficiency is no longer a public health problem, largely due to the government's vitamin A supplementation program.

On the other hand, over weight and obesity present significant challenges in Bhutan. According to the National Nutrition Strategy and Action Plan (2021), 33.5% of the population is overweight, and 11.4% are classified as obese. These trends may be attributed to unhealthy dietary habits and cultural practices of diets high in carbohydrates but low in protein and micronutrients. Rural households, in particular, tend to have less diverse diets compared to urban households, often lacking in iron and essential micronutrients. Additionally, urbanization and the shift toward processed foods have contributed to the increasing rates of obesity and non-communicable diseases (NCDs).

Over the years, awareness of health issues related to nutrients has steadily increased, due to government initiatives, and efforts by international organizations like the World Health Organization (WHO) and the Food and Agriculture Organization (FAO). However, significant work remains to be done, particularly in rural areas where traditional dietary practices and limited access to nutritious foods continue to pose challenges. Biofortification presents a promising solution to these issues, but in Bhutan, awareness of biofortified varieties is still in its early stages, although it is beginning to gain attention as a potential strategy to address the country's nutritional challenges.

2. Status of Biofortified varieties developed and disseminated:

With significant advancements in plant breeding, addressing global nutritional deficiencies has become more feasible. Biofortification, which involves enhancing the nutrient content of crops through genetic methods such as plant breeding and genetic modification that aims to deliver higher levels of essential vitamins and minerals like iron, zinc, and vitamin A directly through the foods people consume daily. This approach offers a sustainable and cost-effective solution to improve dietary intake, particularly in regions with limited access to diverse diets or fortified foods. In Bhutan, the development of biofortified crop varieties began in 2012 with the release of the country's first quality protein maize (Katwal *et al*., 2013). Since then, the initiative has gained momentum, with ongoing evaluations of lines and germplasms received from international centres. The status of some of the crop varieties developed in Bhutan are the following.

2.1. Maize: In 2007, Bhutan's Maize Program faced a significant challenge due to an outbreak of grey leaf spot (GLS) disease caused by *contributes* to over 70 percent production losses from any maize farmers. To combat the disease, the National Maize Program partnered with the CIMMYT South Asia Regional Office in Nepal to develop or identify GLS-tolerant maize varieties suited to high-altitude, rain-fed, mountainous regions of Bhutan. Over 100 GLS-tolerant

Picture 3: Farmers engaged in preserving maize seeds

maize varieties were introduced from CIMMYT centres located in Colombia, Zimbabwe, Mexico, and Nepal, and were tested in naturally occurring GLS hot spots. After several years of multi-location, nationally-coordinated evaluations, two varieties from CIMMYT Colombia were identified and officially released following successful large-scale demonstrations in 2012. One of these varieties, S03TLYQAB05, a quality protein maize, was named "***Shafangma ashom***" (Katwal *et al.*, 2013). The variety has an average yield of 6.87 tons per hectare and is recommended for growing above 1800 m above sea level. The variety is tolerant to GLS and contains more lysine and tryptophan compared to other maize varieties. The variety is being cultivated by some communities in eastern Bhutan.

Picture 4: Nutrient dense Potatos (Yusimao & Nasphel Kewa Kap)

2.2. Potato: Potato is staple crop in Bhutan, contributing significantly to food security and its economy (Rai et al., 2021). They are vital source of nutrition. As of now, Bhutan have released six potato varieties and among them one is chipping variety (ARID, 2023). In response to this gap, biofortified potato clones from the International Potato Centre were introduced in Bhutan two years ago and are under rigorous multi-location field testing and evaluation. Some of the clones showed promising results. The eventual final selection and release of biofortified potato variety is expected to play a crucial role in improving the nutritional security of the Bhutanese people.

2.3. Wheat: Wheat is the third most important cereal crop cultivated and consumed in Bhutan (Chopheletal *et al*., 2019)., About 65% of the wheat is cultivated after the harvest of rice. Historically, wheat was a staple food for the people living in the high-altitude regions of the country.

Picture 5: Wheat field at Tang, Bumthang Bhutan 2024

However, overtime, shifts in dietary preferences and consumption patterns have led to a decline in wheat consumption as people increasingly favor rice. Currently, Bhutan has four officially released wheat varieties, but none of these are biofortified (ARID, 2023). Recognizing the health benefits of wheat, there has been a recent interest by the people for its consumption. In response to this, efforts to introduce biofortified wheat varieties began in 2014, with the introduction of 50 biofortified lines from CIMMYT. These lines are now in advanced stages of evaluation, and two promising lines have been selected for large-scale demonstration in farmers' fields. Following this demonstration phase, the most promising variety among the two, will be proposed for official release. In addition to these biofortified lines, 234 elite Zinc lines were introduced in 2023 and are currently undergoing evaluation. A promising line from this group will be proposed for release once the evaluation is completed. These efforts represent a significant step towards improving the nutritional quality of wheat and enhancing food security in Bhutan.

2.4. Rice: Rice is one of the main staple foods in the country. Between 2012 and 2014, there was a notable rise in neuropathy cases, leading to fatalities in schools. This alarming trend prompted the Ministry of Health to conduct a National Nutrient Study, which identified a deficiency in micronutrients, particularly vitamin B, as the primary cause. In response, the government directed the Department of Agriculture and the Ministry of Education to begin food fortification efforts to address these nutritional gaps through fortified rice. Since 2017, the World Food Programme has supported this initiative by importing fortified rice for the school feeding program, significantly enhancing the nutritional security of students.

Picture 6: Fortified Rice in School Feeding Program

3. On-going value addition activities of biofortified crops products:

The Ministry of Agriculture and Livestock acknowledges the important role that Biofortified crop varieties play in combating micronutrient deficiencies and boosting food security. Current initiatives focus on collaborating with international agricultural research institutions to develop biofortified crops tailored to Bhutan's diverse agro-ecological zones through rigorous evaluation. For example, the National Potato Program is working with the International Potato Centre on the evaluation of biofortified potato clones, and the National Wheat Program is also Woking with CIMMYT. Additionally, recognizing the importance of nutrition for children and young, the government has begun promoting Nutri-dense foods in the school feeding program, such as fortified rice (School Health and Nutrition Division, 2019). The government aims to scale up these efforts by strengthening public-private partnerships to ensure a wider distribution network, enhancing research and development to introduce more Biofortified crop varieties, and integrating Biofortified products into public food procurement systems for school and hospital feeding programs, to ensure broad-based access and acceptance among the population.

The above strategies are crucial for improving the nutritional status of the Bhutanese people, particularly in rural areas where malnutrition is more prevalent. Further, efforts such as awareness campaigns, social media outreach, and promotion through national television are being used to increase the consumption of biofortified and nutri-dense crops. Moreover, the collaboration of various departments and organizations will be crucial in combating malnutrition and enhancing food security by developing and promoting biofortified crop varieties. Agricultural Research and Development Centers (ARDCs) should focus on developing and testing of biofortified seeds to ensure their adaptability across different agro-ecological zones. Extension services must prioritize educating farmers on the benefits of these crops.

4. Marketing Issues:

Biofortified crops are still relatively new to Bhutan, but they have been gradually gaining momentum over the years. For example, Biofortified maize, which was introduced in 2012, is now cultivated by farmers and primarily consumed at the household level. The National Seed Centre is responsible for producing the seeds. Currently, these Biofortified crops have not yet reached the commercial market.

5. Challenges and opportunities (Way Forward):

The development and promotion of biofortified crops in Bhutan face significant challenges, primarily due to the country's unique socio-economic and agricultural landscape. One of the main barriers is the lack of awareness and understanding among farmers and consumers about the nutritional benefits of these crops. Hesitation of farmers to adopt new crop varieties, coupled with lack of financial and institutional support, further hinders progress. Bhutan’s limited research and development (R&D) capacity and resources slow the development of high-yielding, resilient crop varieties. Additionally, the country’s rugged terrain and the prevalence of smallholder farming complicated the distribution and access to these seeds. The lack of a well-established market and supply chain for Biofortified crops also hampers their commercial viability and wide spread adoption.

However, there is considerable potential for Biofortified crops, especially in achieving nutritional security. To advance their development and dissemination in Bhutan, a comprehensive approach is necessary, focusing on capacity building and awareness-raising initiatives. Enhancing the country's R&D capabilities through collaboration with international agricultural organizations will enable exchange of knowledge and advanced breeding techniques & material. Simultaneously, increasing farmer participation through participatory breeding programs, field demonstrations, and improved extension services will help to promote these crops. Furthermore, integrating biofortified crops into national nutrition policies and promoting their inclusion in school feeding programs and integrating local markets with production system may help to adopt these crops by farmers. By prioritizing these efforts, Bhutan has the potential to significantly improve nutritional security, particularly in rural areas where malnutrition remains a concern, thereby contributing to the overall health and well-being of its population.

6. Conclusion:

Bhutan has made notable progress in the development and dissemination of crop varieties, significantly contributing to agricultural sustainability and food security. However, the advancement of biofortified crops, which are essential for combating nutritional deficiencies, remains in the early stages. This offers Bhutan a valuable opportunity to invest in research and development aimed at enhancing the nutritional content of staple crops. By prioritizing the growth of biofortified varieties, Bhutan can take decisive action to improve nutritional security and ensure that its population receives vital micronutrients. As the country continues to advance in its agricultural initiatives, integrating biofortification into crop development programs will be crucial in addressing both food and nutritional security, ultimately promoting a healthier and more resilient society.

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Chapter 4

Development and Dissemination of Biofortified varieties of Different Crops in Maldives

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1. Introduction:

The Republic of Maldives is a small island developing state (SIDS) located in the Indian Ocean isolated from the Asian mainland. The nation consists of 1,190 coral islands that are scattered into an area of 90,000 km^2. Despite the isolated nature of these islands and its small size, the total population of nearly 500,000 of the country resides in only 186 islands that are spread across the country (NBS, 2015). In addition to the small size, the natural resources available in these islands are limited. Nonetheless, the country achieved significant economic growth in the past few decades by increased development of tourism and fishing, which are the major two industries of the Maldives.

Till late 1970s, coconut, maize, sorghum, finger millets, sweet potato and other root crops such as taro, cassava and breadfruits traditionally grown in the island and fishing were the main sources of food of the island communities. At that time crop cultivation and its trade were not easy due to the geographic isolation and transportation difficulties between islands. The agriculture sector has transformed significantly over the past few decades. However, the contribution of agriculture to the GDP continued to decline.

Backyard gardening is the most commonly practiced crop cultivation in Maldives. Family members used to engage in farming and a variety of crops were cultivated in a small piece of land at the backyard. Coconut is cultivated in almost all the islands. Exchange of agricultural produce with dried fish between fishing and farming islands was a common practice until 1970s. Official trade of agricultural produce started during the first quarter of 1970s. Copra, a product produced from coconut was the major agricultural export commodity. Coconut tree were very close to the hearts of Maldivians and considered as the “tree of life”. Apart from the income generated from copra trade, coconut trees were the main source to fulfil basic needs of the island communities. Palm leaves were used for thatching and the wood from the trunk of palms were utilised to build almost everything from basic shelter, furniture and household utilities to boats which were used as vessels to travel in between islands.

Transportation from one island to the other gradually started to improve during 1990s opening better opportunities for agricultural trade. The household head, the men, shifted the farm operation responsibilities to their housewives. Men started travelling to Male' with their agricultural produce to sell them in the local market. Women played a pivotal role in the development of Maldivian agriculture. Although women's primary responsibility in Maldives has been traditionally in managing home and taking care of children. However, their engagement in agriculture related activities like managing farm operations, taking care of plants, harvesting, processing and selling are remarkable.

A significant development in agriculture were seen during 1990s. Several new crops and varieties were introduced to farmers along with the provision of technical support services through a newly established government extension service system. Compared to the earlier days, agriculture industry in the country has transformed and today the main staples crops are rice and wheat. It is surprising to know that none of these crops were cultivated locally before 90's. The list of commonly cultivated crops has changed over the past few decades.

Presently the most popular crops grown by Maldivian farmers are coconut, breadfruit, guava, wax apple, custard apple, pond apple, mango, banana, papaya, betel nut, betel leaves, and leafy vegetables such as collard greens, amaranthus etc. Popular cash crops include various types of chillies, eggplant, passion fruit, collard greens, pumpkin, papaya and watermelon including other improved commercial varieties of melons. Moreover, some root crops including sweet potato, cassava, yam and taro are still common in some islands. According to the statistics published by the National Bureau of Statistics (NBS) in 2017 the agriculture shared only 1.8% of the GDP of Maldives. Official records of the Ministry of Fisheries Marine Resources and Agriculture (MOFMRA) shows that as of July 2019, 7,536 registered farmers are active in agricultural operations in 77 inhabited islands. Furthermore, in 2019, commercial agriculture production is underway in 50 uninhabited islands (MOFMRA, 2019).

Figure 1: A backyard cultivation of Taro field in one of the southern islands.

The overall economic development achieved during the past few decades have had tremendous impact on the family farming activities of the islands. People in the islands started to move away from homes for better employment opportunities that came along with the opening of new tourist resorts. At the same time fishing industry flourished with the establishment of Tuna fish canning factories.

The working age group contributes 68% of the total population (NBS, 2015). The typical mindset of youth made more challenging to retain them in farming activities. Majority of the people engaged in agricultural activities are old age pension holders. Very few people from working age group practice farming to supplement their income. Family members that used to work together in farms have been replaced by expatriate labourers.

Thus, this change in employment opportunities and working conditions and high migration rates to urban centres together with the availability of imported, processed and unprocessed foods, the food habits of most of the population have been gradually changing.

Figure 2: Millet grown in the North, millet used to be a major food crop grown in the North till the late 80s, and is considered one of the more nutrition rich foods crops but millet can hardly be seen grown.

Although major nutritional deficiencies are little to negligible among the majority adult populations, it has been found that about 17% of children in the Maldives are underweight or stunted and health studies have found out about 22% of children under 8 are overweight or obese. (NBS, 2018). Various reports have suggested poor integration of vitamins and micro nutrients in the diet due to eating habits or not adding fresh fruits and vegetables in the diet particularly by the people of rural islands.

Underlying policies for agriculture development within the strategic action plan of the government are:

1. Ensure that competitiveness of the agriculture sector is promoted, improved and sustained, in both domestic and foreign markets;
2. Ensure that the agricultural sector significantly increases its contribution to food security and safety;

3. Mainstream climate smart and sustainable agricultural practices;
4. Ensure that meaningful partnership opportunities are fostered with stakeholder institutions, in order to improve capacity and access to relevant data and mobilization of resources.

2. Status of biofortified varieties and constraints to its development:

Agricultural research related activities are comparatively low compared to other SAARC member countries. Scarcity of land and other related resources necessary for the development of agriculture is challenging. Majority of agricultural development activities are focused on extension and training, providing administrative services etc. Nonetheless research related activities on improved variety testing, and developing appropriate agronomic new techniques are demonstrated before delivering to farming communities.

There is no record of any related production of biofortified variety development program nor testing of imported biofortified cultivars in the country. However, to some extent such cultivars are being cultivated through importation of planting material and also through imported fruits and vegetables (at home garden level). One of the examples are root crops such as sweet potatoes (purple and orange coloured) and purple taro (higher in flavonoids and other such compounds). Improved varieties of corn, banana and other fruits & vegetables which are mostly hybrid are being cultivated. Some of these imported hybrid varieties does claim its improved nutritious value but lacks proper testing and is not solely cultivated for nutritional value for incorporating a certain element or vitamin in the diet. But these crops are not “farmer friendly due to higher requirement of agricultural inputs specially fertilizers.”.


Figures 3& 4: Cash crops for the tourist industry such as melons and papaya are much popular among farmers. However, these imported hybrid variety seeds are not particularly developed for their nutritional values. Additionally, consumption habits among locals and because of high prices they are not much favored among the local population.

As land and labour costs are challenging the main aims of the farming communities of Maldives are for the trade and income rather than to add to their food supplement. Hence nutritional aspects of food items are neglected and is given less priority. Majority of agricultural produce are targeted towards the tourist industry thus special crops like chillies, melons papaya, banana etc are cultivated. Food crops like millet, corn, yams etc are not preferred.

Important points to consider and potential use for biofortified verities in the Maldives are the following;

- Majority of the crops grown for consumption requires lot of inorganic and organic fertilizer, they are totally reliant on additional nutrients. Thus, introduction of lesser "hungry" crops would mean healthy and "organic" safe produce.
- Iron deficiency and some micro-element deficiency among pregnant women and children are common among rural populations thus incorporation of improved varieties and marketing to bring a change in diet habits are important.
- Regional exchange of such varieties of seeds could help better identify suitability to local conditions for adoption.
- Promotion or marketing of biofortified crops.
- As an island nation totally reliant on imported foods, regional ease of availability of biofortified varieties will benefit the farmers and consumers of Maldives.

Conclusion

Rapid economic growth that the Maldives achieved in the last few decades have transformed all economic sectors including agriculture. Complete dependence on food grown at the backyard has now become a part of the history for the island communities. Fortified food products from baby formulae to dietary supplements are available through importation from various countries. However, shortage of nutritious food is still prevalent in outer atolls, at times and due to selective food habits and transportation difficulties. It is also important to emphasis on the cost of being reliant on imported foods thus to change the foods habits it should be more affordable and easily available.

Availability of biofortified foods within the islands of Maldives and affordability of imported biofortified food commodities would be possible by improving the status of regional availability and trade access.

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Chapter 5

Development and Dissemination of Biofortified varieties of different Crops in Nepal

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Abstract

As an agrarian nation dependent on small-scale farming, Nepal continues to face significant food and nutritional challenges. To address these issues, a study was conducted to evaluate the development and deployment status of biofortified crop varieties, identify adoption constraints, and provide recommendations for their promotion. The review was based on data gathered from multiple stakeholders, especially from commodity programs of the Nepal Agricultural Research Council, policymakers, and academicians. Despite implementing several agrifood system interventions, such as food fortification, agronomic biofortification, and biofortification itself, the use of biofortified crops, though being sustainable, remains underutilized and underexploited in Nepal. Currently, only thirteen biofortified varieties, in maize, wheat, lentil, and sweet potato, have been developed to enhance protein, zinc, iron, and vitamin A content in the diet. While these varieties offer both yield and nutritional advantages, they have not been widely deployed to reach their full potential to meet national dietary demand. The major challenges include technical barriers, entrenched food habits, limited consumer awareness, and undifferentiated product and market segmentation. The study highlighted the need for coordinated efforts to promote biofortification in Nepal, such as increased investment in national breeding programs, regional collaboration through initiatives like Custom Seed Production and the Seed Without Borders approaches among SAARC countries, and consumer sensitization for rapid deployment of the biofortified varieties. Regional and national supportive policies are also crucial to enhance the adoption and impact of biofortified crops, ultimately contributing to improved nutrition in Nepal.

Keywords: Biofortified varieties, Hidden hunger, Nutritional security, consumer sensitization

1. Introduction

Nepal is a landlocked country featuring with predominantly small- scale farming with fragmented land holding (per capita 0.16 ha). It employs 51.8 % labor force and contribute 25% to the country's GDP. About 21% area is utilizing for cultivation where rice, maize, wheat, legumes, millet & oilseeds are the major crops. Rice, maize and wheat are the major cereals having approximately three and quarter tons of productivity, whereas minor cereals (millets, barley and buckwheat) yield is one and quarter tons per hectare. Rice is the staple food that significantly contributes to the nutrition of nearly all households and plays a major role in the country's GDP (AITC, 2024; MoALD, 2024).

Nepal's Constitution (2015) guarantees food as a fundamental right, which is further strengthened by the Right to Food and Food Sovereignty Act (2018). The government also committed to achieve the goal of the Sustainable Development Goals on zero hunger by the year 2030. However, the government of Nepal has challenges to achieve the target of reducing the prevalence of childhood stunting to 15%, underweight to 10% and wasting to 4% by 2030. Moreover, Nepal's Global Hunger Index is 15 (Moderate) where it ranks 69th out of the 125 countries (GHI, September 2, 2024). National Demographic and Health survey (2022) reported that one of 12 people are undernourished, 19% people are still suffering from food-based poverty, Child wasting 8% and anemic pregnant women are 48%. Out of 7 provinces in Nepal, Karnali Province has the highest rate of severe food insecurity at 17.5%, while Gandaki Province has the lowest at 6.0%. The national average for severe food insecurity is 9.9%. Regarding the adult nutrition status, 66% man and 61% women only having properly nourished and rest are fall under malnutrition (NDHS, 2022).

To cope with this nutrition related anomaly, Nepal has implemented a wide range of multisectoral (agriculture, food, medical, public health, supplement, clinical etc.) interventions (Adhikari *et al.,* 2024). The agri-food system related interventions are more likely to be sustainable than the other ways are fortification, agronomic biofortification and biofortification (Batool, 2022).

Food fortification is the process of improving the nutrient content of food through physical means. Nepal has a wealth of documentation supporting food fortification as a key nutrition intervention. Notable examples include the Iodized Salt Act (1992), the National Nutrition Policy and Strategy (2004), the National Nutrition Strategy (2020), and the Multisector Nutrition Plan (2018–2022). These policies emphasize the recommendation of fortified commercial products, such as wheat flour enriched with iron, folic acid, and vitamin A; rice fortified with essential micronutrients; and salt fortified with iodine. This method is especially implemented in remote communities in the hills and mountains with homogenous population, as well as in school feeding programs, to boost food and nutrition. Additionally, this intervention is primarily focused on providing supplements to key groups only, including children, adolescents, and women during pregnancy and lactation.

Fortification faces more limitations and challenges in heterogenous population compared to agronomic biofortification and biofortification. Agronomic biofortification is customized biofortification approach where it could enhance desired mineral nutrients in crops and variety of our choice (Gameda, 2024).Agronomic biofortification can effectively increase the mineral content, such as Iron, Selenium, and Zinc etc. (Maqbool & Beshir, 2019).Foliar application of Zinc has been found to be more efficient for Zinc biofortification (Up to 20-30% over control) in rice, wheat, and maize compared to zinc priming, seed coating, and Zinc soil application in many trials conducted in Nepal Agricultural Research Council (NMRP, 2023).

Biofortification is the process of naturally enhancing food crops with vital nutrients which offers a sustainable and enduring solution to nourish both agricultural and non-agricultural communities with essential micronutrients (Ghimire *et al.*, 2019; Yadava *et al.*, 2020). Although biofortification is a sustainable approach, it remains underexplored, and underutilized in Nepalese agriculture. Thirteen biofortified varieties in four crops have been developed, and their proper deployment has the potential to significantly reduce agri-food system-related malnutrition in Nepal.

2. Methodology

This conference paper was compiled through a comprehensive review of articles, literature, progress reports, and working group review papers of various commodity programs. Additionally, personal communications and consultations with health and nutrition experts, as well as senior plant breeders from the Nepal Agricultural Research Council's commodity programs.

3. Status of Biofortified varieties in Nepal

Nepal has released 13 biofortified varieties out of 744 varieties released and registered so far(AITC, 2024). The first biofortified maize variety was introduced in 2008. Since then, a total of 2 maize varieties, 6 wheat varieties, 3 lentil varieties, and 2 sweet potato varieties have been released under the biofortified category.

Table 1: Status of biofortified crop varieties, nutrient trait improved and breeders seed deployment in Nepal, 2024.

Crop	Name of the Variety	Released Year	Trait improved	BS* Deployed (Kg in 2023)
Maize	Poshilo Makai -1	2008	Lysine & Tryptophan	1380
	Poshilo Makai -2	2017	Lysine & Tryptophan	520
Wheat	Zinc Gahun 1	2021	Zinc	2540
	Zinc Gahun 2	2021	Zinc	513
	Borlaug 2020	2021	Zinc	1717
	Bheriganga	2021	Zinc	2399
	Himganga	2021	Zinc	808
	Khumal Shakti	2021	Zinc	3510
Lentil	Khajura Masuro-3	2017	Iron, Zinc	270
	Khajura Masuro-4	2018	Iron, Zinc	200
	Shradha	2020	Iron, Zinc	45
Sweet potato	Suntale Sakharkhand-1	2019	Provitamin A	NA
	Suntale Sakharkhand-2	2019	Provitamin A	NA

BS- Breeder seed deployment from the respective commodity program. NA-Not applicable and data are not available for seed tuber/ seed vine deployment.

4.Variety profile of Biofortified varieties in Nepal

4.1 Biofortified varieties of maize

In collaboration with CIMMYT, Nepal Agricultural Research Council (NARC) has developed two quality protein maize varieties so far and has been working on developing and promoting zinc-enriched and provitamin A-rich maize varieties in the future, which are being gradually introduced to farmers to improve nutritional status, especially in mid-hills areas where maize is a staple crop**.**

Maize			
Poshilo Makai-1		**Poshilo Makai-2**	
Biofortification Target Nutrient	Quality Protein maize (Tryptophan and Lycine)	Biofortification Target Nutrient	Quality Protein maize (Tryptophan and Lycine)
Released Year	Released Year:2008	Released Year	Released Year:2008
Recommended Domain	Mid-hills below 1600 m east to west	Recommended Domain	Mid-hills below1600 m
Grain Color	White	Grain Color	Yellow

Origin	CIMMYT	Origin	CIMMYT
Pedigree	S99TLWQ-HG-AB	Pedigree	S99TLYQ-B
Maturity days	145-155	Maturity days	120 (Summer)160 (Winter)
Grain yield	5.3 t ha^{-1}	Grain yield	4.6 t ha^{-1}

Source: Koirala, (2017)

4.2 Biofortified varieties of wheat

The National Wheat Research Program, Bhairahawa, and National Plant Breeding and Genetics Research Center, Khumaltar under Nepal Agricultural Research Council (NARC), in collaboration with CIMMYT, Mexico has developed six biofortified wheat varieties in 2021 AD enriched with zinc and iron (Thapa *et al.*, 2022; Pant *et al.*, 2023). These nutritionally enhanced varieties are being gradually introduced to farmers to improve the nutritional well-being of smallholder communities, particularly in the Terai, inner-Terai, mid-hill and high-hill regions. It can be used in the school feeding program where wheat is directly milled and consumed without further nutrient fortification.

Wheat			
1. Zinc Gahun 1		**2. Zinc Gahun 2**	
Grain Zinc content	35 -46 ppm	Grain Zinc Content	40 ppm
Grain Iron content	39-41 ppm	Grain Iron content	39 ppm
Released year	2021	Released year	2021
Recommended Domain	Terai & Inner Terai	Recommended Domain	Terai & Inner Terai
Plant height	100 cm	Plant height	94 cm
Days to maturity	121 days	Days to maturity	120 days
Grain Yield	4.7 to 5.9 t/ha	Grain yield	5.0-6.4 t/ha
No. of grains/spike	47-51 g	No. of grains/spike	52
Thousand grain weight	41-55 g	Thousand grain weight	38-40 g
No. of Tillers/m^2	210-312	No. of Tillers/m^2	351-364
Resistant to leaf rust and yellow rust and tolerant to spot blotch		Resistant to leaf rust and yellow rust and tolerant to spot blotch	

3. Borlaug 2020		4. Bheriganga	
Grain Zn content	44 ppm	Grain Zn content	48.4 ppm
Released year	2021	Grain Iron Content	36.8 ppm
Recommended Domain	Terai & Inner Terai	Released year	2021
Days to maturity	120 days	Recommended Domain	Irrigated Mid and high-hills
Plant height	87 cm	Days to maturity	164 days
No. of spikes/sq.m	304	Plant height	94 cm
No. of grains /spike	44-51	No. of spikes/sq.m	345
Thousand grain weight	42-46 g	No. of grains /spike	46
Grain Yield	4.5-5.5 t/ha	Thousand grain weight	51 g
Grain Color	White color	Grain Yield	4.56 t/ha
Resistant to leaf rust and wheat Blast disease		Stripe and Leaf rust resistant	
Drought tolerant variety			

5. Himganga		6. Khumal Shakti (WK 3027)	
Grain Zinc content	54.1ppm	Grain Zinc content	39.4 ppm
Grain Iron content	32.3 ppm	Grain Iron content	32.9 ppm
Released year	2021	Released year	2021
Recommended Domain	Irrigated mid and high hills	Recommended Domain	Irrigated mid and high hills
Days to maturity	181 days	Days to maturity	165 days
Plant height	82 cm	Plant height	92 cm
No. of spikes/sq.m	288 cm	No. of spikes/sq.m	275
No. of grains /spike	44-51	No. of grains /spike	53
Thousand grain weight	49 g	Thousand grain weight	55 g
Grain Yield	4.51 t/ha	Grain Yield	5.09 t/ha
Stripe rust and leaf rust resistant		Stripe rust, leaf rust, and Stem rust (Ug 99) resistant	

Source: Thapa *et al*. (2022); Pant *et al*. (2023)

4.3 Biofortified varieties of lentil

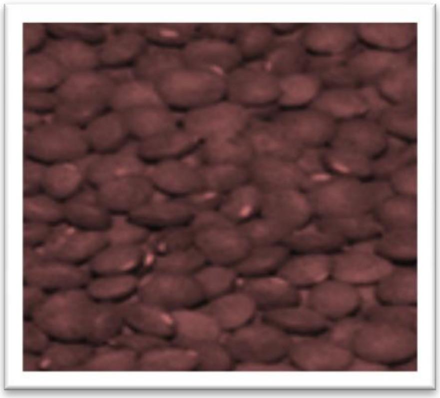
Nepal has made significant step in developing biofortified lentil varieties, particularly focused on enhancing iron content. The National Legume Research Programme (NGLRP) under Nepal Agricultural Research Council (NARC), in collaboration with international organizations such as HarvestPlus and the International Centre for Agricultural Research in the Dry Areas (ICARDA), has developed and released 3 varieties to address iron deficiency (Darai *et al.*, 2020).

Lentil			
Khajura Masuro 3		**Khajura Masuro 4**	
Grain Iron content	81.47 ppm	Grain Iron content	79 ppm
Grain Zinc content	65.2 ppm	Grain Zinc content	45.19 ppm
Protein %	26.73	Protein %	27

Released Year	2017	Released Year	2018
Recommended Domain	Central to western Terai from 180 m to 1700 m	Recommended Domain	Mid to far western Terai
Origin	Nepal	Origin	Pakistan
Pedigree	ILL 6037 x ILL8007	Pedigree	FLIP 95-672 (ILL-7723)
Days to flowering		Days to flowering	87
Plant height	33 (18-43) cm	Plant height	33 cm
Days to maturity	142 (122-160)	Days to maturity	136
Thousand Grain Weight, g	19.4 (11-30)	Thousand Grain Weight, g	21.6
Yield t/ha	1.8 (1.01-2.30)	Yield t/ha	1.81 (2.50)
Dal recovery %	82	Dal recovery %	77

Special Characters: Moderately resistant to fusarium wilt and stem phylum blight and tolerant to rust. Red cotyledon

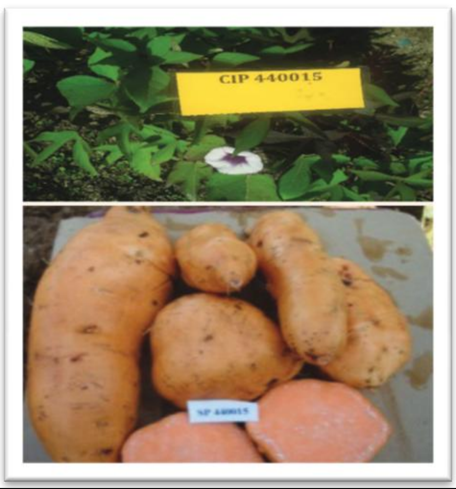
Special Characters: Moderately resistant to stemphylium and fusarium wilt, light green foliage, white flower with blue veins, plain and attractive light brown seed with orange cotyledon

Shradha		
Grain Iron content	75 ppm	
Grain Zinc content	42 ppm	
Protein %	25	
Released Year	2020	
Recommended Domain	Terai, Inner Terai and Mid-hills	
Origin	Nepal	
Pedigree	Black lentil	
Days to flowering	94	
Plant height	33 cm	
Days to maturity	142	
Thousand Grain Weight, g	18 (10-27)	
Yield t/ha	1.208	
Dal recovery %	76	
Special Characters: Moderately resistant to fusarium wilt and stem phylum blight. Dark green foliage, blue flower, attractive black seed		

4.4 Biofortified varieties of sweet-potato

Sweet Potato			
Suntale Sakharkhand-1		**Suntale Sakharkhand-2**	
Beta Carotene	40-95 mg/100 gm	Beta Carotene	17.58 mg/100 gm
Dry matter %	18.71	Dry matter %	29.52
Total minerals content	3.62%	Total minerals %	3.87
Released Year	2019	Released Year	2019
Recommended Domain	Terei, Inner terai and Mid-hills below 1600 m east to west	Recommended Domain	Terei, Inner terai and Mid-hills below 1600 m east to west
Origin	USA	Origin	Vietnam
Pedigree	W-220	Pedigree	(GAO x Bidalat) x (Tinung 57), Hung Loc 4

Genotype	CIP 440015)	Genotype	CIP 440267
Plant type	Semi compact	Plant type	Spreading
Maturity days	130-150	Maturity days	130-150
Vine length cm	75-150	Vine length cm	151-250
Vine diameter, mm	4.7-8.0	Vine diameter, mm	3.3-5.7
Internode length, cm	3.5-6.4	Internode length, cm	5.5-9.5
Leaf type	Lobed	Leaf type	Triangular
Leaf lobed type	Moderate	Leaf lobed type	Complete, Lobed-less
Lobe number	5	Lobe number	1
Yield, t ha^{-1}	12.91	Yield, t ha^{-1}	20.80
Drought and root knot nematode tolerant, Good for salad purpose		Best for salad purpose also	



Source: Bhattarai *et al*. (2021)

5. Value addition activities of biofortified crops products:

Among the four crops with biofortified varieties, only biofortified lentils are sold in Nepalese supermarkets with added value. Regular bold lentils cost NRs 170 per kg, while the biofortified fine grain variety, Khajura Masuro-3, is priced at NRs 225 per kg. The native and flavorful biofortified variety, Black Lentil (Shradha), is the most expensive and selling at a price NRs 280 per kg and is becoming popular among Nepalese consumers (Bhaat-Bhateni Supermarket, September 2024). This represents a price increase of up to 30% compared to non-biofortified lentils, driven by the added value. However, other three crop varieties are not yet disseminated well and found exclusive demand by the consumers although these varieties are nutritionally enriched.

6. Deployment and adoption constraints

Many varieties from four crops have been developed and are being deployed to enhance food and nutritional security. However, the promotion, adoption, and marketing challenges vary across different crops. The detail of which is given below:

6.1 Maize

Although introduced in 2008 as the country's first biofortified crop, the two biofortified maize varieties have not been disseminated to meet their full potential or national demand. The promotion, distribution, and impact of quality protein maize (QPM) have been hampered by technical barriers to adoption. A major challenge is the difficulty in maintaining seed and grain quality at the farm level due to cross-pollination and the recessive nature of the QPM gene. When QPM varieties are grown near conventional maize, cross-pollination gradually diminishes the QPM traits, ultimately reducing the bioavailability of lysine and tryptophan. These characteristic forces farmer to seek isolated areas for cultivating QPM, and they must purchase new seeds each season to ensure genetic purity, much like hybrid seeds (MKB, 2011). Additionally, studies have shown that QPM varieties are more susceptible to storage pest infestations than other open-pollinated varieties (OPVs) commonly cultivated in the mid-hills region when stored in traditional seed and grain containers (Bhandari *et al.,* 2015; Bhandari *et al.,* 2017).

6.2 Wheat

In Nepal, six biofortified wheat varieties released in 2021, have quickly gained popularity among smallholder farmers due to their higher yields, adequate disease resistance compared to existing varieties (Pant *et al.,* 2023; Thapa *et al.,* 2023). However, certain challenges remain in promoting the exclusive use of flour from these biofortified varieties. Biofortified wheat products are often given lower priority when compared to factors such as taste, flour quality, and baking performance. Additionally, biofortified varieties are primarily aimed at smallholder farming communities, where farmers grow and mill their own wheat to benefit from the enhanced nutritional value. In contrast, urban consumers are consuming fortified flours with appealing packaging, strong marketing, superior baking quality, and taste, such as those offered by popular brands like Hulas and Gyan.

6.3 Lentil

Nepalese lentils are comparative rich in micronutrients like Iron and Zinc (Darai, 2023). In the case of biofortified lentil varieties, one of the major barriers to promoting the three biofortified varieties is the adulteration of processed lentils with other varieties of similar color and size. The most popular biofortified variety is Black Lentil (Shradha), which is gaining widespread popularity not only for its enhanced zinc and iron content but also for its quick cooking time and appealing taste, both of which are highly favored by consumers.

6.4 Sweet-Potato

The National Potato Research Program, in collaboration with the International Potato Center (CIP), has released two orange-fleshed sweet potato (OFSP) varieties, Suntale Sakharkhand-1 and Suntale Sakharkhand-2, both rich in ß-carotene (Bhattarai and Subedi, 2023). However, sweet potato cultivation remains uncommon and limited, largely due to its absenteeism from the regular diet of the population. Commercially, it is one of the neglected crops in Nepal as Nepalese agriculture has not prioritized sweet potato production, and its consumption. Hence the actual national database on its area of production and yield are not available (Bhattarai *et al*., 2021) and the minimal production is mostly limited to religious festivals like *Makar Sankranti* and *Shivaratri* (Gautam, 1991).

In addition to these specific crop related challenges, biofortified varieties in Nepal face several common obstacles in terms of adoption and marketing. Limited awareness among both farmers and consumers hampers the broader uptake of these nutritionally enhanced crops. Many consumers are not aware of the health benefits linked to biofortified products, which contributes to a lack of consumer sensitization. Inadequate extension services further exacerbate the issue, with insufficient outreach and support for promoting these varieties at the grassroots level. Moreover, certification challenges hinder the proper labelling and recognition of biofortified products, making it difficult for consumers to distinguish them from conventional varieties.

Conclusion

In conclusion, despite the development of thirteen biofortified crop varieties in maize, wheat, lentil, and sweet potato that can enhance nutrition and support sustainable agriculture, their adoption remains limited due to challenges like technical barriers, entrenched food habits, and low consumer sensitization and undifferentiated product and market segmentation.

Recommendations and way-forward:

Promoting biofortified crop cannot be accomplished in isolation, as it requires coordination with other agricultural strategies such as improving crop management and addressing market demands. Additionally, a diverse range of varietal qualities including yield, taste, and biotic and abiotic stress resilience must be considered to ensure widespread acceptance.

1. Investment in national breeding programs and technological innovations in SAC as well as National Agricultural Research System (NARS) of Member state countries to develop biofortified varieties with multiple attributes like improved nutrition, yield, and stress-tolerance. In this regard, the collaboration with global research consortiums like Harvest-plus, CGIARs, IMIC and IARCs is essential to access and adapt germplasms of consumer preferences.

2. Enforcement of the Seed Without Border Agreements to strengthen regional collaboration and accelerate the exchange of elite biofortified varieties of rice across SAARC nations.
3. Facilitation of custom seed production and marketing by biofortified-rich states to supply biofortified varieties to deficit regions that ultimately create mutual benefits for both regions (SQCC, 2024).
4. Enhance seed access and affordability by providing ample source seeds and reliable supply of biofortified seeds, improving distribution networks, and collaborating with seed companies to reach farmers.
5. Consumers' sensitization by increasing awareness and education to farming communities about the benefits of biofortified varieties. This includes organizing workshops, training sessions, and field demonstrations to showcase the advantages of biofortification in improving nutrition and livelihoods.
6. Enhance product certification & market linkages for biofortified products to build consumer trust and ensure authenticity. Simultaneously, create strong market linkages by connecting producers with retailers, consumers, and institutional buyers like schools and hospitals.
7. Promote P4 (Public, Private, Producer, Partnership): Foster collaboration between public institutions, private companies, producers, and partnerships to drive the adoption of biofortified crops. This model encourages shared responsibility and resources to scale up biofortification efforts.
8. Develop Supportive Policies and Incentives: Implement policies that support growers and processors, such as subsidies on seeds and fertilizers, tax incentives, and grants for packaging and marketing biofortified products. These measures encourage both production and processing sectors to invest in biofortification. For example fixing additional minimum support price (MSP) for biofortified crop products as compared to other non-biofortified crop product.
9. Develop Production Pockets: Create specialized production zones for specific biofortified crops, such as Quality Protein Maize (QPM) villages or Zinc wheat villages. These areas can serve as hubs for targeted crop cultivation and link their products to larger markets, such as school meal programs, public distribution systems (PDS) etc. to boost demand and support local economies

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Chapter 6

Development and Dissemination of Biofortified Varieties of Different Crops in Pakistan

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Background:

Pakistan is the home of about 234 million people. It has total area of 79.90 million hecatres, while the cropped area of the country is about 24.10 million hectares. Climatically most parts of Pakistan are arid to semi-arid with significant spatial and temporal variability in climatic parameters. Ninety five percent (95%) of the annual rainfall is due to monsoon rains; a dominant hydro-meteorological re-source for Pakistan. Agriculture is the mainstay of the country and it contributes 24% to overall GDP and provides employment of over 43% of the workforce. This sector is contributing in food security and is helping reducing poverty. It is playing a vital role in improving the national growth of the country.

Major crops of the country are wheat, rice, maize, cotton, sugarcane, pulses and vegetables etc (GOP, 2023). During 2023-24, an overall increase of 16.82% has been recorded in the production of important crops. There was 11.6% increase in the production of wheat crop and the total production of wheat was 31.44 million tonnes, while its previous year total production was 28.16 million tonnes. There was 34.8% increase in the production of rice crop with the total production of 9.87 million tonnes, compared to 7.32 million tonnes of last year production. Though enough food is produced in the country meeting food consumption requirement of the population, but however the nutritional status of produce needs to be improved. Malnutrition is also one of the serious public health concerns in Pakistan and its economic consequences are touching $7.6 billion loss every year, equivalent to ~ 3% of GDP and more than three quarters of this financial burden emerges from nutrition deficits faced by women and children in the 1000 days from conception to a child reaching 24 months of age (NNS,2011).

Climate change impacts in the form of severe droughts, devasting floods, which results in the form of low crops yields, loss of livestock, and similarly extra heat leads early grain formation which stunts crops grains size, reducing yields. According to Ministry of Planning Development & Special Initiatives (2022), heat waves followed by a devasting flood event caused economic losses of US$ 9,244 million and flashed out 4,410 million acres of agricultural land.

Accordingly, increases in temperature can result in the form of reduced protein, zinc, iron and quality protein in crops, contributing to malnutrition and stunting (Government of Pakistan, 2021).

According to the 2011 national survey of nutrition, Zn deficiency was 47.6% and 41.3% in pregnant and non-pregnant women, while 39.2% children were suffering from Zn deficiencies(Government of Pakistan, 2011). Similarly, according to the report of Ministry of National Health Services Nutrition Wing, (2018), in Pakistan, 12 M children were stunted and 22.1% of women and 18.6% of children (under-age of five) were Zn deficient. In the case of Zinc deficiency in women, Punjab has the largest share (24.1%), followed by Baluchistan (23.4%), and Sindh (21.4%), while Khyber Pakhtunkhwa has lowest prevalence (15.9%).

Nutrient deficiency estimates in Pakistan show multiple health related issues in men, women and children due to Zn deficiency and this Zn deficiency is further linked with other multiple consequences, including stunted growth on the different stages of children development. It results in increased susceptibility to infections, pregnancies and childbirth complications and sometimes, it results in the form of severe illness and deaths. This seemingly invisible deficiency, poses negative economic impact on the family, community and as well as on regional level (Ohly, 2018). According to Akhtar, (2013), Zn deficiency was about 54.2% of the children and 37.1% of Preschool children were also Zn deficient. Similarly other nutrient deficiencies like iron and vitamin A & D were also severely affecting the female population, especially to the women in their reproductive age (WRA) ranging between 15-49 years and result in the form of different health issues like anemia, low energy, low birth weight, impaired brain development, maternal mortality, visual impairment, diarrhoea, impaired immune system in urban and rural communities (GOP & UNICEF 2019). According to the World Bank, in Pakistan the essential minerals and vitamins deficiencies cost about US$ 3 billion in GDP losses annually. One quarter of the Pakistan’s population is living below the national poverty line and 39% is poor (FAO 2022) and 40% children under 5 year are stunted.

Government of Pakistan is committed to reduce stunting among children by developing and adopting several national level policies and strategies. Most prominent of which are Pakistan Infant and Young Child Feeding Strategy 2016-2020, Infant Young Child Feeding Communication Strategy (2016),Vitamin A supplementation guidelines, revised guidelines for community based management of acute malnutrition, 2015, IYCF in Emergencies, Pakistan Dietary Guidelines for better Nutrition (PDGN) 2019, Framework on action and guidelines on Adolescents Nutrition, Multisectoral National Nutrition Action Plan 2019 and national framework of Early Childhood & Development 2019, have been developed and distributed to provinces for planning and implementation.

In recent years Pakistan Multi-sectoral Nutrition Strategy has been developed to address malnutritional in all its forms and to meet international commitments of Pakistan towards Sustainable Development Goals (SDGs).

Similarly, Pakistan Vision seeks a healthy and hunger - free Pakistan. The emphasis has been on targeting the most food - insecure segments of the population. Innovative and cost-effective strategies will be implemented to achieve sustained development. These include: the Hunger Free Pakistan Program; Ready to use fortified feed for breast feeding mothers and pregnant women; Food for work schemes; Livelihood Initiatives for Improved access to food; Nutrition specific and sensitive interventions; Ready to use fortified food supplementation, fortification and bio-fortification; Feeding programs for infants and young children.

In Pakistan mainly wheat and rice are consumed in a larger quantity to fulfill the daily food requirement. The higher concentrations of Zn and other micronutrients are mainly present in germ and aleurone of wheat and constituents only ~ 20% of the total seed and these are usually removed during milling process leaving the starchy endosperm having low Zn concentration. Zn deficiency can be reduced through fortification, which is Zn enrichment of food products during processing or supplementation but these methods are expensive and not sustainable approaches. Genetic (conventional or molecular breeding and transgenic techniques) or agronomic approaches including suitable soil and plant fertilizer application are the main interventions for Zn biofortification of food crops (Cakmak and Kutman, 2018). In Pakistan, the agronomic biofortification approach has also been successful in improving the grain Zn concentration and crop productivity (Rehman *et al.,* 2018a, b, d; Ullah *et al.,* 2019, Ullah *et al.,* 2020 c, d, e).

Each year CIMMYT provides approximately 2,000 new wheat lines which also include high zinc wheat lines to strengthen national wheat breeding system of Pakistan through PARC, Ministry of Food Security & Research for the development of disease resistant, drought and heat tolerant, high yielding wheat varieties. From this material a significant number of high yielding, disease resistant and climate resilient wheat varieties have been developed for the different ecologies of the country. Until now 5 Zinc biofotified wheat varieties have been developed from these materials and approved for cultivation in different areas of the country. According to the report by the national survey, the deficiency of Zn was decreased to 22.1% and 18.6% in women and children, respectively (Ministry of National Health Services Nutrition Wing, 2018). This decrease in Zn malnourished population was outcome of several factors including public awareness through electronic and print media, for the Zn biofortified wheat varieties, farmers training and awareness.

CGIAR initiated the HarvestPlus challenge program on “Biofortified Crops for Improved Human Nutrition” with funding from Bill and Melinda Gates

Foundation, the World Bank, and USAID in 2004. The target of the program was to enhance the micronutrients (Zn, Fe, and vitamin A) level in staple food crops of the developing world. This program has seven target crops which are staple in developing countries. In Pakistan, this program was focused to develop nutrient dense wheat genotypes. Wheat is the staple crop of the country and is low in different micronutrients particularly Zn and Fe. The HarvestPlus target of wheat grain Zn concentration was 37 mg kg^{-1} (Bouisand Saltzman, 2017). Pakistan Agricultural Research Council (PARC) with the collaboration of HarvestPlus and CIMMYT developed the first Zn wheat cultivar Zincol-2016. This cultivar has Zn concentration of ~37 mg $kg^{-1}$and it has 30% more Zn than most of the cultivated wheat varieties in Pakistan (Hussain *et al.,* 2012b; Rehman *et al.,* 2018d). Research work is in progress for the development of biofortified varieties of other crops including rice and maize. Two biofortified varieties of rice (i.e. Vital Basmati and G.M Ali-5) have been developed and approved for cultivation in Pakistan.

1. Status of Biofortified varieties developed

1.1 Wheat

In 2004, with the support of CIMMYT, research work was initiated for the development of Biofortified varieties of wheat crop, at PARC- NARC Islamabad and as well as in the different wheat crop related research centres of the country. In 2010, first zinc enriched wheat line was introduced for its field testinng and as well as for it's early generation seed production. Research work is in progress also for the development and dissemination of biofortified varieties of wheat crop with the support of international centres like CIMMYT and HarvestPlus. As wheat is the staple crop of Pakistan, so a lot of work has been done for the development of biofortified varieties of wheat crop and these biofortified varieties of wheat crop are cultivated in large areas in the country.

First biofortified wheat variety i.e. Zincol-2016 was developed in 2015-16 by the Wheat program PARC–National Agricultural Research Centre Islamabad. The National Agricultural Research System (NARS) has developed four other biofortified varieties including Akbar-2019, Nawab-21, Tarnab Gandhum-1, and Tarnab Rehbar-23 and Zn content of these varieties ranges from 34 - 37 ppm (Table 1). These varieties are now being grown on over two million hectares and contributing to better nutrition for the people who cannot afford diverse diets. According to a study, eating zinc biofortified wheat flour for six weeks increased adolescent girls' intake of zinc by 21% but did not increase plasma zinc (Ohly, H. *et al.,* 2019). The impact assessment of scaling-up of zinc wheat and rice in Pakistan found that replacement of all wheat and rice varieties consumed in this country with zinc biofortified varieties by 2035 can result in a 12% reduction in inadequate zinc intake and 4.9% reduction in stunting (Zelar, LK 2015).

After Zincol-2016, other biofortified wheat varieties have been developed which include Akbar-19, Nawab-21, Tarnab-Gandhum-1 and Tarnab-Rehbar respectively. Akbar-19 has been developed by the Wheat Research Institute (WRI), Ayub Agricultural Research Institute (AARI) Faisalabad. Akbar-2019, is a high yielding mega wheat variety, having Zinc contents from 37~39 ppm with high grain yield potential of about 7.5 tons/ha. Nawab-21 has been developed by the Regional Agricultural Research Institute (RARI) Bahawalpur while biofortified wheat varieties Tarnab-Gandhum-1 and Tarnab-Rehbar have been developed by the Agricultural Research Institute (ARI) Peshawar during the years 2020-2023 respectively and all these biofortified wheat varieties are being cultivated in the country. Different stakeholders i.e. HarvestPlus, GAIN, World Vision and National Rural Support Program etc aided in public awareness and large-scale dissemination of the biofortified varieties of wheat crop among the farming community.

1.2 Rice

Two biofortified rice varieties have been developed which include rice variety G.M Ali-5 and Vital Basmati (Table 1). Rice variety G.M Ali-5, has been developed by the National Institute for Genomics and Advanced Biotechnology (NIGAB), Vital Basmati rice variety has been developed by the Rice Research Institute (RRI), Kala Shah Kaku Punjab province Pakistan. Rice variety GMAli-5, has Fe 11.5 ppm and Zn 16.5 ppm contents on its grains respectively. Both these rice varieties (i.e. G.M Ali-5 and Vital Basmati) are being scaled- up for their cultivation at large scale in the country.

Figure: Rice variety GMAli-5 developed by National Institute for Genetics and Advanced Biotechnology (NIGAB), PARC- NARC Islamabad Pakistan.

1.3 Maize

The Agriculture Innovation Program (AIP) which was implemented by the CIMMYT, has contributed to the development of biofortified varieties of maize crop and these varieties contain high levels of pro vitamin A (PVA) and kernel Zn. During 2014-2016, with the assistance of CIMMYT, maize crop Biofortified germplasm was introduced and tested on large scale which included Open Pollinated Varieties (OPVs) and as well as hybrids having high level of Provitamins A (PVA) and kernel Zn. These varieties were recommended for registration for their commercial release, and for their further seed scale-up and delivery in the target ecologies. Additionally, several governmental and private partners have shown their interests in the commercialization of PVA, especially for their products made from PVA maize which contain higher level of zinc (Table 1).

Table 1: Biofortified varieties of different crops developed in Pakistan.

No.	Bio fortified Crops	Commodity	Element	Institute	Year of Release
1.	Zincol-2016	Wheat	Zinc	PARC/NARC	2016
2.	Akhbar-2019	Wheat	Zinc	AARI Faisalabad	2020
3.	Nawab-21	Wheat	Zinc	RARI Bahawalpur	2021
4.	Tarnab-Gandhum-1	Wheat	Zinc	ARI Tarnab Peshawar	2023
5.	Tarnab-Rehbar	Wheat	Zinc	ARI Tarnab Peshawar	2023
6.	Vital Basmati	Rice	Zinc	KSK, RRI	2023
7.	G.M Ali-5	Rice	Zinc	NIGAB, PARC	2023
8.	19 (HP1100-21)	Hybrid Maize	Pro Vitamin A	CIMMYT, PARC	2016
9.	2 (HP1097-2)	Hybrid Maize	Pro Vitamin A	CIMMYT, PARC	2016
10.	(HP1097-10)	Hybrid Maize	Pro Vitamin A	CIMMYT, PARC	2016
11.	16 (HP1100-6)	Hybrid Maize	Pro Vitamin A	CIMMYT, PARC	2016
12.	1 (HP1097-1)	Hybrid Maize	Pro Vitamin A	CIMMYT, PARC	2016
13..	6 (HP1097-6)	Hybrid Maize	Pro Vitamin A	CIMMYT, PARC	2016
14	4 (HP1097-4)	Hybrid Maize	Pro Vitamin A	CIMMYT, PARC	2016

2. On-going value addition activities of Biofortified crops products

Pakistan Agricultural Research Council (PARC) is working and supporting National Agricultural Research System (NARS) for the development of high yielding, disease resistant and climate resilient varieties of all crops. Already developed biofortified varieties of different crops are currently being used in breeding programs for further development of new, high yielding, disease resistant, biofortified varieties by the scientists of NARS. Pre-basic seed of developed biofortified varieties of different crops are being produced by their concerned institutes for regular supply to the farming community, to different seed corporations and seed companies, with the aim to overcoming the nutritional deficiencies of the dietary minerals and vitamins in the country.

PARC, different research centres, Agriculture Extension Departments, Private seed companies, different international organizations like HarvestPlus are also working for the promotion of biofortified varieties of different crops by providing seed to the farmers, establishing demonstration plots and by organizing farmers field days.

3. Constraints

Lack of sensitization and motivational activities on economic and nutritional advantages of Biofortified crops to farmers, processors and consumers. Farmer' access to the Biofortified seed of different crops during planting seasons is limiting their extension, Seed distribution, branding, marketing and multiplication program are necessary. Insufficient segregation of Biofortified grains in the supply chain, especially for those with invisible characteristics (such as zinc in wheat, rice and maize grains etc), as well as difficulties in creating and promoting traceability and segregation mechanisms within supply chains. Inadequate regional and national level consideration for the promotion and exchange of seeds of Biofortified varieties of different crops.

4. Way forward

Large scale seed and production program are essential to promote biofortified crop varieties to create impact. Research and Development activities need to be strengthened. Production program needs to be linked with food business market. Through food product R&D, expedite the development of grain and food collaborations. Make use of technology for all value chain participants, including farmer platforms, digital aggregation networks, complete supply chain traceability, food product certification, and e-commerce. Mainstreaming biofortification activities which entails inclusion of nutrition into all plant breeding and agronomic initiatives. High-throughput micronutrient phenotyping, genomic selection, and speed breeding are expected to propel the mainstreaming of Biofortification features that will accelerate genetic advances.

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Chapter 7

Development and Dissemination of Biofortified varieties of different Crops in Sri Lanka

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1. Introduction:

i. General introduction of agriculture:

Sri Lanka, a tropical island, boasts a rich agricultural heritage. Blessed with fertile soils, abundant rainfall, and diverse climatic zones, the country supports a vibrant agricultural sector that plays a crucial role in its economy and culture. The earlier predominantly export-oriented agricultural economy has been transformed into a free market economy. It recorded an average annual growth rate of around 6.4% during the period 2003-2012, but this had slowed down to 3.1% in 2017 (Rajapaksa *et al.*, 2021). In Sri Lanka, the COVID-19 pandemic, poverty, government policy changes, and climate change pushing food insecurity and increasing the risk of undernutrition. The agriculture sector of Sri Lanka has immense potential but faces several challenges. Major challenges are abiotic stresses due to changing weather patterns, including unpredictable rainfall and rising temperatures, moisture stress, and salinity. The farming population of the country is aging, leading to a decline in agricultural labour. Soil degradation and occurrence of pests & diseases are common problem in agriculture. Sri Lanka has the opportunity to modernize the agricultural sector and boost productivity by utilizing modern agricultural technology including digital farming, precision agriculture, and nutrient-enriched food crops and value addition agricultural produce. This innovative agricultural technique offers a sustainable and cost-effective solution to address micronutrient deficiencies, a widespread health issue in Sri Lanka. With its rich farming heritage and diverse agroecological zones, Sri Lanka offers a promising landscape for creating and disseminating biofortified crops. Biofortification, a strategic approach to enhancing the nutritional content of staple crops, presents a viable solution to address widespread micronutrient deficiencies in the country. Many Sri Lankans, especially those in rural areas, suffer from "hidden hunger", where individuals may consume sufficient calories but lack essential micronutrients. Biofortified crops can enhance the nutritional value of staple foods, promoting dietary diversity and improving overall health. This environmentally friendly approach does not require significant changes in farming practices, making it easily adaptable by farmers. The dissemination of biofortified varieties in Sri Lanka involves several key steps. Agricultural scientists and researchers work to develop new crop varieties that are rich in specific micronutrients. Once new varieties are developed, they are multiplied to produce sufficient seed for distribution to farmers. Farmers are educated about the benefits of biofortified crops and trained on cultivation practices. Then, seeds are distributed to farmers through various channels, including government programs, NGOs, and private seed companies. Efforts are made to promote the consumption of biofortified foods through awareness campaigns and market linkages. There are potential benefits of Biofortification in Sri Lanka to a healthier and more sustainable future.

ii. Staple crop

Rice is the staple food for the majority of Sri Lankans. The country has two main rice cultivation seasons *Maha* (main) and *Yala* (minor). A diverse range of rice varieties, both traditional and newly improved varieties, are cultivated. Rice cultivation provides livelihoods for many farmers and contributes significantly to the country's food security. While Sri Lanka has made significant strides in rice production, challenges like climate change, water scarcity, and rising input costs continue to impact the sector. While rice dominates Sri Lankan agriculture, a variety of other field crops are also cultivated. These are maize, sorghum, finger millets, pulses like green gram, black gram, and cowpea, oilseeds like groundnut, sesame, chilli, onion, ginger, and turmeric. Root and tuber crops like potato a popular vegetable, especially in the hilly areas; sweet potato a nutritious root crop, often consumed as a staple food and cassava a versatile root crop used for food and industrial purposes. These crops are playing a vital role in food security, nutrition, and rural livelihoods.

iii. Main health-related issues

According to the World Health Organization, malnutrition means imbalances of vital nutrients, deficits or excesses in nutritional intake, or impaired nutrient utilization (www.who.int.2020).The Government of Sri Lanka has acknowledged the need to address malnutrition. At the central level, a Food and Nutrition Policy Planning Division and a Nutrition Coordination Unit were created in 1978. Nutrition policy 2004-2010 focused on integrating nutrition with other sectoral activities, such as health, agriculture, education, economic reform, and rural development (Meera *et al.*, 2007).

The country had achieved upper-middle-income status although it was down graded to lower-middle-income in July 2020 due to economic recession (Rajapaksa *et al.,* 2021). Malnutrition rates in Sri Lanka ranges from 24% to 74%, (Jayatissa *et al.,* 2017). More than 33 percent children in Sri Lanka are iron-deficient. The country's malnutrition rate increased quickly due to the current food and economic crises. Micronutrients, especially, iron, zinc, vitamin

A, and iodine are essential for appropriate human growth, development, and physiological functioning (Damayanthi *et al.,* 2018). Health problems caused by under nutrition are stunted growth, weak immune system, anemia, osteoporosis, muscle wasting, increased mortality, and delayed wound healing (Meera *et al.,* 2007). Health problems caused by over nutrition are obesity, type 2 diabetes, cardiovascular diseases, liver diseases, stroke, and certain cancers. Women and children are particularly vulnerable to malnutrition. Pregnant women who are malnourished are more likely to have low birth weight babies. Elderly populations are also at higher risk, as nutrient absorption declines with age, leading to issues such as muscle loss and weakened immune function (Abeywickrama *et al.,* 2018).

In Sri Lanka, deficiencies in iron, zinc, calcium, folate, and vitamin A are more prevalent. Iron deficiency anemia among children and women of reproductive age continues to be a significant public health problem, although prevalence rates have declined in recent years. Anemia rates in women and children are generally lower than elsewhere in South Asia (Meera *et al.,* 2007). Zinc deficiency results in impaired growth, cognitive development, and immune function. It can also lead to delayed wound healing and increased susceptibility to infections. Vitamin A deficiency can cause night blindness, impaired immune function, and increased risk of infections. In severe cases, it can lead to irreversible blindness. Children, adolescents, and pregnant women are at higher risk of these deficiencies. The Sri Lankan government has implemented various strategies to combat these micronutrient deficiencies including food fortification such as adding micronutrients to staple foods like rice, flour, and salt. It is implementing dietary diversification by introducing a variety of nutrient-rich foods providing targeted supplementation with iron, folic acid, and vitamin A to vulnerable groups, and launching health education and awareness campaigns that highlight the risk of micronutrient deficiencies and the significance of a balanced diet. While significant progress has been made, addressing micronutrient deficiencies remains a complex challenge. Continued efforts are needed to monitor the nutritional status of the population, strengthen food fortification programs, and promote healthy dietary practices.

iv. Awareness building among the common people related to the lower intake of zinc, iron and vitamin A

The government and health organizations have implemented various awareness campaigns to promote healthy diets and the importance of micronutrients (Damayanthi *et al.,* 2018).The Sri Lankan government's health and nutrition programs include public awareness campaigns about the importance of a balanced diet and the risks of micronutrient deficiencies. However, the effectiveness of these campaigns in reaching the general population and improving awareness remains to be fully assessed. There are dietary diversity promotion programs to encourage the consumption of a variety of nutrient-rich foods, including fruits, vegetables, legumes, and animal-source foods. Biofortification is the process of creating micronutrient-dense staple crops using conventional breeding techniques or biotechnology (Nalubola, 2005). Food fortification programs for support to increase the micronutrient content of staple foods. Moreover, there is access to healthcare facilities to ensure that healthcare services, including nutrition, counselling, and supplementation programs targeted to vulnerable populations. These programs are helping reducing the burden of micronutrient-related diseases in the country.

v. Awareness among the farming communities on biofortified crop varieties

Department of Agriculture plays a crucial role in promoting improved management and crop varieties technologies by conducting field demonstration and organizing field days, seminar, workshop to motivate and educate farmers about the benefits of biofortified varieties. Non-Governmental International Organizations local NGOs working in the agriculture and nutrition sectors could be involved in promoting these varieties, particularly in rural areas.

2. Status of biofortified varieties developed:

i. Main research and development work already done for the development of biofortified varieties of different crops

Sri Lanka has been involved in research and development efforts to develop biofortified crop varieties. The goal of biofortification is to contribute to reducing the high prevalence of specific nutritional deficiencies, which commonly occur in low-income populations. Biofortification is intended to contribute to the prevention of micronutrient deficiencies by revealing all household members. Fortification is the addition of key vitamins and minerals such as iron, iodine, zinc, and vitamins A & D to staple foods to improve their nutritional content. The biofortified rice generally contains Iron and Zinc. Rice fortification has great potential to reduce the prevalence of iron deficiency and other micronutrient deficiencies. Rice milling removes 70-90% micronutrients. In Sri Lanka, very little research and development has been done on iron, vitamin B, zinc, and bioactive fortification of rice kernels or flour using methods such as mixing, soaking, parboiling, and extrusion. Recently, the government has launched a rice fortification program to address the malnutrition of school children. This collaborative effort involves the Ministry of Agriculture and Plantation Industries, the Ministry of Education, the World Food Program, and the National Food Promotion Board. Though rice is a preferred cost-effective appropriate carrier for micronutrient fortification, one of the major limiting factors in rice fortification is the lack of simple and affordable technology in Sri Lanka. There are various fortification techniques; using a mixture of vitamins and minerals, micronutrient powder is applied to rice that sticks to the grains or the surface of regular rice grains in multiple layers to create a protective layer. Dusting is an additional technique, and an extruder machine can be used to fortify rice kernels with micronutrients.

Plant breeding initiatives, aim to improve the yield, nutritional value, and resilience of crops to combat malnutrition. Biofortification is the process of developing crops that are rich in essential vitamins and minerals. Efforts are underway to develop rice varieties with increased iron and zinc content. The physical, physicochemical, nutritional, and nutraceutical traits of popular traditional rice cultivars, improved varieties, and breeding lines are evaluated to ascertain the quality attributes, nutrition composition, nutraceutical, and functional properties that are currently available in Sri Lanka. It will help to identify varieties and breeding lines for future breeding programs based on quality characteristics. Another method of a nutritious healthy diet is the formulation of nutritionally rich rice blends. Developing value-added food products by blending rice varieties to cater to the need of population at risk. Red and white rice varieties were selected considering the properties with higher iron and zinc content, similar gelatinization temperature values, red rice with high health properties (low glycaemic index, high antioxidant properties), and white rice with high sensory qualities (aroma, tenderness, taste).

ii. Biofortified varieties of various crops, and their main characteristics i.e. yield potentials, quality parameters and resistance against diseases

There is potential to biofortify other crops like legumes, vegetables, and fruits to improve their nutritional value. Maize (*Zea mays* L.) occupies the second largest extent of the total cultivated extent of cereals in Sri Lanka (Kumari *et al.*, 2013). The production of maize in the country must be increased. It is used as human food, animal feed and as an extra source of nutrition for nursing mothers and babies. The maize occupies second largest crop area in the country. The maize hybrid development program in Sri Lanka was initiated in 2000 at the Field Crops Research & Development Institute, Mahailuppallama (anonymous 2000).The first local maize hybrid 'Sampath' was released in 2004 (VRC,2004). Hybridization allows scientists to enhance the nutritional profiles of crops by increasing their protein content and essential amino acids. As an example, Quality Protein Maize has been bred to provide better quality protein than traditional maize, making it a vital food source in regions having protein deficiencies. The quality protein maize (QPM) hybrid MI Maize hybrid Hy 01 was released in 2013 by using QPM inbred lines developed by CIMMYT (Kumari *et al.*, 2013). The MI Maize hybrid Hy 02 with an average yield of 5.5t $^{ha-1}$ was released in year 2016. Breeding maize with improved protein quality was started in the mid-1960s with the discovery of mutants, such as Opaque-2 that produce enhanced levels of lysine and tryptophan, the two amino acids deficient in the maize endosperm. Five promising QPM hybrids, namely, KH74, KH76, KH156, KH157, and KH38 were evaluated along with the local variety Sampath, and Pacific 984 under National Coordinated Varietal Test (NCVT) at research stations. Three QPM hybrids, KH74, KH156, and KH157 showed comparable adaptability with check hybrids. QPM hybrids KH74, KH76, and KH157 have better adaptability comparable to commercial check hybrid Pacific984. These hybrids also had higher tryptophan contents compared to check hybrids. The lines, namely, KH74, KH76, and KH157 were selected as candidate QPM hybrid for release.

Marker-assisted introgression of opaque 2 alleles used for the development of quality protein maize inbred lines in Sri Lanka. Molecular markers are used for enhancing selection efficiency and expediting the process of development of new lines and varieties. The objective is to screen the *opaque-2* gene in QPM and incorporate maize lines for the development of QPM-incorporated maize lines or variety.

Challenges for future research are limited resources especially adequate funding and essential for sustained research and development efforts. Further public awareness and acceptance of biofortified varieties are crucial for their successful adoption and consumer acceptance. Well-performing biofortified varieties in local agricultural conditions are important. Future research is essential to develop new biofortified varieties and optimize their production and utilization. Collaborative research with IRRI, IFRI and ICRISAT is important for capacity building and for accessing advanced breeding techniques and expertise.

iii. Seed availability of biofortified varieties of different crops

The Department of Agriculture and other relevant institutes are working on seed multiplication of different varieties and distribution of quality seeds to farmers.

3. On going value addition activities of biofortified crops products:

i. Present and future strategies of the government for the promotion of the use of products of biofortified varieties among the people

The government should strengthen research by investing in cutting-edge research for developing biofortified varieties with higher nutrient content and improved agronomic traits. Program need to be developed to encourage farmers to cultivate biofortified crops on a larger scale through various incentives and support programs. A market should be established for the promotion of value-added goods derived from biofortified crops to increase their market value. The consumer should be educated about the nutritional benefits of biofortified foods and their role in improving public health. A regulatory framework should be developed to guarantee the safety and quality of products that have been biofortified. International collaboration needs to be strengthen to exchange biofortification-related information and technologies.

ii. Future role of different departments and organizations in the promotion of biofortified varieties of different crops

Several departments and organizations in Sri Lanka can play crucial roles in the promotion of biofortified varieties. The Department of Agriculture will implement seed multiplication and distribution programs of high-quality seeds of biofortified varieties and supply them to farmers. Furthermore, the extension services of the Department of Agriculture will provide technological advice to the farmers and inform them about the benefits of biofortified cultivars. Further, research and development programs are needed to develop new biofortified varieties with improved nutritional content and agronomic traits. Emphasis should be given to disseminate the new technology. Research institutes and universities will have collaboration with international research institutions to access advanced technologies and expertise. A partnership with the Ministry of Trade would be required to encourage the sale of biofortified products. The Ministry of Health will conduct public awareness efforts to educate people about the nutritional benefits of biofortified foods and their role in preventing malnutrition. High-quality seeds of biofortified types should also be developed and marketed by private seed companies. Food Processing Industries should be linked with biofortified food products to meet consumer demand.

iii. Collate information and analyse available data to assess how biofortification of different crops have contributed to the improvement of the health of the people:

Biofortification will be a potential way to improve the health of the nation. Biofortification, a process of breeding crops to increase their nutritional value, holds promise for addressing micronutrient deficiencies in Sri Lanka. While specific data on the direct impact of biofortified crops on public health are limited, there is growing evidence to suggest its potential benefits. Biofortified crops can offer a sustainable and cost-effective solution to increase the nutrient content of staple foods. Biofortification can enhance food security and reduce the need for additional supplements.

iv. Role of public-private partnership

Biofortified crop varieties can be developed through shared finance by public-private partnerships (PPPs). Public research institutions can collaborate with private seed companies to share their expertise and accelerate the breeding process. Private seed companies can scale up the production of biofortified quality seeds for ensuring sufficient seed supply to farmers. It can effectively reach farmers particularly in remote areas, and build stronger distribution networks. Public institutions can set quality standards and conduct regular inspections to ensure the purity and genetic integrity of biofortified seeds. PPPs can establish demonstration plots to showcase the performance of biofortified varieties and their impact on crop yields and nutritional value. Government can support farmers to adopt biofortified varieties. Private companies can create market linkages connecting farmers with processors, exporters, and retailers. Joint marketing campaigns can promote the nutritional benefits of biofortified foods and create consumer demand through branding and marketing. Private sector involvement can lead to developing value-added products from biofortified crops, such as fortified flours and cereals. Public institutes can ensure adherence to safety and quality standards for biofortified foods Public health campaigns can make consumers aware of the importance of micronutrient-rich diets and the role of biofortified foods. By leveraging the strengths of both public and private sectors, PPPs can accelerate the adoption of biofortified crops, improve food security, and contribute to the overall health and well-being of the Sri Lankan population.

v. Challenges in the adoption of biofortified crops

There is growing interest in biofortification in Sri Lanka, more research is needed to assess its impact on public health outcomes. Public awareness and acceptance of biofortified crops are essential for the widespread adoption of these varieties. Furthermore, a supportive regulatory framework is crucial to facilitate the development and commercialization of biofortified crops. Collaborative work is essential for strengthening partnerships with government agencies, NGOs, and the private sector to promote the adoption of biofortification technologies. Supportive Policies should be adopted to create a conducive policy environment that encourages the development and commercialization of biofortified crops. Biofortification has the potential to significantly improve the nutritional status of the Sri Lankan population. By addressing micronutrient deficiencies and promoting healthier diets, biofortified crops can contribute to a healthier and more prosperous future for the country. However, sustained efforts are needed to overcome these challenges and realize the full potential of this innovative approach.

4. Marketing issue:

i. Marketing seeds of biofortified varieties of different crops

Widespread adoption of Biofortification and consumer acceptance face several marketing challenges. Seeds of biofortified varieties are not readily available to farmers, especially in rural areas. Lack of awareness among farmers about the benefits of biofortified crops and the availability of improved seeds. Furthermore, seeds of biofortified varieties are somewhat more expensive than other varieties.

ii. Branding and certification of biofortified crop products

A lack of strong branding and labelling for biofortified products can hinder consumer recognition and trust. Establishing reliable and affordable certification processes for biofortified products is complex.

iii. Promotion of biofortified crops on a large scale:

The Sri Lankan government and various organizations are actively promoting biofortified crop cultivation. National Nutrition Policy 2021-2030 prioritizes biofortification as a strategy to improve the nutritional value of staple foods. Ministry of Agriculture supports research and development of biofortified crop varieties. It also provides extension services to educate farmers. Ministry of Health promotes public awareness campaigns about the nutritional benefits of biofortified foods. International Organizations such as the World Bank support initiatives like improving nutrition through the Modernizing Agriculture in Sri Lanka project, which aims to improve the nutritional quality of crops.

iv. Promoting the use of products of biofortified varieties among the people

Campaigns for consumer education and awareness that highlight the nutritional benefits of biofortified crops should be developed through mass media, social media, and community outreach programs. It must promote the sale of value-added products made from biofortified crops, such as fortified cereals, snacks, and flours. Strong public-private partnerships that fortify relationships between the public and private sectors and non-governmental organizations enable the cultivation, processing, and marketing of biofortified crops providing farmers with incentives, technical assistance, and financial support to encourage them to grow biofortified crops. Strengthening Research and Development helps to continue research to develop new biofortified crop varieties that are adapted to local conditions and consumer preferences. Expanding Extension Services will enhance extension services to reach more farmers, especially smallholders, and provide them with the necessary knowledge and skills to cultivate biofortified crops.

v. Barriers/Issues/Challenges in the Promotion of Marketing of Biofortified Crops on a Large Scale

Consumers may be hesitant to accept new food products, particularly if they perceive them as different or less desirable. Lack of consumer trust in the quality and safety of biofortified products can be challenging, especially in the absence of strong regulatory frameworks and certification systems. Weak market infrastructure, including storage, transportation, and distribution facilities, can hinder the efficient marketing of biofortified crops. The production costs of biofortified crops may be higher than other varieties, impacting their competitiveness in the market. Policy and regulatory barriers and restrictive policies and regulations can create obstacles to the commercialization of biofortified crops.

5. Constraints:

i. Problems faced by the farmers in r adopting biofortified varieties:

Many farmers are not aware of the benefits of biofortified crops or how they can improve the nutritional value and economic benefits of their harvests. There is limited access to quality seeds of biofortified varieties especially in rural areas. Farmers require additional training and technical support to cultivate biofortified crops effectively, as they may have different agronomic requirements compared to other varieties. The initial cost of fortified seeds is more expensive than other seeds, which can be a barrier for small-scale farmers. There is limited market demand for biofortified crops, especially if consumers are not aware of their benefits or if there is a lack of infrastructure to support their distribution. A multifaceted approach including government agencies, educational institutions, non-governmental organizations, and the private sector is required to address these challenges by increasing awareness, providing technical support, facilitating the availability of high-quality seeds, and highlighting the benefits of biofortified crops to both farmers and consumers.

ii. Seed availability / purity of biofortified varieties in the market

Seeds are not available in the market easily. Government can take special program for seed production and their distribution to farmers with affordable price.

Way forward:

Effective enhancement and scaling up of biofortified crops require a multipronged strategy that combines research, policy, value chain management and stakeholders' involvement. It should establish clear and efficient regulatory frameworks for the development and release of biofortified crops, including biosafety regulations.

Targeted research should be planned to identify and develop biofortified varieties of key staple crops, such as rice, maize, and legumes, that are adapted to local agroecological conditions and consumer preferences. Research for agronomic practices, post-harvest technologies, and consumer acceptability should be optimized.

Enforce stringent food safety and quality requirements to ensure the safety and nutritional value of biofortified foods.

It should encourage multi-stakeholder partnerships, knowledge-sharing platforms, capacity building, and public-private partnerships to accelerate the development, commercialization, and dissemination of biofortified crop varieties.

There should be adequate financial, extension, and capacity-building support from the government to encourage the use of biofortified agricultural varieties. Proper policies and regulatory support from decision-makers are required. Sri Lanka can effectively scale up biofortification programs and improve the nutritional status of their populations by addressing these key areas.

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Chapter 8

Importance of Proper Nutrition in Human Health

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Importance of Proper Nutrition in Human Health

Nutrition is essential for a healthy life. It provides our bodies with the energy and nutrients they need to function properly. A well-balanced diet plays a critical role in preventing chronic diseases and promoting overall well-being. Proper nutrition plays a crucial role in maintaining optimal health throughout the lifespan. Adequate dietary intake provides essential nutrients required for growth, development, and overall well-being. Micronutrient malnutrition is an eminent problem globally. Insufficient dietary intake of micronutrients and limited dietary diversity are thought to be responsible for human micronutrient deficiencies. These factors are especially important in developing countries, where high proportions of cereal grains with inherently low concentrations of Zn, Fe and Se, such as wheat, rice and maize are consumed as staple foods (Wang *et al.*, 2013; Beal *et al.,* 2017; Cakmak and Kutman, 2018).

Many people do not have access to "healthy and nutritious food" to carry out a healthy lifestyle. Malnutrition is a global issue as nearly 1/4th of world population is suffering from one or more micronutrient malnutrition disorders (Kumssa *et al.,* 2015). Malnutrition issue is high in the world and progress made to overcome this problem is still at a low pace. Around the world, 149 M (21.9%) children are stunted, 49.5 M (7.3%) are wasted, and 40.1 M (5.9%) are overweight due to multifaceted malnutrition (UNICEF, 2020). In South Asia, 60-70% of people are Zn deficient (Gibson, 2006).

Definition of Nutrition and Health

Nutrition refers to the process of consuming and utilizing food for growth, maintenance, and repair of our bodies. Health encompasses physical, mental, and social well-being, and proper nutrition plays a pivotal role in in maintaining all aspects of health.

Physical Well-being	Mental Well-being	Social Well-being
A balanced diet fuels our bodies, strengthens our immune system, and helps prevent diseases.	Nutrition impacts brain function and mood. Deficiencies can lead to fatigue, depression, and cognitive decline.	Sharing meals fosters social connections and contributes to a sense of community.

Classification of Nutrients

Nutrients are classified into six main categories based on their function and chemical structure. These categories include carbohydrates, proteins, fats, vitamins, minerals, and water.

Macronutrients

1. Carbohydrates
2. Proteins
3. Fats

These provide energy and building blocks for our bodies.

Micronutrients

1. Vitamins
2. Minerals

These are required in smaller amounts but are essential for various bodily processes.

Water

Water is crucial for hydration, regulating body temperature, and transporting nutrients.

Importance of Protein in Health

Protein is a fundamental nutrient for overall health, playing a crucial role in various bodily functions. It serves as the building block for tissues and is essential for repairing damaged cells. Additionally, protein is involved in the production of enzymes and hormones, which regulate vital processes like growth, metabolism, and immune response. Adequate protein intake is particularly important for athletes and growing children, as it supports muscle growth and repair. Moreover, protein aids in the production of antibodies, strengthening the immune system's ability to combat infections. By promoting feelings of fullness, protein can contribute to weight management and reduce cravings, making it a valuable component of a balanced diet.

Importance of Essential Fatty Acids in Health

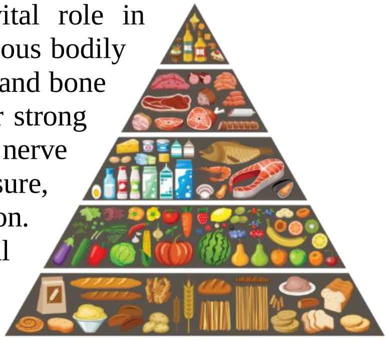
Essential fatty acids, such as omega-3 and omega-6, are vital nutrients that our bodies cannot produce on their own. These fatty acids are crucial for various bodily functions, including brain health, heart health, and inflammation reduction. Omega-3 fatty acids, in particular, are essential for brain development, cognitive function, and mood regulation. They also play a significant role in heart health by lowering blood pressure and improving blood vessel function, thus reducing the risk of heart disease. Both omega-3 and omega-6 fatty acids are involved in regulating inflammation, a natural response to injury or infection. Additionally, essential fatty acids contribute to maintaining a healthy skin barrier, reducing dryness and inflammation.

Importance of Vitamins in Health

Vitamins are organic compounds that are essential for various metabolic processes, supporting immune function, and promoting overall health. They play vital roles in energy production, cell growth and repair, and maintaining healthy vision, skin, and bones.

Vitamin	Function	Deficiency Symptoms
Vitamin A	Vision, immune function, cell growth	Night blindness, dry skin, impaired immune function
Vitamin C	Collagen synthesis, antioxidant, immune function	Scurvy, fatigue, slow wound healing
Vitamin D	Calcium absorption, bone health, immune function	Rickets, osteoporosis, muscle weakness

Importance of Minerals in Health



Minerals are inorganic elements that play a vital role in maintaining overall health. They contribute to various bodily functions, including fluid balance, nerve function, and bone health. Key minerals like calcium are essential for strong bones and teeth, muscle function, and nerve transmission. Potassium helps regulate blood pressure, maintain fluid balance, and supports muscle function. Iron, a crucial component of haemoglobin, is vital for oxygen transport and energy production. Magnesium, involved in over 300 biochemical reactions, is essential for muscle and nerve function, and energy production. By incorporating a balanced diet rich in these minerals, individuals can support a healthy heart, strong bones, and a balanced metabolism.

Importance of Nutrition during Different Life Stages

Nutrition plays a pivotal role in every stage of life, with specific dietary needs varying across different age groups. From infancy to old age, a well-balanced diet is essential for optimal growth, development, and overall health. In infancy, breast milk or formula provides the necessary nutrients for rapid growth. As children grow, a balanced diet rich in proteins, vitamins, and minerals becomes crucial for cognitive development and energy levels. Adolescence, a period of rapid growth and hormonal changes, demands increased nutrient intake to support puberty and bone development. In adulthood, maintaining a healthy weight and preventing chronic diseases becomes a priority, requiring a balanced diet and regular exercise. As individuals age, adjusting dietary intake to meet age-related changes in metabolism and nutrient needs becomes essential to focus on bone health and prevent malnutrition.

Importance of Nutrition for Infants and School-going children

Nutrition is pivotal for infants and school-going children. During infancy, rapid growth necessitates a nutrient-rich diet to support brain development, bone health, and immune function. Adequate nutrition ensures healthy physical development, including appropriate weight and height, and lays the foundation for future growth. It also plays a crucial role in cognitive development, impacting language skills, memory, and overall brain function. Additionally, a well-nourished infant is better equipped to fight off infections and diseases due to a strengthened immune system.

For school-going children, nutrition remains equally important. A balanced diet fuels their growth and development, enabling them to achieve healthy weight and height, build strong bones, and develop healthy muscles. It provides the necessary energy for physical activities, promoting overall health. Furthermore, proper nutrition is essential for cognitive function, supporting concentration, learning, and memory. It contributes significantly to overall brain development, ensuring children are well-prepared for academic success.

Importance of Nutrition for School Going Children

Nutrition plays a pivotal role in the overall well-being of school-going children. Adequate nutrition fuels their growth and development, enabling them to achieve healthy weight and height, build strong bones, and develop robust muscles. A balanced diet provides the essential energy and nutrients required for active lifestyles, promoting healthy growth and development. Moreover, proper nutrition is crucial for cognitive function, supporting concentration, learning, and memory. It also plays a vital role in overall brain development, ensuring children are well-equipped to excel academically and socially.

Importance of Nutrition for Adolescents

Adolescence, a period of rapid growth and hormonal changes, necessitates proper nutrition to support this growth spurt. Essential nutrients like calcium, iron, and protein are crucial for healthy development. Adequate calcium and vitamin D intake are particularly important for strong bones and preventing future osteoporosis. Additionally, proper nutrition plays a significant role in mental health by providing essential nutrients for brain function and emotional well-being, contributing to reduced stress and a positive mood.

Importance of Nutrition during Pregnancy and Lactation

Nutrient	Benefits
Folic Acid	Prevents neural tube defects in the baby
Iron	Supports blood production for both mother and baby
Calcium	Builds strong bones and teeth for both mother and baby
Vitamin D	Supports calcium absorption and bone health
Protein	Supports baby's growth and development

Importance of Nutrition for the Elderly People

Nutrition plays a vital role in maintaining the health and well-being of older adults. A well-balanced diet provides the necessary energy and nutrients to support independence and activity levels. Proper nutrition can also help prevent chronic diseases like heart disease, stroke, diabetes, and certain cancers, which become more prevalent with age. Additionally, certain nutrients are crucial for cognitive function and memory, helping seniors maintain mental sharpness and reduce the risk of cognitive decline.

Importance of Nutrition for Preventing Non-Communicable Diseases

Nutrition plays a crucial role in preventing non-communicable diseases. A heart-healthy diet low in saturated and trans fats, cholesterol, and sodium can help lower blood pressure and cholesterol levels, reducing the risk of heart disease. Similarly, a diet rich in fruits, vegetables, and whole grains, while low in processed foods and red meat, can help lower the risk of certain cancers. Maintaining a healthy weight and consuming a balanced diet rich in fibre, whole grains, fruits, and vegetables can help manage blood sugar levels and prevent type 2 diabetes. Lastly, a diet rich in antioxidants, omega-3 fatty acids, and B vitamins can help protect brain health and reduce the risk of cognitive decline.

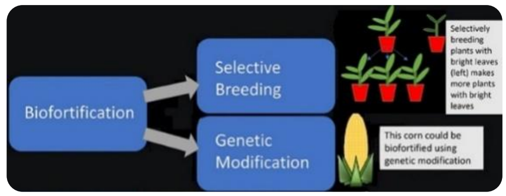
Key Takeaways

Proper nutrition is crucial for growth, development, and overall health at all stages of life. A balanced diet can help prevent chronic diseases and promote long-term well-being. It's recommended to consult with a healthcare professional or registered dietitian to create a personalized nutrition plan that meets individual needs.

Positive Impact

By prioritizing proper nutrition, individuals can enhance their quality of life, reduce the risk of health problems, and live longer, healthier lives.

Biofortification in Enhancing Nutrition for All



Biofortification, a sustainable approach to improving nutrition, holds immense promise for the people and especially by enhancing the nutrient content of staple crops, bio-fortification empowers individuals to access essential nutrients through their regular diet.

Biofortification is a viable and economical method to reduce the Zn nutritional disorder and to improve the bioavailable Zn in edible plant parts (Farooq *et al.*, 2018; Ullah *et al.*, 2020a). Genetc (conventional or molecular breeding and transgenic techniques) or agronomic approaches including suitable soil and plant fertilizer application are the major interventions for Zn biofortification of food crops (Cakmak and Kutman, 2018). According to Bouis and Saltzman (2017), biofortified crops are produced and consumed by over 20 M people globally.

Importance of Nutrient-Rich Foods for Health

Nutrient-rich foods are the building blocks of a healthy life. They provide our bodies with the essential vitamins, minerals, and other nutrients needed to thrive. From boosting our immune systems to sharpening our minds, the benefits of a nutrient-rich diet are far-reaching.

Improved Growth and Development

Nutrient-rich foods are vital for optimal growth and development, especially in children and pregnant women.

Enhanced Immunity

Essential nutrients like vitamins and minerals bolster the immune system, making individuals less susceptible to infections.

Reduced Risk of Chronic Diseases

Consuming a balanced diet with adequate nutrients can lower the risk of developing chronic diseases, such as heart disease and diabetes.

Increased Productivity and Cognitive Function

Adequate nutrition is crucial for optimal cognitive function, learning and overall productivity.

Addressing Malnutrition through Bio-fortification

Biofortification offers a sustainable and cost-effective solution to combat malnutrition by increasing the nutritional content of staple crops. This approach makes nutritious food accessible to a wider population, particularly those living in poverty. By enhancing the nutritional value of crops, biofortification leads to improved health outcomes, reducing the incidence of malnutrition and related health issues. Ultimately, it empowers communities by providing them with access to nutritious food and improving their overall well-being.

Benefits of Biofortification

Biofortification emerges as a promising solution to address the pervasive issue of hidden hunger. By enriching food crops with essential micronutrients, this innovative approach contributes to overall health improvement. Biofortified crops exhibit enhanced resilience to various adversities, including diseases, pests, and droughts, thereby boosting yields and ensuring food security. Notably, it offers a sustainable and affordable alternative to iron supplements, particularly benefiting marginalized communities who may lack access to such interventions. This strategy is highly cost-effective, requiring minimal additional input once the initial research phase is completed. By addressing the widespread problem of anemia and iron deficiency, biofortification holds the potential to significantly improve the well-being of vulnerable populations, especially women and economically disadvantaged individuals. Many review articles have reported the biofortification interventions on cereals and legumes in developing countries (Cakmak, 2008; Rehman *et al.,* 2018a; Ullah *et al.*, 2020a).

Challenges of biofortification

Biofortification faces several challenges. One major hurdle is the public's hesitation to accept biofortified food, particularly when it involves changes in appearance, as seen with golden rice. Additionally, widespread adoption by farmers is crucial for success. Finally, the initial costs associated with implementing biofortification can be a barrier for both individuals and communities.

Conclusion and Future Prospects

Biofortification is a powerful tool for addressing malnutrition issue and improving the health of the population. Development and dissemination of biofortified varieties of different crops on large scale can be helpful in minimizing the malnutrition issue in the SAARC Member States. SAARC Member States can help each other in the development of biofortified varieties of different crops and exchange of seed of biofortified varieties. Agricultural Extension Departments of all SAARC Member States can play a pivotal role in popularization of biofortified varieties of different crops among the farming community. Print and digital media can also support in the popularization of these varieties and similarly along with governments research centres and seed corporations, private seed industry can be helpful in the production of seed of biofortified varieties of different crops and their rapid dissemination. Likewise proper processing and marketing of products of biofortified varieties of different crops can be helpful in their rapid popularization among the people.

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Chapter 9

Success Story: Akbar-19 High Zinc and High Yielding Wheat Variety of Pakistan

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Introduction

Punjab province contributes 76% of the wheat cultivation area and 80% of the total wheat production in Pakistan. In the heart of Pakistan's agricultural landscape, the Wheat Research Institute (WRI), Ayub Agricultural Research Institute (AARI) in Faisalabad has been at the forefront of wheat research. Research institutes play a vital role in ensuring a sustainable food supply for the nation by producing high-quality seeds, which form the backbone of the entire seed multiplication system. Among WRI significant achievements is the development of the Akbar-19 wheat variety for irrigated areas of Punjab. Pakistan to maintain food security through replacement of the existing susceptible cultivars to avoid yield losses due to unexpected disease wave and high nutritional norms. Akbar-19 was approved in the year 2019 for wider cultivation due to it's promising stable performance over the years for better grain yield, nutritional quality and resistance against rusts. This story explores how wheat variety Akbar-19 is transforming wheat production, enhancing food security, and improving the livelihoods of farmers across the region.

In Punjab, AARI produces most of the pre-basic seed, resulting in a 50% seed replacement rate, which is notably high. This achievement is largely due to the superior quality of wheat seed developed by AARI. As a result, 99% of the wheat varieties grown in Punjab released by AARI specifically WRI, Faisalabad. Since 1950, wheat production has increased eightfold, and the demand for varieties developed by the WRI continues to rise, not only in Punjab but also other provinces in Pakistan.

Background

Wheat is a staple food in Pakistan, essential for the nutrition of millions. However, challenges such as climate change, pests, and diseases have posed significant threats to wheat yields. In response, researchers at WRI, AARI set out to develop a new variety that could withstand these challenges while providing higher yields. Currently (2023-24), Wheat is cultivated on an area of 7.06 mha with production of 24.24 million tons, achieving the yield of 3.48 t/ha in Punjab. With the advent of new varieties, the area under cultivation of Wheat crop is increased 8.28% in Punjab, with 24.9% increase in production and 15.6% of increased yield over the course of 5 years. During the crop season 2023-24, area under the zinc-enriched wheat variety, Akbar 2019, was approximately 3.78 million hectares, which was about 42% of the total cultivated area in Punjab, with the record harvest of 15 million metric tons of biofortified, zinc-enriched wheat. Pakistan is self-sufficient to meet domestic demand as wheat production during 2023-24 remained 11.3 percent more (31.40 million tons) than that of the previous year's (28.2 million tons) showing an increase of 6.6 percent area devoted to wheat (9.6 million hectares) (GoP, 2024).

Micronutrient malnutrition is an eminent problem globally and many people do not have access to healthy and nutritious food. Nearly 1/4th of world population is suffering from one or more micronutrient disorders (Kumssa *et al.*, 2015). The daily Zn requirement of an adult and pregnant /lactating women ranges from 8 to 11 mg and 11 to 13 mg, respectively (Bhowmik *et al*., 2010); while, 8-18 mg/day daily iron (Fe) intake is recommended depending on age, gender and body weight, and 27 mg/day Fe intake is advise for pregnant women [National Institute of Health (NIH), 2019]. Zinc plays many vital roles in reproductive health, immune system functioning, neurotransmission, intestine signalling, and as well as in body growth (Herschfinkel *et al.*, 2007; Wessels and Rink, 2020). These are the reasons that Zn deficiency is associated with several health problems such as impaired learning, abnormal immune system, increased infection rate and as well as impaired physical growth (Gibson, 2006; Prasad, 2007; Wessels and Rink, 2020). In Pakistan, 12 million children are stunted and 22.1% of women and 18.6% of children (under-age of five) are Zn deficient. In case of Zn deficiency in women, Punjab has the highest share (24.1%), followed by Baluchistan (23.4%), and Sindh (21.4%), while, Khyber Pakhtunkhwa has lowest prevalence (15.9%) (Ministry of National Health Services Nutrition Wing, 2018).

Wheat and rice are mainly used for daily food requirement in Pakistan. Cereals are poor in bioavailable Zn and consumption of cereal-based diets is amongst the leading causes of dietary Zn deficiency disorder in developing countries like Pakistan (Cakmak and Kutman, 2018; Rehman *et al.*, 2018a, bc, d). Human Zn deficiency can be reduced through fortification (Zn enrichment of food products during processing), or supplementation but these are expensive and sustainable approaches. Biofortification is a viable and most economical method to reduce the Zn nutritional disorder and to improve the bioavailable Zn in edible plant parts (Farooq *et al.*, 2018; Ullah *et al.*, 2020a).

Development of wheat variety Akbar-19

The successful research and development of Akbar-19 was not possible without the support of the Government of Punjab, Pakistan. The breeding material was developed in collaboration between Wheat Research Institute, Ayub Agricultural Research Institute Faisalabad, CIMMYT-International organization, HarvestPlus and Global alliance for improved nutrition (GAIN) private partners, and funding assistance from Punjab Government and Punjab Agricultural Research Board (PARB) Project # 904 (Nutrition enhancement of crops, fruits, vegetables and their products under climate change scenario). The variety was officially released in 2019 and it quickly gained attention for its impressive botanical attributes (Table 1). Akbar-19 demonstrated a yield potential of 10-15% higher than traditional varieties enhancing food security, along with a robust resistance to prevalent diseases like rust, reducing crop loss and minimizing the need for chemical treatments. Above all, Akbar-19 offers improved nutritional quality particularly Zinc (38.4 ppm), contributing to better health outcomes for consumers.

Wheat Research Institute (WRI), Faisalabad has introduced mega wheat varieties like Mexi-Pak-65, Chenab-70, Pak-81, Inqilab-91, Seher-06, Faisalabad-08 and Galaxy-13 over the span of time. The development of Akbar-19 variety proceeds through a rigorous process of breeding and selection, focusing on traits such as disease tolerance, and high yield potential along with improved nutrition. CIMMYT shared improved germplasm for development of wheat varieties and WRI responsible for local testing and release of improved wheat varieties.Akbar 2019 was identified from mainstream breeding.The entity BECARD/QUAIU # 1 with pedigree CMSS07B00230S-099M-099NJ-099NJ-23WGY-0B was selected after careful breeding work and years of evaluation. It is better yielding, highly nutritious and disease resistant than local commercial varieties. The research team of WRI conducted extensive field trials across various agro-climatic conditions of Punjab, ensuring that Akbar-19 could thrive in diverse environments making it a reliable choice for local farmers. To maintain the food security through replacing the existing susceptible cultivars gradually to avoid yield losses due to unexpected disease wave. GAIN and HarvestPlus aided in public awareness and large-scale dissemination of the variety.

Table 1: Botanical characteristics of Akbar-19

S. No	Traits	Range
1	Plant height	105-115 cm
2	Anthocyanin at seedling stage	No
3	Growth habit	semi-erect
4	Waxiness on Stem	Weak
5	Stem Diameter	4.5 mm
6	Head Shape	Tapering
7	Straw Colour	Whitist
8	Maturity	140-145 days
9	Tillering capacity	380-430 tillers/m^2
10	Flag Leaf	Moderate waxy and erect
11	Leaf Length	21-23 cm
12	Leaf Width	1.4-1.7 cm
13	Auricle nature	Hairy
14	Seed	Amber and Bold
15	Seeds per ear	50
16	Rachis length	12.5-14.0 cm
17	Rachis segments	19-21
18	1000-Kernel weight	40-42g
19	Days to Maturity	140-145
20	Glume length	8.60 mm
21	Glume Width	5.8 mm
22	Protein	12.5-14.9%
23	Starch	53.7-55.8%
24	Gluten	25-30%
25	Test weight	71.4-76.4 kg/ha
26	Chapati quality	Good

Pre-Basic Seed Production

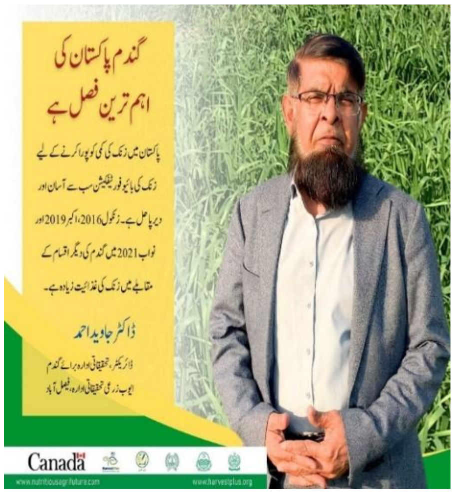
The production of Breeder Nucleus Seed involves numerous well-planned and scientifically defined steps, starting with the careful selection from hundreds of well-maintained generations. This process involves selecting the best-looking heads, followed by head-to-row progenies, and finally, progeny blocks and selection of true to type. The pre-basic seed production of Akbar-19 in 2024 is increased to 354 percent over its release in 2019 (Table 2) at WRI farm areas, represents its popularity. The average area increased from 26.21% (2022-23) to 42.37% (2023-24) in the region encompass its strength and popularity. The rapid dissemination of Akbar-19 seed became possible due to the improvement in early generation Seed system (EGS). During the 2023-24 cropping season, over 175,000 metric tons of certified Akbar 2019 seed were planted, complemented by farm-saved seeds.

Table 2: BNS (pre-basic seed) of Akbar-19 at WRI, AARI Faisalabad

S. No	Year	Pre-basic seed Production (kg)
1.	2019	500-600
2.	2020	700
3.	2021	1200
4.	2022	1800
5.	2023	2200
6.	2024	2500

Impact on Farmers

The introduction of Akbar-19 has had a profound impact on local farmers. Extensive training programs have been provided to farmers on best cultivation practices, highlighting its nutritional aspects for maximizing the benefits of Akbar-19. The HarvestPlus and GAIN private partners played a crucial role in the variety's dissemination among farmers.



Many smallholders in Punjab, where wheat is a primary crop, adopted Akbar-19 due to its resilience and high productivity. Farmers reported significant increases in their yields, with some achieving harvests of over 6 tons per hectare compared to 4-5 tons from older varieties.

Farmers adopting Akbar-19 have reported higher profits due to better yields and reduced input costs. One notable success story is that of farmer Ali Khan from the Faisalabad district. "The benefits of Akbar-19 are clear," Ali said. "It has changed my life and the lives of my fellow farmers." Dr. Shadab Shaukat, from Lasbella university, Baluchistan, Pakistan said that farmers in Baluchistan are cultivating Akbar-19 on water stressed areas and getting good results.


CIMMYT conducted a survey in Pakistan April 26, 2024, to determine the performance of CIMMYT-derived high zinc and high yielding wheat variety Akbar-19. Several areas and local farming communities were surveyed (License number: 902271 CIMMYT). One of the farmer Muhammad Mubashir Sharif from Nankana Sahab District says, we have cultivated Akbar wheat on 4-5 acres this year and we have been producing its seed since last 2 years. It has good yield that's why we cultivated it. Another farmer Rashed Mehmood from a village Kotla kalan chak # 43 says that previously, they were cultivating old wheat varieties and the yield was not reasonable. For the first time, this year they cultivated Akbar-19 on 2-3 acres. Its spike is long and beautiful, and it has appealing yield. Rashed said. It is my suggestion to all farmer brothers that try Akbar-19 as it has pretty good average yield . Abdullah Saif from Bahawalnagar District cultivated 5-7 acres of Akbar. Abdullah got superb grain yield, 40-45g of 1000-grain weight, with an appealing average of 65-70 maunds/acre. Mohammad Taimoor from Sheikhupura District is cultivating Akbar-19 from last 3 years. It is a good variety, and its results are very appealing, said Taimoor.

Dr. Javed Ahmad, Chief Scientist Wheat Research Institute addressed the importance of biofortified wheat variety Akbar-19, its evolution in collaboration with HarvestPlus and CIMMYT. He said, we worked together for the quick seed multiplication and dissemination of Akbar-19 to farmers resulted a big success within short period of time. “Akbar 2019’s significance lies not just in its yield but in its potential to improve the health of millions suffering from zinc deficiency,” Dr. Ahmad said. “This wheat variety ensures both food security and improved public health outcomes”. This year Akbar-19 is occupying more than 42% of the total wheat cropped area in Pakistan. “Akbar 2019 was developed not only for its nutritional benefits but also for its ability to withstand climate stress,” explained Yaqub Mujahid, Country Manager at HarvestPlus in Pakistan. This variety is revolutionizing wheat production and contributing to healthy diets among wheat consumers in Pakistan.

Health Impact and value addition (Supply Chain)

Zinc is vital for immune function, growth, and development. Zinc deficiency can lead to stunted growth in children, weaken immune system, and increased susceptibility to infections. Rural communities in Pakistan, where access to nutritious foods is often limited, are particularly at risk. To address this issue, the introduction of zinc-enriched wheat aims to provide a fortified staple food that can help improve nutrition and reduce these health challenges.

Zinc deficiency is an emerging health problem as about 20.6% children are found in the levels of zinc, below 60 ug/dL. Malnutrition is the most common cause of zinc deficiency and 25% of the world's population is at risk of zinc deficiency. 36.9% of the household is labelled as food insecure and 40% of children under 5 are stunted due to the deficiency of essential nutrients (Zn, Fe, Ca, Vit-A & D).

Agricultural development has enormous potential to contribute to reducing malnutrition. The estimated prevalence of stunting growth is projected 25.7% in 2025 Asia. The quality of wheat grain is at risk from new and more aggressive diseases and unstable weather conditions related to climate change. Wheat crops play an important role in satisfying daily calorie intake in Pakistan, but they are inherently very low in Zn and protein concentrations in grain. Punjab government provides substantial support in the development and dissemination of biofortified crops. Biofortification of staple food crops is the need of time to address malnutrition in the country and Akbar-19 is an important addition to cope with malnutrition and stunted growth in Pakistan.

The scientists at WRI, Faisalabad has rightly executed new high yielding and high Zinc wheat variety for wider cultivation with the name of Akbar-19 well in time, due to not only its high yielding ability along with lodging tolerance but it has also kept strong podium on sound traction against any type of diseases. The plant breeding (genetic bio-fortification) strategy is a most sustainable and cost-effective approach. In Punjab, more than 70% of wheat cultivated soils are deficient in plant available Zn. Therefore, the soil application of Zinc will also help to increase Zinc contents in Zinc receptive wheat varieties like Akbar-19. Overall, the feasibility of production practices for Akbar-19 are cost effective.

The average Zinc enriched varieties can accumulate up to 25ppm of Zn in their grains. Akbar-19 offers improved nutritional quality particularly Zinc (37~39 ppm) with high grain yield potential (~7.5 tons/ha), contributing to better health outcomes for consumers.

Overall, the quality contents were tested in >90 commercial chakki's by GAIN. Akbar-19 is a good value addition (from grain to value chain), avoiding additional supplements intake for Zn deficiency or fulfil the body demand. Different universities and institutes in Pakistan are conducting research to study the health impact on pregnant women after feeding Akbar-19 flour. Initial results are very encouraging regarding health condition of pregnant women. Industry is also interested in furthering the advancement in this regard.

Economic Benefits

The economic impact of Akbar-19 extends beyond individual farmers. Increased wheat production has contributed to local and national food security, reducing reliance on wheat imports. The success of this variety has also stimulated the agricultural sector, leading to job creation in processing, distribution, and retail. Akbar-19 promotes sustainable agricultural practices, contributing to soil health and environmental conservation. The economic gain of 14.17% in Wheat productivity is attributed to this variety. Over 130 seed companies along with HarvestPlus participated in channelizing the demand of Akbar 2019 to farmers, ensuring availability even in remote areas. Public-private partnerships, such as Punjab’s seed subsidy programs, were instrumental in promoting its widespread adoption. Dr. Ahmad stated. “The rapid adoption of Akbar 2019 exemplifies what can be achieved through collaboration, innovation, and advocacy”. **With 15 million metric tons of zinc-enriched wheat now in the market, Pakistan is taking a significant step toward alleviating zinc deficiency and improving public health.** The government of Punjab has included Akbar 2019 and other zinc wheat varieties in their seed subsidy plan for smallholder farmers. **Over 70 million people are consuming Zinc fortified Akbar 2019 alone in 2024-25.** Amidst the challenges of malnutrition and climate change, biofortified crops like Akbar 2019 offer a powerful solution to boost food security and improve nutrition in Pakistan.

Future Prospects

With its proven resilience and yield potential, Akbar-19 is paving the way for further advancements in wheat research at AARI. Ongoing studies aim to further improve wheat varieties and address emerging challenges in Agriculture, including improving nutritional quality and adaptability to changing climatic conditions. Related issues should be addressed on broader scale, especially the lack of awareness among farmers, segregation/aggregation, low supply of Zn bio-fortified seed and no additional price to the farmer. To cope with this, increase participation and capacity of value chain actors in the production, processing, and marketing of biofortified seeds, grains and food products is needed. Zinc fertilizers with subsidized price should be made available to local farmers. Ensure market penetration of biofortified foods and food products through their integration in markets. The impact of Akbar-19 at farm and market exemplifies the vital role of Wheat Research Institute in agricultural research in ensuring food security and economic stability. As Pakistan faces the challenges of a growing population and climate change, innovations like Akbar-19 will be crucial in sustaining the agricultural backbone of the nation.

Conclusion

Wheat Research Institute has developed a successful nutritional enhancement breeding program and has developed a number of elite wheat lines with high Zinc contents. The Institute is carrying the legacy to fulfil the nutritional deficiency in Pakistan. Akbar-19 showed progressive adaptive features which outperformed during different phases of testing and finally the strength embarks the worldwide recognition of Akbar-19. The transformative impact of Akbar-19 on wheat production in Punjab, Pakistan, showcasing its benefits for farmers and the broader agricultural community, stands as a testament to the dedication and ingenuity of the researchers at Wheat Research Institute, AARI. By providing a reliable and high-yielding alternative for farmers, it not only boosts production but also uplifts communities and strengthens the country's agricultural sector. As more farmers embrace this variety, the future of wheat farming in Pakistan looks brighter than ever.

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Proceedings of the Regional Consultation Meeting on the "Development and Dissemination of Biofortified Varieties of Different crops in the SAARC Member States"

2-4 September 2024

A three days (2-4 September, 2024) regional consultation meeting was organized by the SAARC Agriculture Centre (SAC) in virtual mode on **"Development and dissemination of Biofortified varieties of different crops in the SAARC Member States". It was approved by** the 15th meeting of SAC Governing Board and the 59th meeting of Programming Committee of SAARC Agriculture Centre (SAC) Dhaka Bangladesh.

Background:

The current population of SAARC countries is more than 1.90 billion over the landmass of 6.4 million square kilometre which is about 3.5% of Earth's land areas. Arithmetically, it implies approximately 25% of global population and it is the most densely populated region of the world (Xue *et al.,* 2021). One-third of the world's poor (earning less than 1.9 $/day) live in this region. and it was estimated that 41% (532 million) of the total 1.3 billion multi dimensionally poor people in the world were from this region (UNDP & OPHI, 2021). Despite significant improvements in last two decades the rates of under nourishment still remain high in South Asia. In 2021, nearly 796.8 million people have been reported moderately or severely food insecure with a high prevalence of micro nutrients deficiencies in the region (FAO., 2022). Even though stunting rates have declined significantly over the years, still more than 30% of the children below 5 years of age have been stunted due to malnutrition in South Asia, which is almost one third of the global burden (Gillepie *et al.,* 2019).

High consumption of cereal based foods with low contents of micronutrients is causing health hazards in humans. The of micronutrients contents in food can be increased either by supplementation, fortification or by agricultural strategies i.e. biofortification and by application of micronutrients containing fertilizers in crop production. Food fortification and supplementation are too expensive, not practical to be applied on large scale and not easily accessible to poor masses. The development of micronutrient efficient genotypes can be a successive tool to overcome the micronutrient disorders in soil and for improvement of human health.

There is a dire need for a rapid approach to improve mineral nutrient concentrations in cereals. Different strategies including supplementation, food fortification and biofortification can be helpful in enhancing the micronutrient densities in staple diets, but as compared to supplementation and food fortification, biofortification holds great promise for improving the nutritional and health of poor populations in both rural and urban areas of the developing world (Grahm & Welch, 1996). Both Conventional plant breeding and modern biotechnological approaches and tools can be used to increase the micronutrient density of staple crops. Biofortification provides a sustainable solution to Fe and Zn deficiencies in food around the world as it is the process of enriching the nutrient contents of staple crops. Biofortification of staple food crops with micronutrients by either breeding for higher uptake efficiency or fertilization can be an effective strategy to address widespread dietary deficiency in human populations (Bouis *et al.*, 1999). The lack of micro nutrients such as Fe and Zn is a widespread nutrition and health problem in developing countries. Reports have highlighted that the current strategies for the biofortification of crops, include mineral fertilization, conventional breeding and transgenic approaches. Any approach which could increase root growth and result in a high transfer of Fe and Zn from the soil to the plant is crucial for biofortification (Graham, 1984).

In almost all the SAARC Member States especially the poor one, children and women are facing the hidden hunger issue of different micro nutrients especially Zn, Iron and Vitamin A which is a big challenge for their health and progress. The purpose of this regional consultation meeting was to find out the ways for the promotion and use of biofortified grains of different crops on large scale for the better health of the people with the following objectives and outcomes.

Objectives:

1. To update the information on the present status of developed biofortified varieties of different crops in the SAARC Member States.
2. To know the status of production and dissemination of seed of developed biofortified varieties of different crops for cultivation.
3. To find out the hurdles and challenges in the dissemination of biofortified varieties among the masses.

Methodology:

The regional consultation meeting was conducted by virtual mode in which Focal points of SAARC Member States presented their country papers. Scientists of different national and international research organizations, professors of different universities and representative from international development partners participated in this three days meeting. Guests speakers of the different international research organizations i.e. CIMMYT, IRRI, CIP, Universities and similarly international development organization i.e. Harvest Plus participated the meeting and gave presentations on the different aspects of biofortification including varietal development and their dissemination. The main purpose of this consultation meeting was to identify strategies for the development and dissemination of biofortified varieties of different crops and exchange of seed of these varieties among the SAARC Member States.

Inaugural Session:

Focal points of 6 SAARC Members States i.e., Bangladesh, Bhutan, Nepal, Maldives, Pakistan and Sri Lanka, scientists of different international and national research and development organizations and universities participated in this regional consultation meeting on "Development and Dissemination of Biofortified varieties of different crops in SAARC Member States".

Honorable Ambassador Mr. Abdul Motaleb Sarker, Director General SAARC and BIMSTEC, Ministry of Foreign Affairs Bangladesh was the Chief Guest and Dr Nazmun Nahar Karim, Executive Chairman BARC, was the Special guest while Mr Jamal Uddin Ahmad, Director (ARD & SDF), SAARC Secretariat Nepal and Mr Rovinder Grover, Global Business Manager HarvestPlus Solutions were the Guests of Honor in the inaugural session of this regional consultation meeting.

Dr Md. Harunur Rashid Director SAARC Agriculture Centre welcomed all the Focal points of SAARC Member States, participants and scientists of different organizations including CIMMYT, IRRI, CIP, CABI, AFA, BARI, BRRI and BAU. He specially thanked HarvestPlus for participating in this regional meeting Dr. Harunur Rashid said that this meeting will be helpful in making the recommendations regarding the development and dissemination of Biofortified varieties of different crops for this region. Dr Sikander Khan Tanveer, Senior Program Specialist (Crops) gave a detailed presentation on Biofortification of crops and highlighted about the concept, purpose and objectives of this meeting.

Guests of Honor, Mr Rovinder Grover, Global Business Manager HarvestPlus Solutions and Mr Jamalud Din Ahmad, Director (ARD & SDF), SAARC Secretariat Nepal, Special guest Dr Nazmun Nahar Karim, Executive Chairman Bangladesh Agricultural Research Council (BARC) and Chief guest, Honorable Ambassador Mr. Abdul Motaleb Sarker, Director General SAARC and BIMSTEC in their speeches appreciated the efforts of the SAARC Agriculture Centre (SAC) for arranging this regional consultation meeting and for bringing together scientists and other stakeholders of SAARC Member States. According to them, maximum poor people of the world are living in this region and this region is severely facing the issue of malnutrition especially in the form of micronutrients deficiency which is the most pressing issue of the region. Climate change is another big issue of this region and it can further impact on the availability of different micronutrients i.e. Zn and Fe etc. They suggested that we should cooperate, collaborate with each other and work together to solve this common issue of the region. They emphasized on the scaling up of these innovations and gave importance on partnerships and long-term investments. According to them South Asia is making a progress in this regard but still a lot of work is needed to be done in solving this problem According to them, presently South Asia, agriculture sector is facing a number of challenges and now therefore knowledge intensive agriculture is the need of the time. According to them, Biofortification could be helpful in solving the issue of malnutrition in SAARC Member States and this consultation meeting would be helpful in the development of policies and recommendations. They said that tis this regional consultation meeting would be supportive in the development and dissemination of Biofotified varieties of different crops on large scale in this region.

Dr Khalida Islam, Professor, Institute of Nutrition and Food Sciences, Dhaka University, Bangladesh was the Key Note Speaker, and she gave a detailed lecture on importance of proper nutrition for human health and explained that how proper nutrition is important for the human life from childhood to old age, and promotion of Biofortified varieties of different crops in this region can play a pivotal role in the health improvement of the people the region.

Technical Sessions:

There were five technical sessions. First three technical sessions were mainly allocated for the country paper presentations from the Focal Points of the different SAARC Member States.

Dr Md. Abdul Salam, Member Director (Crops), Bangladesh (BARC), Mr B.B. Rai, Senior Agriculture Supervisor Department of Agriculture, Ministry of Agriculture & Livestock Bhutan, Mr Gopal Bhandari, Senior Technical Officer National Maize Program, Nepal, Mr Mohammad Rihvaan, Assistant Director, Ministry of Agriculture & Animal Welfare Maldives, Dr Muhammad Sohail National Coordinator Wheat PSD, PARC and Dr Shahid Ahmad, Director PSD, PARC, Pakistan and Dr. (Ms) B.M.K Senarathana Menike, Assistant Director of Agriculture, Research & Development Institute Sri Lanka gave their detailed presentations on research and development activities on the development and dissemination biofortified varieties of different crops in their respective countries.

All Technical sessions were chaired by different eminent scientists including Dr Md. Harunur Rashid, Director SAARC Agriculture Centre (SAC) Dhaka, Dr Md. Abdur Razzaque, Former Executive Chairman Bangladesh Agricultural Research Council (BARC) Bangladesh, Professor Dr. Md. Abdur Rahim, Professor (Retired), Department of Horticulture, Bangladesh Agricultural University Mymensingh and Dr Khandakar Md. Iftekharuddaula, Chief Scientific Officer and Head Plant Breeding Division Bangladesh Rice Research Institute, Gazipur, Bangladesh.

There were eight invited guest speakers who gave detailed presentations on the different aspects of development of biofortified varieties of different crops, their dissemination and marketing. Dr Hummanth Bhindari, Country Representative for Bangladesh and Senior Agricultural Economist IRRI gave presentation on Biofortified Rice- Experience of IRRI; Dr Abdur Rahman Bashir, Seed Systems Specialist Asia, CIMMYT office Nepal gave presentation on Maize Biofortification initiatives by CIMMYT in South Asia; Dr Javed Ahmad, Chief Scientist / Director Wheat Research Institute, Ayub Agriculture Research Institute Faisalabad Pakistan gave presentation on Biofortified wheat varieties production in Punjab -Pakistan; Mr Md. Wahidul Amin, Country Coordinator HarvestPlus Bangladesh gave presentation on Rice varieties in Bangladesh: Ways to impact and policy support; Dr Velu Govindan, Senior Scientist Wheat Breeding Global Wheat Program, CIMMYT, Mexico gave presentation on Wheat Biofortification at CIMMYT; Dr Arif Hussain Khan, Professor, Bangladesh Agricultural University Mymensingh Bangladesh gave presentation on Bio-fortification in Potato and Sweet potato and Dr Yaqub Mujahid, Country Manager, HarvestPlus Pakistan gave presentation on Akbar-2019, a success story of Biofortified wheat in Pakistan. There were detailed discussions and questions and answers after each technical session. At the end of each technical session, participants discussed all the aspects of Biofortification and about the ways for the promotion of Biofortified varieties of all crops in SAARC Member States.

Table 1: Detail about the invited guests during the inaugural session.

S. No	Name	Designation	Organization
1.	Ambassador Mr. Abdul Motaleb Sarker (Chief Guest)	Director General	SAARC and BIMSTEC, MOFA, Dhaka Bangladesh
2.	Dr. Nazmun Nahar Karim (Special Guest)	Executive Chairman	Bangladesh Agricultural Research Council (BARC), Dhaka Bangladesh.
3.	Mr. Ravinder Grover (Guest of Honor)	Global Business Manager	HarvestPlus - Solutions
4.	Mr. Jamal Uddin Ahmed (Guest of Honor)	Director (ARD&SDF)	SAARC Secretariat, Nepal.

Table 2: Technical Sessions & Concluding session along with the detail of Session Chairs.

S.No	Name	Designation	Organization
1.	Dr. Md. Harunur Rashid	Director	SAARC Agriculture Centre
2.	Dr. Md. Harun ur Rashid	Director	SAARC Agriculture Centre
3.	Dr. Md. Abdur Razzaque	Former Executive Chairman	BARC, Dhaka Bangladesh
4.	Professor Dr. Md. Abdur Rahim	Professor (R), Department of Horticulture	Bangladesh Agricultural University Mymensingh Bangladesh
5.	Dr Khandakar Md. Iftekharuddaula	CSO and Head Plant Breeding Division	Bangladesh Rice Research Institute (BRRI), Gazipur Bangladesh

Table 3: Focal Pints of different SAARC Member States.

S.No	Name	Designation	Organization	Country
1.	Dr. Md. Abdus Salam	Member Director (Crops)	BARC	Bangladesh
2.	Mr. B.B Rai	Senior Agri. Supervisor	DOA, MoA& L	Bhutan
3.	Mr. Mohammad Rihvaan	Assistant Director	MoA& Animal Welfare	Maldives
4.	Mr. Gopal Bhandari	Technical Officer, NMRP	Nepal Agricultural Research Council (NARC), Ministry of Agriculture and Livestock Development	Nepal
5.	Dr Muhammad Sohail	National Coordinator Wheat	Pakistan Agricultural Research Council (PARC)	Pakistan
6.	Dr. (Ms) B.M.K Senarathana Menike	Assistant Director of Agriculture	R&D Institute	Sri Lanka

Table 4: Detail information of Key Note Speaker and other Guest speakers of the regional consultation meeting on Development and Dissemination of Biofortified varieties of different crops in SAARC Members States.

S. No	Name	Designation	Topic of Presentation
1.	Pro. Dr. Khalida Islam (Keynote Speaker)	Chairman, Institute of Nutrition and Food Sciences Dhaka University, Bangladesh.	Importance of proper nutrition for Human health.
2.	Dr Hummanth Bhindari	Country Representative for Bangladesh and Senior Agricultural Economist IRRI.	Biofortified Rice-experience of IRRI.
3.	Dr. Abdur Rahman Bashir	Seed Systems Specialist Asia, CIMMYT Nepal	Maize Biofortification initiatives by CIMMYT in South Asia.
4.	Dr Javed Ahmad	Chief Scientist / Director WRI,Ayub Agriculture Research Institute Faisalabad	Biofortified wheat varieties production in Punjab-Pakistan.
5.	Mr MD. Wahidul Amin	Country Coordinator HarvestPlus Bangladesh	Biofortified Rice varieties in Bangladesh: Ways to impact and policy support
6.	Dr Velu Govindan	Senior Scientist, Wheat Breeding, Global Wheat Program CIMMYT, Mexico	Wheat Biofortification at CIMMYT.
7.	Dr Arif Hussain Khan	Professor Bangladesh Agricultural University Mymensingh	Bio-fortification in potato & sweet potato.
8.	Dr Yaqub Mujahid	Country Manager HarvestPlus Pakistan	Akbar -2019, a success story of Biofortified wheat in Pakistan

It was concluded that Biofortification of crops for different nutrients is sustainable way to minimize the issue of malnutrition, prevailing in the form of hidden hunger which is causing a number of problems and the poor people are the most sufferer .Through Biofortification of different crops, maximum people will get their needed nutrients i.e., Zn, Fe and other vitamins through their normal diet and there will be no need of fortification of food. Research and development work along with awareness of common people, and farming community are needed. Governments of all SAARC Member States should include the Biofortification of crops in their national policies.

Main outcomes of this regional consultation meeting are given as under

- All SAARC Member States, populations are facing micronutrients (i.e. Zn, Iron and different types of vitamins) deficiency problem and issues.
- Research and Development work is in progress on the development and dissemination of Biofortified varieties of different crops in almost all SAARC Member States except in Maldives for different crops according to their priorities and preferences.
- Biofortified varieties of Rice, Wheat, Maize, Lentil, Potato and Sweet Potato have been developed in SAARC Member States.
- There are evidences that Biofortified crop varieties are more resistant to diseases.
- Governments and different national and international organizations are encouraging Biofortified crops development and dissemination activities, however more policy support is needed by all SAARC Member State Governments.
- Awareness building is needed among the people for the promotion of Biofortified varieties on large scale.
- Demand for Biofortified varieties of different crops is increasing with the passage of time.
- New coming Biofortified varieties of different crops have equal and or even more yield as compared to the non-Biofortified varieties of that crop.
- Different SAARC countries have developed and are further working for the development of biofortified varieties of different crops. Bangladesh has already developed biofortified varieties of different crops i.e. rice, wheat, lentil and sweet potato and further work is in progress. Bhutan is working for the development of maize and potato biofortified varieties. Nepal has developed biofortified varieties of wheat, maize and lentil crops. Likewise, Pakistan has developed biofortified varieties of wheat and rice crops and is also further working for the development of biofortified varieties of wheat, rice and maize crops. Similarly in Sri Lanka research work is going on for the development of rice and maize biofottified varieties.
- In some SAARC Member States Biofortified grains of different crops have even more price in the market than the non-biofortified varieties of that crop.
- Branding of biofortified varieties of different crops is also in progress in some SAARC Member States.
- Zn biofortified rice varieties are competitive in yield with non-biofortified rice varieties.
- Further research work is needed for the development as well as for the promotion of biofortified crops in all SAARC Member States.

Some other important points discussed / identified during the different technical sessions that included:

- It was reported that during rice milling process about 70-90% nutrients are removed / lost.
- It was suggested that still a lot of work is needed to be done for technology transfer of Biofortified crops to farming community.
- It was reported that in Sri Lanka, rice is fortified with Fe, Iodine & Zinc.
- In Sri Lanka – 33% children's have Fe deficiency issue.
- It was pointed out that university students and other technical people working in agriculture departments should be sensitized about the latest developments on biofortification of crops.
- There is also need of teaching the School children's about use of nutrient rich crop varieties and their beneficial effects on human health.
- Dr Abdur Rehman Bashir, CIMMYT Scientist Nepal told that QPM is also giving higher yield.
- It was suggested that Private sector could be involved in biofortification of crops and their dissemination.
- Capacity development of all stake holders has been emphasized for further development and promotion of biofortified varieties of different crops on large scale.
- It was also suggested that seed value chain development of biofortified varieties of different crops need to be strengthened.
- Value chain development of Biofortified varieties of different crops is very important.
- Dr Javed Ahmed, Director Wheat Research Institute (WRI), Ayub Agricultural Research Institute Faisalabad Pakistan informed that, WRI has a number of wheat crop genotypes which have 36.32 -55.91 ppm zinc in their grains.
- According to Dr Javed Ahmed, Director Wheat Research Institute (WRI), Ayub Agricultural Research Institute (AARI) Faisalabad Pakistan, 42% area of wheat crop in Punjab province of Pakistan is under Akbar-2019, which is a high zinc and as well as high yielding wheat variety. However, he added that nutritional contents are not considered during marketing of any biofortified variety.
- It was also mentioned in the different technical sessions that farmers awareness about the Biofortified crops is very important and for this purpose, free seed should be provided to the farmers and more number of demonstration plots of Biofortified crops should be established on the farmers' fields.

- Mr. Wahidul Amin from HarvestPlus Bangladesh told that Zn biofortified rice varieties of Bangladesh are competitive in yield with non biofortified rice varieties. According to him seed production of Biofortified rice varieties is being increased in Bangladesh with the passage of time.
- It was also suggested that brand development of Biofortified varieties of all crops is the need of the time.
- Replying about the question regarding the cultivation of QPM in SAARC Member States, Dr Abdur Rehman Bashir, CIMMYT Scientist Nepal office told that about QPM use / cultivation data in the SAARC region is not clear but in China QPM is being cultivated/used on large scale.
- Mr. Wahidul Amin Officer HarvestPlus Bangladesh indicated that farmers always prefer yield as compared to quality.
- It was mentioned that regional ease of availability of Biofortified varieties means nutrition benefit of neighbor countries.
- Dr Velu Govindan, Senior Scientist CIMMYT- Mexico told that Biofortification research started 15 years before and a lot of successes have been achieved until now.
- BB Rai – Focal point of Bhutan asked Dr Velu Govindan, (Senior Scientist CIMMYT- Mexico) that either white color grain Biofortified maize varieties are available in CIMMYT ?.Dr Velu replied to the question of BB Rai, that I will ask the concerned scientists of CIMMYT and will share the email address of concerned maize crop scientist with B.B Rai and he can further discuss with the concerned scientist in detail regarding availability of white color maize varieties.
- Wahidul Amin, officer HarvestPlus Bangladesh wanted to know from Dr Arif Professor BAU, Mymensingh Bangladesh about the plan of spreading biofortified orange potato and sweet potato on large scale, which is available with them since a long time.
- Mr. Benu Chearn Country head HarvestPlus India emphasized the need of more investment by all the countries / organization for the research purpose in this sector and SAARC Agriculture Centre can play coordinating role in this regard. He also suggested to set standards for micronutrients in the region. He appreciated SAARC Agriculture Centre (SAC) for organizing this regional meeting.
- Dr Md. Harunur Rashid, Director SAC, appreciated the achievement of Wheat Research Institute (WRI), Faislabad Pakistan for the development of high yielding and high zinc wheat variety Akbar-2019, which has become a successes story. He also hoped that this region can also achieve successes of Biofortified varieties of other crops. He opined that SAARC countries can also learn a lot from the success story of wheat variety Akabr-2019.

- It was suggested that Seed without boarder agreement can also be helpful in the spread of seed of Biofortified varieties in the region.
- It was also suggested that Genomics and Artificial Intelligence should be used for the development of Biofortified varieties of different crops.
- It was suggested that seed availability of Bioforyified varieties of different crops on large scale should be made sure for the cultivation of these varieties on large scale.
- Dr Md. Harunur Rashid, Director SAC informed that SAC is working on Material Transfer agreement among SAARC Member States and for this purpose SAC needs help of all SAARC Member States. It will be helpful in the easy exchange of germplasm / seed of different varieties of all crops in the SAARC Member States.
- It was pointed out that good management practices are also important for harvesting the maximum production of biofortified varieties of different crops.
- All the participants had the common point of view that malnutrition is the common problem of this region and for this reason effective Research & Development work is needed for the development of biofortified varieties of all crops. Common policy of all SAARC Member States is needed and similarly Seed without border or Custom seed production can be supportive in the spread of biofortified varieties in the region.
- Benu Cherian, Country Head HarvestPlus, India told that for the analysis of grains for different micronutrients like zinc etc, XRF machines are needed but there are few number of XRF machines in the SAARC Member States. Availability of more number of XRF machines needs to be increased in the SAARC Member States.
- It was suggested that SAARC Agriculture Centre can be helpful for better promotion and development of Biofortified varieties of different crops in the region, through technical capacity improvement, development of labs, nutrition policy development and it can develop a platform for the SAARC Members States on the same pattern like that of European Union for this purpose. SAARC Agriculture Centre can arrange regular meetings on the Biofortification of crops in the region.
- Mr. Rihvaan Focal Point of Maldives, suggested that there is also need of conducting more research to combat the Fe deficiency, because still either there is no research or very less research has been conducted to combat the Fe deficiency. He also suggested that already developed Biofortified material should be provided to Maldives.
- It was suggested that Certification mechanism needs to be developed for Biofortified varieties of different crops.

- As testing of germplasm for the different types of micronutrients is very expensive so it was suggested that there should be a regional lab for the testing of germplasm of different crops for the development of Biofortified varieties and SAARC Agriculture Centre can assist in the development of a such kind of regional lab.
- From Dr M. Yaqub Mujahid, Country Manager HarvestPlus Pakistan suggested that close collaboration of SAARC Member States can be supportive for the development of Biofotified varieties. According to him, value chain development is needed for the better promotion of Biofortified varieties on large scale from producer to the consumer. He also suggested that PP mode can also play an important role in the large scale promotion of Biofortified varieties of different crops. He also suggested that women should be sensitized for awareness building about the beneficial effects of u Biofortified varieties and they can play an important role in the promotion of use of Biofortified varieties of different crops. He also suggested that seed exchange of Biofortified varieties in the SAARC region can boost the use of such kind of varieties in this area.
- It was suggested that Biofortified varieties of different crops could be included in School children's feed programs and School children's should be given awareness about these kind of varieties.
- Dr Makhdoom Hussain, who is currently working as Consultant HarvestPlus Pakistan, and he is also the Former Director of Wheat Research Institute (WRI), Ayub Agricultural Research Institute (AARI) Faisalabad, congratulated SAARC Agriculture Centre (SAC) for arranging this regional consultation meeting. He said that it is good to know that almost all SAARC Member States are working for the development of Biofortified varieties of different crops. He also suggested that SAARC Member States should help each other in this sector.
- Dr Ganga Dutta Acharya, Senior Program Specialist (PSPD), SAARC Agriculture Centre suggested that there is need to identify the reasons why Biofortified crop varieties which have already been developed are not expanding. He suggested that all SAARC Member States need collaboration in this sector and SAC should play its role in this regard for policy process and research. He also suggested that scale up of Biofortified varieties is also very important and is the need of the time.
- Javed Iqbal, from HarvestPlus Pakistan said that it was a very good meeting and it should be continued in future. He suggested that there should be material transfer / germplasm exchange among the SAARC Member States.
- DR Debashish Chanda, Country Head CIP Bangladesh, suggested that recommendations / conclusions should be sent to all SAARC Member States. He suggested that Biofortification should be included in all Governments policies.

- Dr Iftikhar, Chief Scientist BRRI Gazipur said that recommendations / opinions given by all participants are very important. He also mentioned that Fe deficiency as indicated by the Focal Point of Maldives is also very important and it is a very big issue, which needs to be addressed. He suggested that human resource exchange is very important for the exchange of knowledge.
- According to Dr Ganga scaling up of biofortified varieties is also very important.
- According to Javed Ahmad Director Wheat Research Institute (WRI) Faisalabad Pakistan, farmers awareness is very important for the promotion of biofortified varieties of different crops.
- Dr Md. Harunur Rashid, Director SAC in his concluding remarks thanked all the participants and said that the objective of this meeting was to know the status of development and dissemination of Biofortified varieties of different crops in the SAARC Member States. He also told that in our future meeting the issue of Material Transfer mechanism will be discussed in detail. He also told that we have noted all the points and suggestions which will be helpful in the finalization of recommendations. He also suggested that there should be a policy for the development and dissemination of Biofortified varieties of different crops for SAARC region and similarly each country should also have its own policy for this purpose. He said that I hope, together we can make a success and similarly success stories of the region in the biofortification sector, can also be helpful in initiating for the development of biofortified varieties of other crops. He gave importance for the investment by all related stakeholders for the development and dissemination of biofortified varieties of all crops in the region.

Recommendations were presented by Dr Sikander Khan Tanveer, Senior Programme Specialist (Crops), SAARC Agriculture Centre, and there was a detailed discussion on different related aspects i.e., Research & Development, Policy, Seed availability, Capacity building and Marketing of biofortified crops. Detail of each is given below:

Recommendations

1. Research & Development:

- Conventional and advanced crop breeding methods and approaches should be used for the development of high yielding, disease resistant and climate resilient biofortified varieties of different crops.
- Comprehensive production and post production technologies for the biofortified varieties needs to be developed and disseminated to farmers.
- Standard agronomic management practices should be developed for the biofortification of different crops.

- All SAARC Member States should have collaborative research, germplasm and advance breeding lines transfer program with different CGIAR Centers (i.e., CIMMYT, IRRI, ICRISAT, World Vegetable Centers, CIP etc.) for the development of biofortified varieties of different crops.
- Success stories of biofortified crops in the form of print media or video could be exchanged among the SAARC Member States.
- Efforts should be made to exchange germplasm/seed of biofortified varieties of different crops among SAARC Member States.
- There is need of screening of local germplasm / land races enriched in micronutrients, for using this material in future breeding programs for the development of biofortified varieties of different crops.
- There is a need for the development of advanced labs facilities specially biotechnology labs for target breeding work for the development of biofortified varieties of different crops.
- There is need of technical capacity improvement of scientists & staff.
- Quality assurance and quality control mechanisms are needed to be developed and maintained for the development and promotion of biofortified crops.
- More investments are needed for the research and development of biofortified varieties of different crops. Similarly along with other micronutrients more research work is also needed to be done to solve the issue of Fe deficiency.
- Research work should be planned to identify and develop biofortified varieties of key staple crops, such as rice, maize, and legumes, that are adapted to local agroecological conditions and consumer preferences.
- To accelerate the development, commercialization, and dissemination of biofortified crop varieties there is a need to develop multistakeholder partnership, capacity building and public-private partnership.
- SAARC Member States needs to invest on priority basis in their national breeding programs in the research to develop biofortified varieties with multiple attributes like improved nutrition, yield, and stress-tolerant.

2. Policy:

- Enforce stringent food safety and quality requirements to ensure the safety and nutritional value of biofortified foods.
- Consumers education and awareness building program focussing on the nutritional benefits of biofortified crops should be developed on mass media, social media, and community outreach programs. National Nutrition Policy of all SAARC Member States should give priority to biofortification as a strategy to improve the nutritional value of staple foods.
- Priority should be given on biofortified seed access to farmers by improving distribution networks, and collaboration with seed companies to ensure seed availability.

- Efforts should be made for product certification and market linkages for biofortified products to build consumer trust and ensure authenticity.
- Develop supportive policies that support growers and processors, such as subsidies on seeds and fertilizers, tax incentives, and grants for packaging and marketing of biofortified products.
- Develop production zones for biofortified crops, such as Quality Protein Maize (QPM), Zinc enriched wheat and link them with market actors.
- Mainstreaming of biofortification Research and Development in the Agricultural policies of all SAARC Member States.
- All SAARC Member State governments should integrate biofortified crops into their national food and nutrition security strategies, public procurement systems, school feeding programs and food aid programs.
- Policy support is needed from the governments of all SAARC Member States for the promotion of biofortified crops on large scale.
- Adequate financial support is needed from the governments of all SAARC Member States for further research and development in this sector.

3. Seed:

- There is need of strengthening of seed system of biofortified crops in all SAARC Members States.
- Strengthen early generation seed distribution to private sector seed companies for quick multiplication of biofortified varieties of different crops.

4. Capacity building:

- There is need of capacity building of different stakeholders.
- Involvement of International and local NGO,s for advocacy and financial support for the promotion of biofortified crops.
- Financial support are needed for farmers and different organizations involved in this sector for quick dissemination of biofortified crops at farm level.

5. Marketing:

- Emphasis should be given on the supply and value chain development of biofortified crops.
- Commercialization of biofortified crops products by special branding, proper milling, processing and retailing are needed to popularize the products developed from bio- fortified crops.

Meeting Agenda

Regional Consultation Meeting on "Development and Dissemination of Biofortified varieties of different Crops in the SAARC Member States"

02-04 September, 2024

Organized by SAARC Agriculture Centre (SAC)

Venue: virtual

Program Schedule

Meeting Time: Sep 2 to 4, 2024 (10:00 am to 13:30 pm, every day, Bangladesh Time

Join Zoom Meeting link

https://us02web.zoom.us/j/84232589126

Meeting ID: 842 3258 9126

Day 1 (2 September 2024)- Inaugural M.C: AHM Taslima, STO, SAC

Time	**Program**	**Responsibility**
	Inaugural Session	
10:00-10:10	Welcome address	Dr. Md. Harunur Rashid, Director, SAC
10:10-10:20	Introduction of the participants	
10:20-10:30	Consultation meeting objectives and overview of the program	Dr Sikander Khan Tanveer Senior Program Specialist (Crops), SAC
10:30-10:45	Importance of proper nutrition for Human health.	Pro. Dr. Khalida Islam Keynote Speaker Chairman, Institute of Nutrition and Food Sciences Dhaka University, Bangladesh.
10:45-10:50	Remarks by Guest of Honor	Mr. Ravinder Grover, Global Business Manager, HarvestPlus - Solutions
10:50-10:55	Remarks by Guest of Honor	Mr. Jamal Uddin Ahmed Director (ARD&SDF), SAARC Secretariat, Nepal
10:55-11:05	Remarks by Special Guest	Ambassador Mr. Abdul Motaleb Sarkar, Director General (SAARC and BIMSTEC) MOFA, Dhaka Bangladesh
11:05-11:15	Remarks by the Chief Guest	Dr. Nazmun Nahar Karim, Executive Chairman, BARC
11:15-11:20	**Break**	

Technical Session: 01, Session Chair (Dr. Md. Harunur Rashid, Director, SAC) Rapporteurs: SPS (PSPD) and SPO (NRM)		
Country Paper Presentations		
11:20-11:40	Country paper presentation of Bangladesh	Dr. Md. Abdus Salam, Member Director (Crops), BARC
11:40-12:00	Country paper presentation of Bhutan	
12:00-12:20	Country paper presentation of Maldives	
12:20-13:00	Open Discussions	
Technical Session: 02, Session Chair: Dr. Md. Harunur Rashid, Director, SAC) Rapporteurs: SPS (PSPD) and SPO (NRM)		
13:00-13:15	Biofortified Rice-experience of IRRI	Dr Hummanth Bhindari Country Representative for Bangladesh and Senior Agricultural Economist IRRI
13:15-13:30	Open discussion	
Closing of the Day 01		
Day-2 (September 3, 2024) Technical Session-03 (Session Chair: Dr. Md. Abdur Razzaque, Former Executive Chairman , BARC; Rapporteurs: SPS (NRM) and SPS (Livestock)		
Country paper Presentation		
10:00-10:20	Country paper presentation of Nepal	
10:20-10:40	Country paper presentation of Sri Lanka	
10:40-11:00	Country paper presentation of Pakistan	
11:00- 11:30	Open discussion	
11:30- 11:40	Break	
Technical session-04 ;Chair: Professor Dr. Md. Abdur Rahim, Department of Horticulture, Bangladesh Agricultural University; Rapporteurs: STO and SPO (NRM)		
11:40-12:00	Maize Biofortification initiatives by CIMMYT in South Asia	Dr. Abdur Rahman Bashir Seed Systems Specialist Asia CIMMYT Nepal
12:00-12:20	Biofortified wheat varieties production in Punjab-Pakistan.	Dr Javed Ahmad Chief Scientist/Director WRI Ayub Agriculture Research Institute Faisalabad
12:20-12:40	Biofortified Rice varieties in Bangladesh: Ways to impact and policy support	MD. Wahidul Amin Country Coordinator HarvestPlus Bangladesh
12:40-13:00	Open Discussions	
	End of the day	

Day-3 (September 4, 2024)		
Technical Session -05: Session Chair: DrKhandakar Md Iftekharuddaula, CSO and Head Plant Breeding Division, BRRI, Gazipur), Rapporteurs: STO and SPS (Livestock)		
10:00-10:20	Wheat Biofortification at CIMMYT	Dr Velu Govindan Senior Scientist, Wheat Breeding Global Wheat Program CIMMYT, Mexico
10:20-10:30	Bio-fortification in potato & sweet potato	Dr Arif Hussain Khan BAU/ Dr. Debashish Chanda, CIP, Bangladesh/ Director, TCRC, BARI
10:30-10:40	Application of micronutrients on the productivity and nutrition of different crops.	Dr Tariq Sultan Director Land Resources Research Institute NARC Islamabad
10:40-11:00	Akbar-2019, a success story of Biofortified wheat in Pakistan	Dr Yaqub Mujahid Country Manager HarvestPlus Pakistan
11:00- 11:20	Tea Break	
11:20- 12:00	• Strategy • Action plan • Recommendation	Dr. Sikander Khan Tanveer, SPS (Crops), SAC
12:00- 12:30	Recommendations / Conclusion	
12:30- 13:00	• Remarks from the participants • Closing remarks	Dr. Md. Harunur Rashid Director SAARC Agriculture Centre Dhaka

Participants List

Regional Consultation Meeting on "Development and Dissemination of Biofortified varieties of different Crops in the SAARC Member States"

02-04 September, 2024

Organized by SAARC Agriculture Centre (SAC)

Venue: Virtual

List of participants

Sl. No	Name	Designation with Address	Email	Contact No
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15..	Mr. Ravinder Grover	Global Business Manager, HarvestPlus - Solutions	r.grover@harvestplus.solutions	
16	Mr. Jamal Uddin Ahmed	Director (ARD&SDF), SAARC Secretariat, Nepal	dirban@saarc.sac.org	+01319674061
	Special Guest			
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	Chief Guest			
18.	Ambassador Mr. Abdul Motaleb Sarker	Director General (SAARC and BIMSTEC) MOFA, Dhaka Bangladesh	dgsaarc@mofa.gov.bd	01888010200
	Chair of Session			
19.	Dr. Md. Harunur	Rashid, Director, SAC)	director@sac.org.bd	0 1716950421
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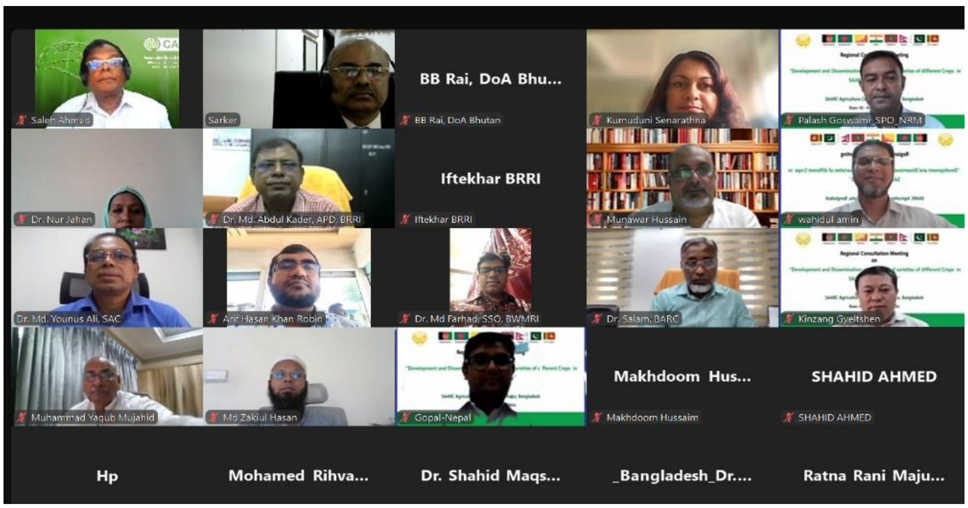
Photo Gallery


SAARC
Maldives
Nepal
Pakistan
Sri Lanka
Meeting
varieties of different Crops in
Bangladesh


SAARC
Afghanistan
Pakistan
Sri Lanka
"Development and
of different Crops in
SAARC
Dr. Md. Harunur Rashid, Director, NATP, BARC


SAARC
Afghanistan
Bangladesh
Bhutan
Maldives
Nepal
Pakistan
Sri Lanka
"Development and
of different Crops in
SAARC
Dr. Sikander Khan Tanveer


Definition of Nutrition and Health
Nutrition refers to the process of consuming and utilizing food for growth, maintenance, and repair of our bodies.
Health encompasses physical, mental, and social well-being, and proper nutrition plays a pivotal role in maintaining all aspects of health.
Physical Well-being
A balanced diet fuels our bodies, strengthens our immune system, and helps prevent diseases.
Mental Well-being
Nutrition impacts brain function and mood. Deficiencies can lead to fatigue, depression, and cognitive decline.
Social Well-being
Sharing meals fosters social connections and contributes to a sense of community.


BB Rai, DoA Bhu...
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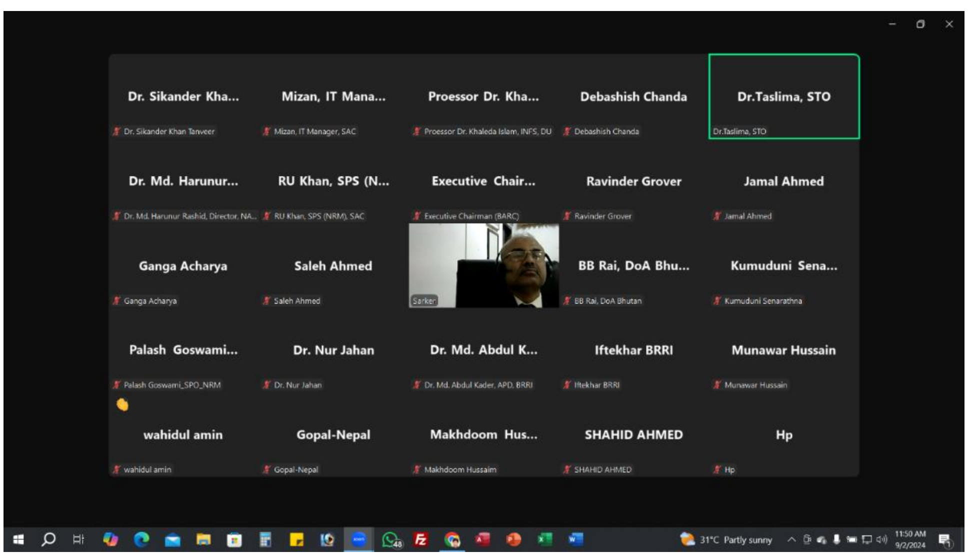
Dr. Sikander Kha...
Mizan, IT Mana...
Proessor Dr. Kha...
Debashish Chanda
Dr.Taslima, STO
Dr. Md. Harunur...
RU Khan, SPS (N...
Executive Chair...
Ravinder Grover
Jamal Ahmed
Ganga Acharya
Saleh Ahmed
BB Rai, DoA Bhu...
Kumuduni Sena...
Palash Goswami...
Dr. Nur Jahan
Dr. Md. Abdul K...
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Makhdoom Hus...
SHAHID AHMED
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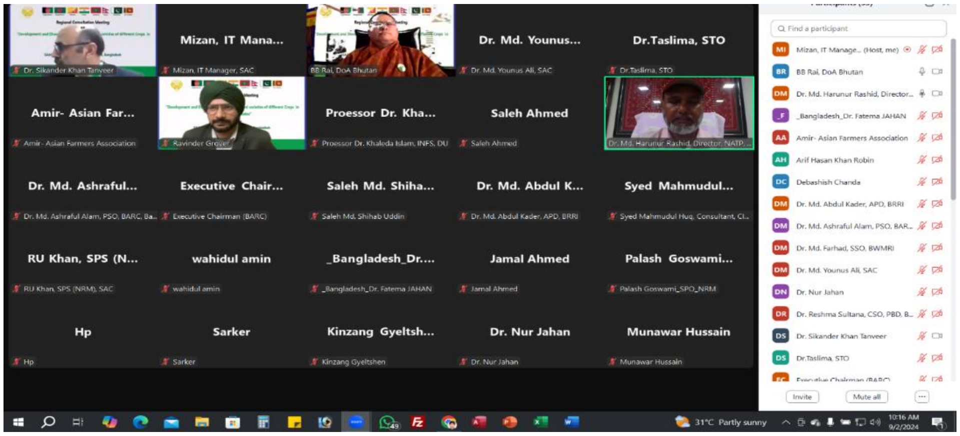
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Dr.Taslima, STO
Amir- Asian Far...
Proessor Dr. Kha...
Saleh Ahmed
Dr. Md. Ashraful...
Executive Chair...
Saleh Md. Shiha...
Dr. Md. Abdul K...
Syed Mahmudul...
RU Khan, SPS (N...
wahidul amin
_Bangladesh_Dr....
Jamal Ahmed
Palash Goswami...
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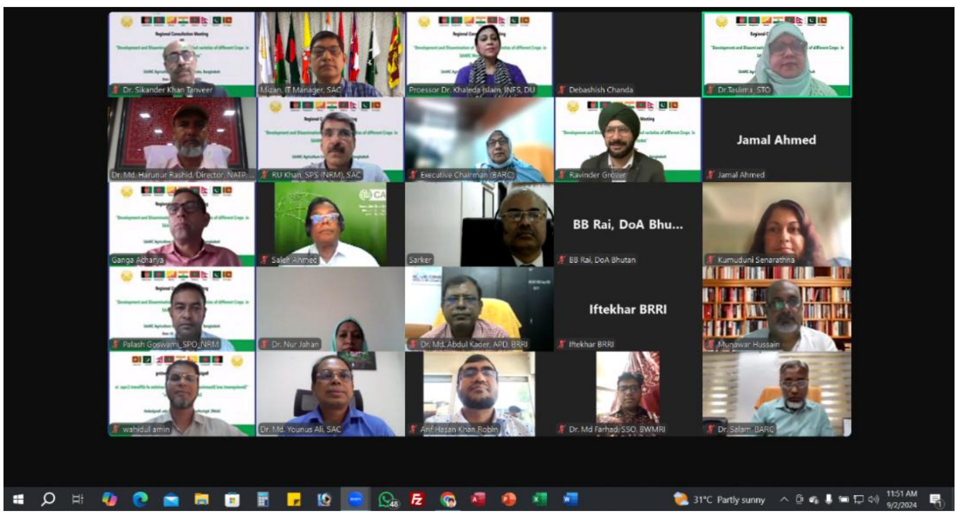
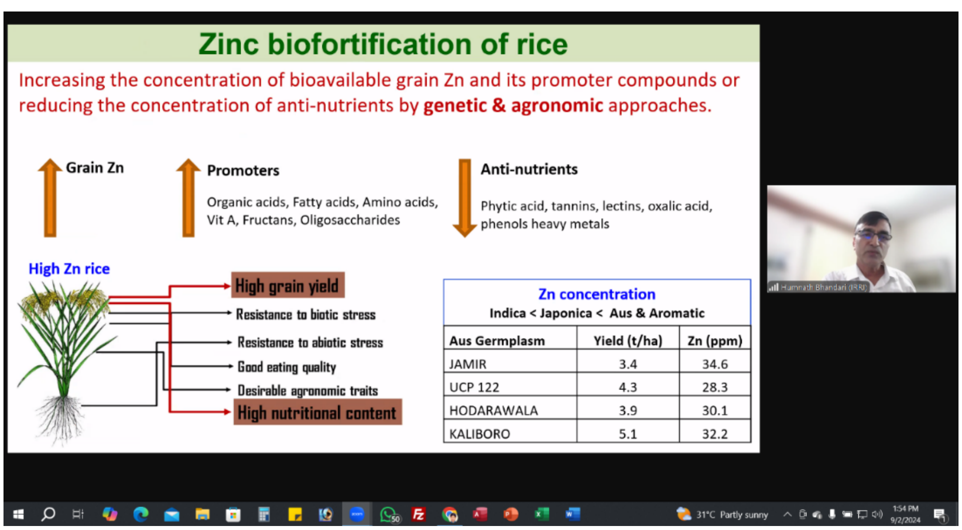
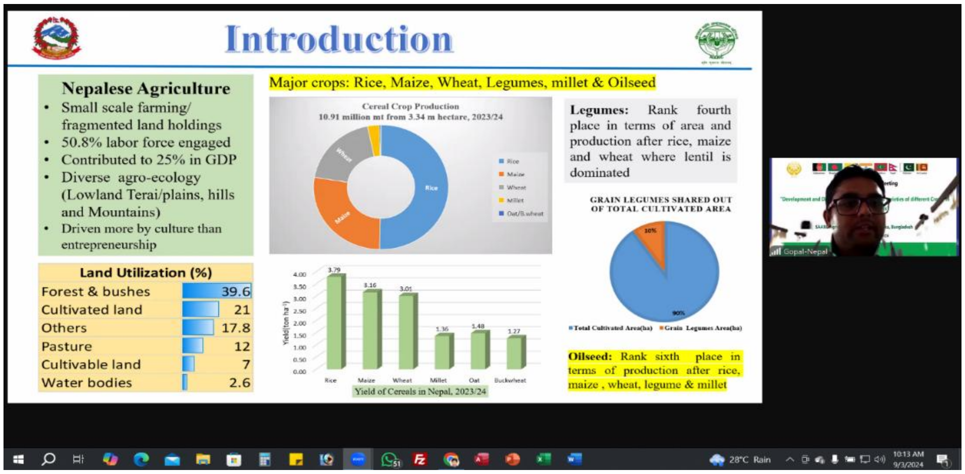
Sarker
Kinzang Gyeltsh...
Dr. Nur Jahan
Munawar Hussain


Jamal Ahmed
BB Rai, DoA Bhu...
Iftekhar BRRI

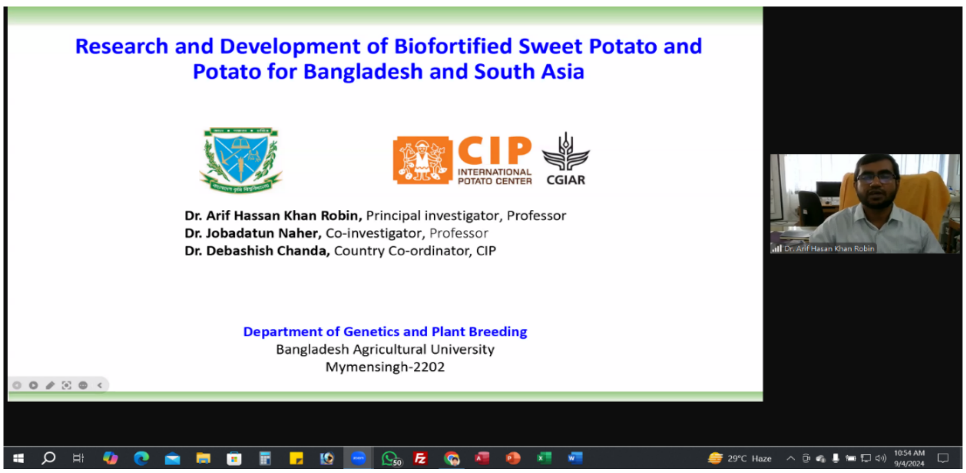

Zinc biofortification of rice
Increasing the concentration of bioavailable grain Zn and its promoter compounds or reducing the concentration of anti-nutrients by genetic & agronomic approaches.
Grain Zn
Promoters
Organic acids, Fatty acids, Amino acids, Vit A, Fructans, Oligosaccharides
Anti-nutrients
Phytic acid, tannins, lectins, oxalic acid, phenols heavy metals
High Zn rice
High grain yield
Resistance to biotic stress
Resistance to abiotic stress
Good eating quality
Desirable agronomic traits
High nutritional content
Zn concentration
Indica < Japonica < Aus & Aromatic
Aus Germplasm | Yield (t/ha) | Zn (ppm)
JAMIR | 3.4 | 34.6
UCP 122 | 4.3 | 28.3
HODARAWALA | 3.9 | 30.1
KALIBORO | 5.1 | 32.2


Introduction
Nepalese Agriculture
Small scale farming/ fragmented land holdings
50.8% labor force engaged
Contributed to 25% in GDP
Diverse agro-ecology (Lowland Terai/plains, hills and Mountains)
Driven more by culture than entrepreneurship
Land Utilization (%)
Forest & bushes 39.6
Cultivated land 21
Others 17.8
Pasture 12
Cultivable land 7
Water bodies 2.6
Major crops: Rice, Maize, Wheat, Legumes, millet & Oilseed
Cereal Crop Production
10.91 million mt from 3.34 m hectare, 2023/24
Yield of Cereals in Nepal, 2023/24
Legumes: Rank fourth place in terms of area and production after rice, maize and wheat where lentil is dominated
GRAIN LEGUMES SHARED OUT OF TOTAL CULTIVATED AREA
Oilseed: Rank sixth place in terms of production after rice, maize , wheat, legume & millet

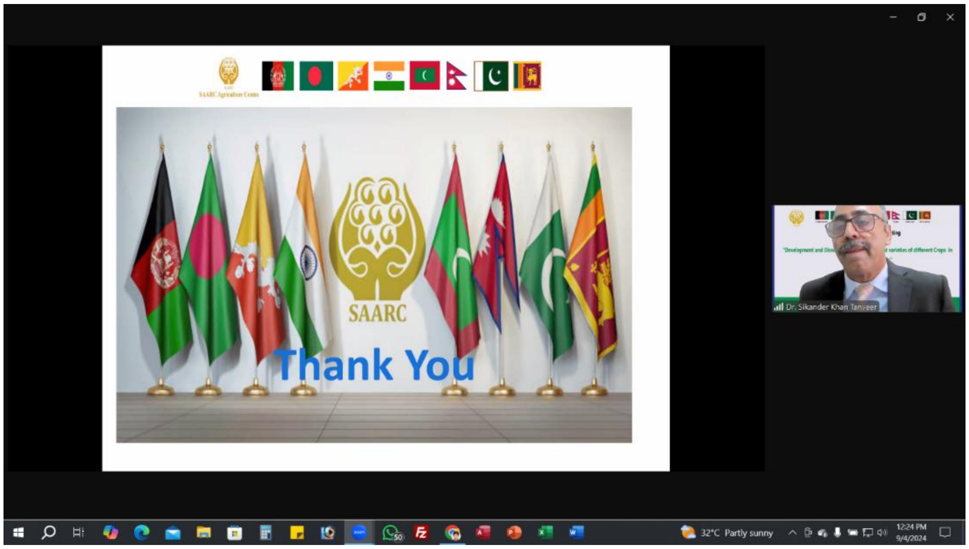

Maize biofortification initiatives by CIMMYT in South Asia
SAARC Online meeting- 03 Sept 2024
Dr. AbduRahman Beshir
Seed System Specialist, Asia
CIMMYT- South Asia Regional Office- Nepal
CIMMYT


Biofortified Rice Varieties in Bangladesh: Ways to Impact and Policy Support
September 03, 2024
Md. Wahidul Amin
Country Coordinator
HarvestPlus.org
HarvestPlus
IFPRI
CGIAR


Improved Food and Nutrition security
Farmers in South Asia supply food to over
1.8 BILLION PEOPLE
approximately 24% of the global population
from less than 15% of the world's agricultural land.
Nutrition indicators in South Asia
Children under 5:
Stunting – 33%
Wasting – 15%
Underweight – 28%
Anemia – 55%
Overweight – 2.5%
Total population:
Undernourished – 14%
Women, 15–49
Anemia– 50%
• Wheat is grown over 40 M ha in South Asia
Velu Govindan, Senior Wheat Breeder, CIMMYT
Velu@cgiar.org
CIMMYT


Research and Development of Biofortified Sweet Potato and Potato for Bangladesh and South Asia
CIP INTERNATIONAL POTATO CENTER
CGIAR
Dr. Arif Hassan Khan Robin, Principal investigator, Professor
Dr. Jobadatun Naher, Co-investigator, Professor
Dr. Debashish Chanda, Country Co-ordinator, CIP
Department of Genetics and Plant Breeding
Bangladesh Agricultural University
Mymensingh-2202


Mizan, IT Mana...
Dr. Sikander Kh...
Debashish Chan...
Gopal-Nepal
SAARC
Afghanistan
Bangladesh
Pakistan
Sri Lanka
"Development and Disseminat
f different Crops in
SAARC Agriculture Ce
desh


SAARC
Thank You
Dr. Sikander Khan Tanveer
32°C Partly sunny
12:24 PM
9/4/2024

SAARC

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