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Alleviating malnutrition with biofortified wheat: past, present status and future challenges

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Abstract

Wheat is a major field crop grown worldwide and plays a critical role in handling aspects of malnutrition and hidden hunger through biofortified varieties of wheat crops, especially in the cereal-based community. Many initiatives were started by FAO and WHO, also the UN sustainable development goal to achieve Zero Hunger by 2030. In this review, with the same idea of alleviating malnutrition with biofortification, especially in staple crops like wheat. Here we try to present before the reader, the past and present status of biofortified wheat and its varieties, also future challenges, along with its role in tackling malnutrition. This review will provide you the insight idea about all the aspects of biofortified wheat, to provide food security to the ever-increasing population.

Keywords biofortification, malnutrition, wheat, zero hunger

Introduction

A major agronomic crop cultivated worldwide is Wheat (*Triticum aestivum* L.), a high lifetime self-pollinated crop belonging to the Poaceae family. The crop grows good in arid and semi-arid land or climate [1]. Mohammadijoo et al., [2] stated that wheat grains constitute a dominant portion of a standard diet consumed by the global population, supplying approximately 35% of their total food. The researchers Muslim et al., [3] described the crop is considered an incredible contributor to global food security by its characteristics of adapting to diverse environmental strains and climatic conditions. The work of Debasis and Khurana [4] reported that most of the wheat harvested throughout the World, about 95% of which is hexaploid, is used widely to prepare various baked consumables. Therefore, the nutritional concentrations and composition of grain considerably influence the health of humans. Even though the crop has the potential for vital nutrients and calorie enrichment, most varieties of crops grown nowadays are deficient in nutrients. Remarkably, deficiency occurs with Zinc (Zn) and Iron (Fe) [5]. Moreover, during the milling process, a considerable amount of these minerals is wasted. It results in malnutrition due to the lack of these minerals in the human diet.

In 2020, the Global Hunger Index continued to increase due to the COVID-19 pandemic globally. Undernourishment prevalence increased from 8.4 to 9.9 percent from 2019 to 2020. Previously, it remained notably constant from 2014 to 2019. Then, a challenge is intensified to achieve the Zero Hunger target by 2030. The 2020 year's estimate ranges from 9.2 to 10.4 percent. Depending on the estimation, it is projected to reflect the uncertainties in the assessments [6]. Globally, predominantly in Asia and the African region, nearly 2 billion people have suffered from malnutrition caused by a cereal-based diet [7]. It is forecasted that the condition will be even more severe than expected soon if no implementation of urgent remedial strategies is done, as the global population is increasing alarmingly. All kinds of malnutrition remain a global challenge. Although it is impossible to interpret the impact of the COVID-19 pandemic completely due to data restrictions, it was estimated that in 2020, 22.0% (149.2 million) of children aged under 5 years were suffering from stunting, 6.7% (45.4 million) were affected by wasting, and 5.7% (38.9 million) were overweight. Due to the effects of the pandemic, particularly the stunting and wasting, actual figures are probably to be more than estimated [6].

To improve nutrient contents in under-nutritive wheat varieties, several researchers, scientists, and research area experts have done a lot of research in finding the techniques and methods. Although several techniques have been proposed, they are not sustainable for combating malnutrition and are cost-effective [8-10]. Agronomic biofortification, fortification, dietary diversification, and supplementation are efficient techniques for solving the problem. To boost their value of nutrition sustainably and economically, biofortification of breeding crops is utilized [11]. The biofortification process is implemented through genetic engineering or conventional selective breeding. Due to a few major impediments to the potential improvement of soil nutrients, mineral deficiency generally occurs in cereal crops like wheat. For this reason, fortification is essential for wheat crops [12]. The repeated usage of weak fertilizers lacking mineral concentrations has undesirably impacted the nutrient availability of wheat crops [13]. Concerning these issues, biofortification is considered a feasible technique to deliver the necessary micronutrients to populations with insufficient access to various diets [14-15]. The process can be done through different approaches to wheat crops utilizing direct foliar or soil application of fertilizers through the Agronomic approach. The Genomic method comprises a genomic section, Quantitative Trait Loci (QTL) mapping, and Marker Assisted Selection (MAS).

The studies of Dempewolf et al., [16] and Ahmadi et al., [17] reported that as numerous wheat relatives of wild existence are still yet to be exploited, the genetic improvement of wheat can exceedingly be attained soon, focusing on programs of crop breeding. Through plant breeding, biofortification can develop the staple foods' content of nutritions that deprived people consume as an essential diet. It provides comparatively cost-effective, cheap, sustainable, and lasting resources to deliver them with more micronutrients. The proposed method can aid sustain a better nutritional status. Likewise, it can decrease the number of severely malnourished people who necessitate complementary intervention treatments. At the same time, biofortification provides viable reachability of fortified foods and supplements to rural people who are undernourished and those who may not have sufficient access commercially.

In July 2003, the Consultative Group on International Agricultural Research (GGIAR) introduced the 'HarvestPlus', an international network program on biofortification to capitalize as a tool for public health on agricultural research. The technology realm development provides us with novel scopes that can integrate natural variation, achievements of genomic, and applications of agronomic to elevate protein, iron, and zinc contents in wheat grains. That may help alleviate the hidden hunger causes of malnutrition, especially amongst the cereal-based population. This study aims to understand the past and present statuses and future biofortification challenges, especially in varieties of wheat crops, and their role in alleviating malnutrition.

Past status

Much progress has been made in the field of wheat biofortification, where such vital questions as the uptake of Zn and Fe, and their accumulation in grains. Genetic causes behind this accumulation, micro¬nutrients' bioavailability and their genetic variation at different wheat ploidy levels have been investigated. Several scientists have determined that the transport of micronutrients in plants, their translocation, and their bioavailability rely on growth conditions, and genetic variations are controlled by several genes [18-20]. Different transporters are employed in signaling Fe and Zn mobilization [21-22]. The bioavailability of iron and zinc is less dependent on their aleurone layer accumula¬tion than the loss when milling, despite their high total content in grain [23]. But they were made unavailable because of the binding with phytates [24]. Although, crop improvement strategies through various plant breeding are dependent on the wheat genetic variation for the micronutrient content. However, wheat ploidy and evolution have their roles in shaping the contents of iron and zinc. Cakmak et al., [25] emphasized the A and D genomes' contributions in developing zinc efficiency and determining high Zinc efficiency in hexaploids compared to tetraploids. A team of researchers has shown that wild relatives of commercial wheat varieties possess a higher Zinc and Iron content in grain comparatively than those cultivated from wheat cultivars [18, 26]. In wild relatives, especially in wheat germplasm, there is enormous variability in iron and zinc contents. But they are not utilized to their full extent. To develop Fe and Zn enrich wheat varieties, pre-breeding efficacy has been analyzed in the wild relatives' potential through the last decade.

Moreover, the researchers Bernardo [27], Balyan et al., [28], and Borrill et al., [29] discussed the utilization of the quantitative trait loci (QTL) and next-generation sequencing techniques in the breeding program had made substantial progress in augmenting the wheat iron, zinc and protein content on the emergence of the molecular markers system. Initially, Joppa et al., [30] proposed and then, Uauy et al., [31] validated that in a variant of wild emmer wheat (*Triticum turgidum* ssp. *dicoccoides*), the chromosome 6BS located with GPC-B1 gene is a significant QTL linked with an upraised Fe, Zn and protein content. Distelfeld et al., [32] stated that the Xuhw89 is one of the tightly associated SSR markers to the GPC-B1 locus. Although several molecular and physiological strategies are used to determine the significance of this gene and related transcription factors in *T. turgidum* accessions, their non-functionality in *T. durum* and *T. aestivum* posed new challenges for the proper utilization of the trait. Thus, gene introgression from wild emmer wheat leading to chromosomal substitution lines was proven to be a sustainable approach Cakmak et al., [33].

Two different QTLs on 2A and 7A chromosomes are determined in some noteworthy mapping studies by Tiwari et al., [34], which are allied with the grains' iron concentrations, and one QTL on the 7A chromosome is linked with the grain Zinc content. On the other hand, according to Velu et al., [35], chromosome 5B is accumulated with boosted zinc, iron, copper, and magnesium concentrations. Another scientist, Genc et al., [36], brought to light that 1 QTL and 4 QTLs were associated with the grains' iron and zinc concentrations, respectively, in a doubled haploid population. In addition, researchers Avni et al., [37] focussed on research on silencing homeo and paralogous genes of GPC-B1to regulate the Zn and Fe concentration in wheat grains. Some scientists, Akhunov et al., [38], Chen et al., [39], Edae et al., [40] and Saintenac et al., [41], stated that with the advancement of molecular marker technologies over the last several years, SNP markers are also being used in this direction to perform association mapping of these crucial traits with different wheat genotypes. The determined genes and linked molecular markers can facilitate greatly marker-assisted breeding programs. However, some genes like GPC-B1, responsible for a high Fe, Zn, and protein content, are simultaneously associated with a decrease in yield.

To be concern with the issues of undernourishment and hidden hunger, the Consultative Group on International Agricultural Research (GGIAR), a global network program on biofortification, established a project, namely 'HarvestPlus' in 2003. They have targeted more than 3000 varieties for iron and zinc screening under different environmental and growth conditions that may be involved in further wheat improvement plans. Potential germplasm, including wheat ancestors like emmer wheat, were engaged in a breeding program¬mes to transfer a high micronutrient trait to selected genotypes, making it more effective for quality consumption [18, 42].

Present status

Wheat grain is essential in the human diet, as it supplies numerous nutrients and minerals. Hence, for global food security, wheat production must double by 2050 [43]. Some extensive research carried out imposing the importance of screening wheat germplasm for its mineral concentrations of Fe, Zn, Se, Mn, and Mg by Esfandiari E. et al., [44], Gupta P.K. et al., [45], vitamins by Kumar et al., [46] and proteins by Aslam et al., [47]. Phytic acid plays an integral part in screening because it limits the bioavailability of nutrients [48-49]. Breeding, agronomic and genetic solutions have been dissected in recent years, aiming to attain the implementation of biofortification. According to Bouis et al., [50], Magallanes-López et al., [51], the origin for growing a combative bread variant wheat cultivars with 40 percent higher Zn concentration is successfully implemented in South Asia through the perseverance of the Harvest Plus project and gene bank of Wheat Improvement Center (CIMMYT), and the International Maize. Following this process, five biofortified wheat cultivars have been released, cv. Zinc Shakti (Chitra), WB-02 and HPBW-01 in India, cv. Bari Gom 33 in Bangladesh and cv. Zincol 2016 in Pakistan. Gupta et al., [45] reported that in a set of high-yielding genotypes, iron content increased by 20 to 60 mg kg^{-1}, and zinc content increased from figure 15 to 35 mg kg^{-1}. The results proved that there are sufficient genetic variations explorable that exist within the wheat gene pool for substantial increases in grain micronutrient concentrations. Moreover, Khan et al., [52], Lockyer et al., [53] reported up to 3-fold enrichment of Zn and Fe minerals content in wheat grains through foliar and soil application methods. But the proper utilization and dissemination of biofortified wheat among the people have been hindered due to a lack of awareness and some safety issues. Therefore, among farmers, creating awareness will contribute to meeting the micronutrient concentration targets to fight unseen hunger in the emerging World. The Organization's strategic framework created the FAO Nutrition Strategy to reduce malnutrition by use of competent, embracive, flexible, and sustainable agrifood systems within a limited time frame. To ensure healthy diets for everyone, the Nutrition Strategy seeks to tackle malnutrition in several strategic implementations by rushing strategies and activities across food and agriculture systems. FAO is forecasting to conduce in achieving the 2030 Agenda for Sustainable Development, making sure none is left non-beneficial employing this mission. The mission aims to leverage all FAO expertise in various aspects of food systems by employing a people-centered approach. The FAO Nutrition Strategy is in pursuit of improving diets and raising levels of nutrition via the following measures.

1. To coordinate the UN Decade of Nutritional Action and also direct its plan of actions associated with the WHO (World Health Organization), in alliance with crucial collaborators; endorse and assist step in the review of the 2nd International Conference on Nutrition (ICN2) held on 2014.
2. Encouraging the obligations of the Committee on World Food Security (CFS) Nutrition Voluntary Guidelines on food systems for nutritional values.
3. To improve nutritional values in diet plans, food composition, food intake benchmarks, and dietary based on food recommendations using food-based research and releasing evidence, information and suggestions.
4. Subsidise international norms and recommendations by employing the scientific directions to the Codex Alimentarius in association with World Health Organisation (WHO) concerning the primary human nutritional necessities.
5. To evaluate and monitor the nutrition situation by strengthening the potential of countries, analyzing options, and implementing agriculturally the policies of food systems and programs positively affecting nutritional values.
6. Boosting effective nutrition education and consumer awareness among national and inhabitants by supplying tools, directions, and support and using schools and agricultural extension services.
7. To evaluate, then improve the market and value-chain strategies for a better nutritional diet by developing and providing policy and program decision-makers with tools, with native-definite methods projecting the trades and food products of Geographical Indications.
8. To reduce food waste and loss in agrifood systems by providing information, indication, and direction, enhancing them as an efficient frontier in suggesting the hale and hearty diets required for the increasing population globally.

Role of biofortified wheat in alleviating malnutrition

Wheat has gained a tremendous position among cereal crops because of its nutritional value. Due to wheat dough's viscoelasticity, wheat flour has become a necessary ingredient in bread and other foodstuffs. Therefore, wheat is the primary nutrition source in developing countries. Researchers confirm that the presence of micronutrient enhancement traits in the wheat genome facilitates the improvement of nutrient content in genotypes with no yield loss [20, 31]. Implementing plant breeding progress is one of the appropriate approaches to eradicating malnutrition. However, micronutrient bioavailability is a major concern [54]. Although many researchers are working on increasing the nutrient quality of wheat grains, more efforts are necessary to overcome the challenge of nutritional disorders and malnutrition.

Malnutrition types

Adapting to an unbalanced diet leads to malnutrition in the human lifestyle. At some point, the utmost of the global population gets affected from infancy to elderliness throughout its lifecycle. Every single nation experiences enormous types of malnutrition. All geographies, age groups, and people are affected without any discrimination as rich or poor. Figure 1 depicts the various types of malnutrition as listed below:

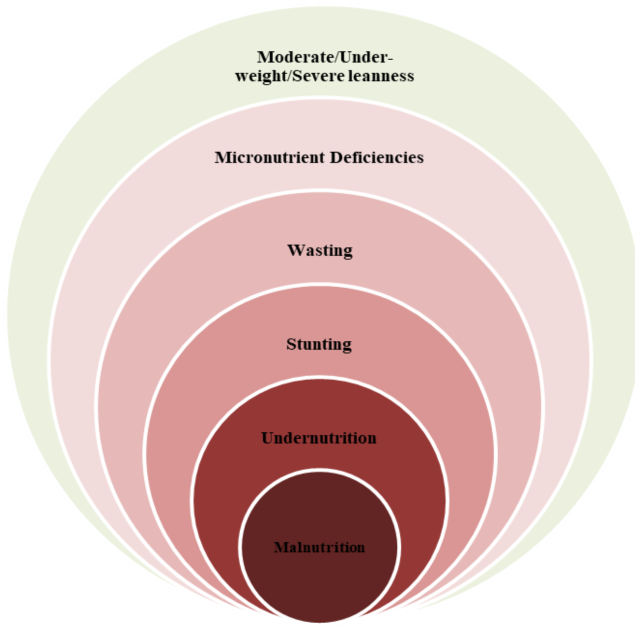

Figure 1. Different forms of malnutrition

1. Undernourishment: Nutritions deficiency due to non-consumption of adequate nutrition.
2. Stunting: Causing shorter height children within five years of age due to inadequate food and health care access.
3. Wasting: Lower body mass relative to their height in children within five years of age because of severe disease or food shortages.
4. Deficiencies of micronutrients: Insufficient food intake, poor nutrient absorption, or intake of supplementary minerals or vitamins caused suboptimal nutritional status.
5. Moderate/Under-weight/Severe leanness: BMI (Body Mass Index)

Malnutrition status

Malnutrition leads to increased stunted physical growth and mental health, disability, morbidity, and suppressed social and economical development of the nations. According to a UN new report, because of the COVID-19 pandemic, malnutrition figures and world hunger rates get worse radically last year. Additionally, the report points out that the malnutrition population rate increased to nearly 768 million as of last year, which is equivalent to 10% of the global population. Compared to 2019, that was increased by 118 million. In Africa, 21% of its population, i.e. 282 million of people, are undernourished. The report stated that at least by 2030, the UN Sustainable Development Goal of Zero Hunger would be unexploited by more or less of around 660 million people [55]. Out of the 768 million global undernourished people, Asia possesses 418 million, Africa holds 282 million, and Latin America and the Caribbean have 60 million. But the sharpest rise in hunger was in Africa, where the estimated prevalence of under nourishment at 21 percent of the population is more than double that of any other region [56] and to overcome these challenges, minerals, vitamins, and protein are required to eradicate the problems of hidden hunger, especially among children living in developing countries. To understand it better, we have discussed some of the roles and their deficiency symptoms below:

Protein

It provides essential amino acids required for tissue growth and repair. Some of the serious problems of protein deficiency include disorderly physical functioning, retarded cerebral growth, and or rather fatality. Protein deficiency in the human food diet can cause marasmus disorders and kwashiorkor.

Lysine

It is an α- an amino acid essential in the biosynthesis of protein. In addition, act as an antecedent for metabolic regulators and numerous neurotransmitters. Lysine deficiency can cause anemia, nausea, dizziness, fatigue, loss of appetite, reproductive tissue regression, and retarded growth.

Tryptophan

It is also an α- amino acid and a building block of proteins and acts as the antecedent for regulators of metabolic pathways and several neurotransmitters. Its deficiency creates depression, anxiety, and impatience. Tryptophan deficiency has primary symptoms like notable bodyweight loss and retarded growth among children.

Iron

It is a mineral element highly essential for the proper working of muscle and brain tissues. It serves as the carrier of oxygen from the lungs to various body tissues employing red blood cells called hemoglobin. The deficiency of iron in the human diet can cause severe anemia. The inadequacy of Fe also tends to retarded human growth and progress.

Zinc

It is a trace mineral element that is essential for around 300 necessary enzymes in humans. It also plays a vital role in regulating the degradation and synthesis of carbohydrates, lipids, nucleic acids, and proteins. A deficiency of zinc causes loss of appetite, increased susceptibility to infections, impaired immune function, and retardation in growth. In 2015, United Nations (UN), 2015, set 17 Sustainable Development Goals (SDGs) to develop an efficient strategy for attaining present human necessities without affecting the ability of future generations humans to meet their needs in the future. Fundamentally, SDGs purpose is to eradicate hunger, malnutrition, and extreme poverty, by so preserve the World, and making sure that all people experience prosperity and peace before 2030. Out of 17, 12 goal indicators are associated with nutritional value. SDGs are associated with ICAR to develop biofortified high-yielding crop breeds [57].

Future challenges

Biofortification implementation is a hopeful crop-based approach that has a high capability of eliminating micronutrient malnutrition among the population. Presently it is a challenging bid that in the recent biofortification approach, a massive exploration hole exists. A thorough learning of the mineral mechanisms of translocation from soil to seed is lacking in most food crops such as wheat. Therefore, progressive learning in the fundamental knowledge of the rate-limiting stages in the acquisition of micronutrients and organic processes in the soil-plant system should be created. In addition, Before promising the biofortified grains obtainable to end consumers for consumption, it is indeed to analyze the safety issues of the grains. There exists a wide knowledge gap to be explored in the micronutrient bioavailability in food grains and distribution patterns of minerals in plant systems. While the selective removal processing of exterior tissues, the loss of micronutrients is also not analyzed and needs to be explored. Near future, researchers can undertake studies to develop advanced strategies in the upgrading methodology and play a vital role in the parts enrichment process. A few of the significant strategies are transferring genes to increase Fe and Zn concentrations throughout molecular cytogenetics, manipulating phytic acid levels to improve bioavailability, minimizing micronutrient loss while postharvest processing via minerals' uniform allocation within the grains, etc. In recent years, nanoscale levels of fertilizers are observed as an efficient agro-input for accurate management of micronutrients also at a shallow rate of application. Subsequently, the biofortification process requires strategic utilization of these nano-based micronutrient fertilizers for constraints-free implementation. However, there is a necessity that all crops directly or indirectly associated with micronutrient deficiencies are to be explored. Hence, an integrated approach of biofortification strategies is utilized to boost human health by consuming micronutrient-fortified food products. However, scientists globally raise a few queries on its scientific practicability, farmers and consumers stage adaptive probability, economical feasibility, and production stability before using this strategy efficiently to mitigate the undernourishment of micronutrients [58]. Based on this upbringing, with upgraded policies, counting with nutrition learning, promotion, farming policies, and finally, public awareness, the biofortification program is successful globally. An interdisciplinary research team including human nutrition and crop research would in essence perform to grow the end products with intended nutritional properties. There is also a possibility that the consumers would not like the end product grains as the enrichment of vitamins and micronutrients may have an undesired impact on the taste and color of the end product.

Therefore, for better and quick adoption by consumers, biofortified wheat and other crops should possess satisfactory cooking and sensory characteristics. Besides, the projected level of the yield of the biofortified crop breeds should be assured. Also, the crops' resistance to abiotic and biotic stresses is ensured. Hence, it is required in the future to eliminate malnutrition of micronutrients and ensure food and nutrition for every human in the global population. For that, additional organized stages to grow biofortified wheat crops with appropriate agronomic management options are essential.

CONCLUSION

Biofortification with molecular biology and plant breeding methods in wheat crops made a remarkable contribution in terms of diminishing food malnutrition across the contemporary World. However, the exploration of genetic variability of wild variety wheat germplasm ensures providing an effective solution in increasing nutrients and its bioavailability, and both are crucial issues to be addressed. Climate fluctuations and emerging global warming are impacting the wheat grains' Zn and Fe content negatively. Hence, it is necessary to develop social awareness about the scientific advancements in the usage of improved nutrient-enriched wheat varieties for production. Also, the FAO Nutrition Strategy measures can be implemented effectively to improve diets and raise levels of nutrition. According to available literature, it is clear that biofortification can achieve a successful contribution in reducing malnutrition and hunger rates globally.

Author contributions

V. Verma drafted the manuscript. V. P. Bagde, D. Saran helped with the information collection and improving the draft and contributed equally. R. S. Shukla checked the draft and help in preparing the final draft.

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