JOURNAL OF CURRENT RESEARCH IN FOOD SCIENCE

E-ISSN: 2709-9385
P-ISSN: 2709-9377
JCRFS 2024; 5(1): 18-26
© 2024 JCRFS
www.foodresearchjournal.com
Received: 28-11-2023
Accepted: 10-01-2024

Enhancing agricultural practices for improved nutrition: A comprehensive review

Sachna Shah, Dr. Krishnaja U, Dr. Seeja Thomachan Panjikkaran, Dr. Suman KT and Dr. Sharon CL

Sachna Shah
Ph.D. Scholar, Department of Community Science, College of Agriculture, Vellanikkara, Thrissur, Kerala, India

Dr. Krishnaja U
Assistant Professor, Department of Community Science, College of Agriculture, Vellanikkara, Thrissur, Kerala, India

Dr. Seeja Thomachan Panjikkaran
Associate Professor and Head, Department of Community Science, College of Agriculture, Vellanikkara, Thrissur, Kerala, India

Dr. Suman KT
Professor, Department of Community Science, College of Agriculture, Vellanikkara, Thrissur, Kerala, India

Dr. Sharon CL
Assistant Professor, Department of Community Science, College of Agriculture, Vellanikkara, Thrissur, Kerala, India

Abstract

It is impossible to exaggerate the significance of agriculture to human welfare. In its most basic form, agriculture provides food and nutrition for everyone on the planet. It encompasses not just plant cultivation but also animal husbandry, fisheries, and any activity that takes place along the value chain from production to consumption. Fish, cattle, and cereals were first cultivated and domesticated by ancient tribes thousands of years ago. Important agricultural innovations including irrigation, fertilizers, and selective breeding allowed agriculture to flourish under varied and occasionally arid terrain all over the world, supporting the well-being of local inhabitants. Agriculture has been seen by people for a large portion of history as a means of supplying adequate food to enable survival. The majority of the world's impoverished, who are consequently most susceptible to illness and malnutrition, rely mostly on agriculture for their food production and as their main source of job and money. Development in the agricultural sector has a huge chance to significantly lower the rate of malnutrition and related illnesses. The agriculture sector can play a much stronger role than in the past in improving nutrition outcomes because of its close ties to both the immediate causes of under nutrition (Diets, feeding practices, and health) and its underlying determinants (income, food security, education, access to WASH and health services, and gender equity). A specific framework that was created for the Tackling the Agriculture–Nutrition Disconnect in India (TANDI) project has been used in recent years to envision ways that the agriculture sector may affect nutrition outcomes. This complements the more encompassing "global" concept because it focuses solely on elucidating the connections and dynamics between one industry agriculture and nutrition.

Keywords: Nutrition, agriculture, water, sanitation and hygiene (WASH), malnutrition

Introduction

Throughout history, the primary objective of agriculture has been to combat hunger. This goal has persisted and influenced the objectives of the Green Revolution, which is arguably the most notable accomplishment of modern agriculture. The Green Revolution aimed to increase agricultural productivity and output by investing in science and technology to improve staple crops like rice, wheat, and maize, irrigation, roads, and fertilizer production. Between 1960 and 1990, this set of investments gave almost 1 billion people better access to food and/or a vital source of income (Evenson *et al*., 2006) [34]. Notwithstanding its notable accomplishments in terms of output and efficiency, as well as its role as a supplier of industrial raw materials, one vital role of agriculture has not gotten enough recognition: nutrition. Beyond calories, food has other contents as well. In addition to micronutrients like vitamins and minerals, it provides macronutrients like proteins, lipids, and carbs [1]. In order to attain healthy growth and development, humans require these micronutrients at every stage of their lives, but particularly from conception to age two. People's desire for highly nutritious food is also influenced by its flavour and quality [2, 11]. In addition to providing food, agriculture is a vital source of income for the world's poorest individuals, allowing them to afford a variety of nutritious foods, medical care, and education [10, 12, 13]. It influences food prices and gender roles, among many other ways that it is connected to nutrition. Despite these intractable links between agriculture and nutrition, the global community has historically been slow to get on board in expanding its vision of what agriculture can really do. Acting inaction has incredibly dire consequences. As per (FAO *et al*. 2018) [37], 821 million individuals suffered from undernourishment in 2017. 151 million children under the age of five worldwide suffer from stunting, which is defined as being too short for one's age (FAO *et al*., 2018) [37]. This amounts to more than one in five children. Twenty-one million more children suffered from wasting, a condition in which their body

Correspondence
Sachna Shah
Ph.D. Scholar, Department of Community Science, College of Agriculture, Vellanikkara, Thrissur, Kerala, India

mass was abnormally low. According to FAO *et al*. (2018) [37], 33% of women who were of reproductive age had anemia. Furthermore, inadequate nutrition has long-term effects that affect generations. According to Alderman *et al*. (2006), [22]. Children who are malnourished at an early age start school later, finish fewer grade levels later in childhood, and earn less money as adults (Behrman *et al*., 2004; Maluccio *et al*., 2009) [24, 57]. The cycle continues when undernourished women give birth to undernourished offspring. According to FAO (2011) [36], and ILO (2017) [45], 7.6 billion people are fed by agriculture, and 69% of people in low-income countries work in the sector. As such, it possesses a great deal of unrealized potential to positively influence nutrition [3, 4, 5]. To close this gap, people, groups, and communities have started working harder to make the connection between nutrition and agriculture. In order to increase the amount of knowledge about how agricultural and food systems can be rebuilt and reimagined to improve nutrition, a lot of work has been done in the last ten years [6, 7].

Conceptual Links between Agriculture and Nutrition

A variety of conceptual frameworks to explain the connection between agriculture and nutrition, each reflecting their respective disciplines [8, 9]. A specific framework that was created for the Tackling the Agriculture - Nutrition Disconnect in India (TANDI) project and is depicted in Figure 1 has been used in recent years to conceptualize ways that the agriculture sector may affect nutrition outcomes [23].

Six pathways linking agriculture and nutrition are high-lighted in this framework, numbered in Figure 1 and summarized here.

Pathway 1: Agriculture as a source of food for household consumption: The most direct pathway by which household agricultural production translates into consumption (via crops cultivated by the household).

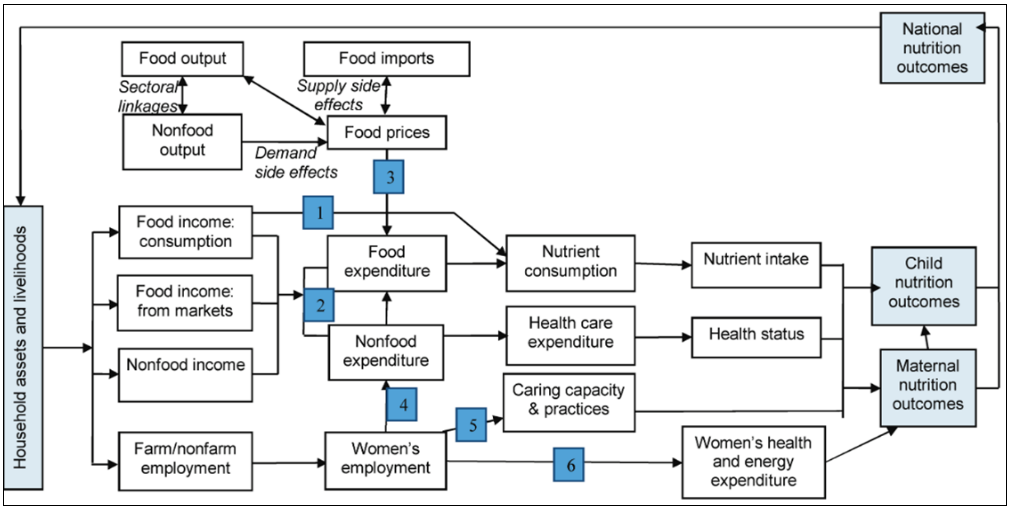

Fig 1: The TANDI framework conceptualizing pathways and links between agricultural livelihoods and nutrition outcomes

Pathway 2: Agriculture as a source of income for food and non-food expenditures: Agriculture generates income (via wages earned or through sale of food produced), which is translated into expenditure on nutrition-enhancing goods and services (including health, education, and social services [14, 15].

Pathway 3: Effects of agriculture policy and food prices on food consumption: This link involves a range of supply-and-demand factors that affect food prices, which in turn affect purchasing power of net buyers.

Pathway 4: Effects of women's employment in agriculture on intrahousehold decision making and resource allocation: Agricultural labour conditions can influence the empowerment of women and thus their control over nutrition-relevant resources and decision making, particularly regarding food and healthcare.

Pathway 5: Effects of women's employment in agriculture on childcare and child feeding: Relates to the challenges that heavy and prolonged female workloads in agriculture present to ensuring adequate care for young children.

Pathway 6: Effects of women's employment in agriculture on their own nutritional and health status: Relates to the energy-intensive nature of agricultural labour and effects on maternal nutritional and health status, and to related health hazards (including exposure to pathogens through waste water irrigation and/or livestock and poultry in the homestead).

Despite being shown separately, these pathways overlap and work together. For instance, pathways 1 and 2 are related to the "separability" hypothesis [25]. Similar to other productive industries, agriculture produces revenue that can be used to purchase goods and services that improve nutrition (Pathway 2). However, in general, agriculture serves as a more significant source of income for the impoverished and underprivileged, both directly and indirectly, through the so-called "multiplier effects" on other industries. However, due to a variety of market failures, farmers may decide to cultivate food for their own consumption (Pathway 1), making agriculture a unique sector for nutrition while also presenting intricate and dynamic policy trade-offs [24]. Pathway 3 emphasizes how food prices and agricultural production conditions are linked on a macroeconomic level, which can influence consumer choices. Pathways 4-6 go beyond price and income to focus on the linkages between child undernutrition and maternal socio-economic and nutritional status. Agricultural production conditions can affect women's decision-making power and control of nutrition-relevant resources (Pathway 4), as well as their ability to manage the care of young children which is of huge importance for nutrition (Pathway 5) [6]. At this point we can again see important trade-offs between several pathways. The TANDI initiative, for example, has shown that if a rise in the demand for female agricultural labour is not matched by enhanced decision-making power and control of household resources (including time), both women and children's nutritional status may suffer. Finally, Pathway 6 addresses the possibility that the often arduous and hazardous conditions of agricultural labour in India pose substantial risks for maternal nutritional status and an intergenerational transmission of undernutrition [16].

Agricultural Growth and Food Security

Agriculture employs 58% of the workforce and contributes 14% of the GDP in countries like India, where increased agricultural productivity has the potential to improve nutrition through increased incomes [58]. From the 1960s through the early 1990s, India's agricultural interventions aimed to achieve self-sufficiency and tackle more significant issues such as hunger and food shortage by boosting food grain productivity and production. The late 1960s saw the beginning of the green revolution, which was sparked by the introduction of high-yielding varieties, increased access to fertilizers, irrigation water, farm equipment, pest control, technology transfer, and minimum support price [21]. Productivity and production growth in agriculture are still vital. Following the Government of India's enactment of the National Food Security Act in late 2013, which guaranteed a legal right to food, there is anticipated to be a rise in demand for food grains.

However, history has shown that unless there is a nutrition focus and the poorest have access to a source of diverse and nutritious foods, increasing food production alone is not sufficient to address the problem of malnutrition. Food security includes "absorption" and the bioavailability of food, which is included in "nutrition security," along with "accessibility," "utilization," and "availability" [17, 18]. In addition to staple foods, a balanced diet should include foods that are well-balanced and provide sufficient amounts of protein, fat, energy, and micronutrients. Under the development paradigm, agricultural interventions must be more nutrition-sensitive and concentrate more on foods that are high in nutrients and have high levels of bioavailability - that is, the percentage of micronutrients that the body can absorb [19, 20, 21]. India was able to address calorie hunger because of its focus on productivity and production, but hidden hunger brought on by micronutrient deficiencies is pervasive. With so many people reliant on agriculture, a farming system for nutrition (FSN) approach is a better way to combat the issue of malnutrition. It may be noted that internationally also there is a drive to end the scourge of malnutrition. The United Nations launched a zero-hunger initiative in 2012 with a target for eliminating hunger, malnutrition and food insecurity by 2025 [22, 23, 26].

The Gap: However, the Gap Experience has demonstrated that unless there is a nutrition focus and the poorest have access to a source of diverse and nutritious foods, increasing food production alone will not be sufficient to address the issue of malnutrition. "Availability," "Accessibility," and "Utilization," which includes "absorption" and "bioavailability" of food, are all included in the concept of "Food Security," which also includes "Nutrition Security." In addition to staple foods, a balanced diet should include foods that are well-balanced and provide sufficient amounts of protein, fat, energy, and micronutrients [30, 31]. Under the development paradigm, agricultural interventions must be more nutrition-sensitive and concentrate more on foods that are high in nutrients and have high levels of bioavailability - that is, the percentage of micronutrients that the body can absorb. India was able to address calorie hunger because of its focus on productivity and production, but hidden hunger brought on by micronutrient deficiencies is pervasive [32, 33]. A farming system for nutrition (FSN) approach can be a more effective way to address the issue of malnutrition, given the significant proportion of the population that depends on agriculture [17, 28, 29].

There is a complex, sporadic, and frequently weak relationship rather than a direct one between agricultural production, consumption patterns, and nutritional outcomes [1]. Research conducted all over the world has made it abundantly evident that changes in income by themselves do not always result in modifications to consumption patterns and dietary diversity that would improve nutritional status. Seven key pathways between agriculture and nutrition were identified by the Tackling the Agriculture-Nutrition Disconnect in India (TANDI) initiative [6], which added two more from the gender perspective to the five pathways the World Bank had previously identified.

The focal theme of FAO's recent report on State of Food and Agriculture is 'Food Systems for Better Nutrition' [4]. Agricultural projects that utilize micronutrient-rich plant varieties have shown high potential for improving nutritional well-being [5]. Reviews by Berti *et al.* [11] and Masset *et al.* [6] found no conclusive evidence of the effects of agricultural interventions on nutritional status in general, but did find positive impacts of selective interventions like home gardening and biofortification. Gulati *et al.* [79] found that improving performance can have a positive impact on nutritional outcomes.

The importance of mediating factors cannot be overstated. Multisectoral interventions are necessary to address the multifaceted issue of malnutrition. Numerous reviews came to the conclusion that initiatives where women were heavily involved in the intervention or where there was a component of nutrition counseling were likely to have demonstrated benefits on increased food intake or nutritional status [11, 16, 25]. Nutrition is impacted by a complex interplay between dietary consumption, water quality, healthcare practices, disease burdens, sanitation, and health services, as well as the underlying social, economic, and political processes that underpin these intermediate outcomes [24]. Overall, though, it appears that efforts are being made to comprehend and prove the effectiveness of pro-nutrition agriculture interventions [3, 5, 15, 26, 27].

Approach to Improve the Nutritional Status

Nutrition-Sensitive Agriculture

According to the Food Security for Nutrition (FSN) model, "agricultural remedies for the nutritional maladies" that are prevalent in a region are to be introduced by mainstreaming nutritional criteria in the selection of crops, farm animals, and, when practical, fish as parts of a farming system [34, 35, 36]. In order to increase absorption and bioavailability, the approach necessitates integration with enabling non-farm factors like sanitation and hygiene [37, 38]. It also places emphasis on the varying nutritional needs of humans across gender and age groups. The main objective of the FSN model is to present replicable and scalable sustainable farming systems that enhance nutritional outcomes at the household level [39]. It attempts to meet the dietary requirements of both farm and non-farm families according to their individual resources, the state of the market, and community preferences [40].

The FSN model is based on the following hypothesis: specifically planned nutrition-focused agricultural interventions can improve farm incomes and productivity while also promoting a more varied and nutrient-dense diet and better nutritional outcomes [41, 24]. The FSN model essentially aims to investigate whether and how agricultural interventions can have a nutritional impact on populations that are malnourished, as well as the extent to which such interventions can be used to improve nutritional status (Table 1).

The FSN model has six major, equally important components [19]

1. Conduct baseline surveys to learn about the current state of agriculture, socioeconomic conditions, and nutrition in the area in order to pinpoint the primary nutritional issues [43].
2. Determine appropriate agricultural solutions to address the issues (cultivation of pulses, biofortified crops, and crop - livestock integration); based on the baseline survey, secondary data that is available, and on-the-ground farming practice demonstrations, design the most appropriate agricultural remedies in community consultation, giving consideration to individual assets, market conditions, and community preferences [43, 44, 45].
3. Ensure that the farming system is designed with particular nutritional requirements in mind; Provide an example of a sustainable farming model that prioritizes nutrition and is done so specifically to improve nutrition [46, 47].
4. Increase the productivity and profitability of small farms to boost cash income; This can be achieved by combining agroforestry, home gardening, livestock (including ruminants, poultry, and fisheries), and the production of nutritious crops, both natural and biofortified [48, 49].
5. Nutrition awareness; Implement literacy and nutrition awareness programs at the home, community, and institutional levels.
6. Implement monitoring systems for process evaluation based on precise and quantifiable standards; create indicators to evaluate the influence on nutritional status; conduct end-of-line surveys to document the shift [50, 51].

Table 1: Steps in FSN intervention design

Steps	particulars
Step 1	Baseline survey of households in the FSN and non-FSN villages to understand the existing agricultural systems and socioeconomic condition, including time use pattern. Identification of key informants and village institutions
Step 2	Constitute technology platform for interaction with academics, research institutions and stakeholders platform with government line department, local self-government, men and women farmers and landless households and NGOs, to leverage collaborations for both feedback and outreach
Step 3	Demonstration and FFS on crop, livestock and horticultural systems to showcase scientific and technological advancement in farming
Step 4	Identify the nutritional disorders/deficiencies prevailing in the area (both protein - energy malnutrition and hidden hunger) through a range of surveys. Collection of household level anthropometric and gender disaggregated information
Step 5	Focus group discussions to understand nutrition sensitivity among the population, gender roles and decision making in access to resources, cultivation and use of the produce
Step 6	Based on the agro-ecological and socio-economic conditions, design farming systems that can provide agricultural remedies to the prevailing nutritional maladies
Step 7	Develop, in association with the farm families, a nutrition-smart farming system. Major components of such a farming system will be: crop - livestock integration - large and small ruminants, poultry, fish, vegetables and fruits, trees, etc
Step 8	Content development for dissemination of improved agriculture practices, exposure trips and training programmes
Step 9	Content development for nutrition education/literacy for all levels, to improve awareness on dietary diversity, storage and cooking practices, health and hygiene, etc.
Step 10	Integrate the relevant existing government programmes and entitlements with the intervention to achieve greater impact

Comparing the effects of interventions within and between villages - which entail baseline and end line surveys of the agricultural production system and nutrition status - is a crucial part of generating evidence. All of the households in the remaining villages in a region are to be introduced to FSN, while a small number of villages (known as non-FSN villages) are to be kept out of the FSN intervention [52, 53].

Initial Survey

As one of the main factors influencing consumption, baseline surveys aim to record the current socioeconomic status, farming practices, productivity and production, nutrition status, and food item sourcing patterns. The primary tools for gathering data are various sets of well-crafted, structured questionnaires for focus group discussions (FGDs), household and village surveys [54, 55, 82].

Village Questionnaire: the village questionnaire has been designed to collect information on food production and consumption systems' availability, access to various natural resources and access to government facilities, health, transport and communication facilities [58, 59]. Household Questionnaire: different sets of household questionnaire have been designed to capture the demographic and socio-economic profile of the households, occupational pattern and nutrition status. These are crucial to design and estimate the impact of FSN based on a set of identified indicators [61, 62]. Discussions in focus groups (FGD): At the baseline, midterm, and finish line levels, record the following: (a) degree of nutrition knowledge (balanced diet, cooking techniques, etc.); (b) childcare practices; (c) access to

WASH (water, sanitation, and hygiene); (d) access to government extension services and entitlements; (e) qualitative aspects of gender roles in decision-making and resource access; and (f) any other pertinent issues that arise during program implementation [63, 64, 65].

Intervention Design and Strategy

The variety, quality, quantity, and nutritional value of the foods that households either produce or purchase for consumption are all determined by food systems. The goal of the FSN intervention strategy is to address the problems associated with households' access to, affordability of, and consumption of nutrient-dense foods as well as their absorption. Through farm sector interventions, such as the introduction of biofortified crops, it seeks to address all the major nutritional maladies, such as calorie deprivation, protein deficiency, and hidden hunger (micronutrient deficiency, e.g., iron, vitamin A, vitamin B12, zinc, iodine). Non-farm and non-food strategies, such as nutrition literacy and awareness and WASH to address absorption, will support these. Strategies for interventions with targeted population and the tools are described in (Table 2).

Biofortified Crops Can Improve Human Nutrition

By utilizing a variety of techniques, such as the engineering of staple crops, biofortification provides developing nations with numerous benefits [57]. In order to improve the most common crops, such as corn, wheat, and rice, research and programs like HarvestPlus are concentrating on iron (Fe), zinc (Zn), and vitamin A, which the World Health Organization considers to be the most limited micronutrients [13]. These common crops are accessible to all people on the planet and don't require any special management because it is possible to enrich produce without compromising the crop's productivity. It may even lead to improved growth and higher yields because the majority of the target minerals are also crucial for the plant's own nutritional needs and may help it tolerate environmental stress. This is particularly important when the environmental conditions for farming are inferior, as they often are in developing countries, and the new varieties have an advantage over conventional varieties [58].

Cereal Biofortification

Millions of people worldwide can benefit from increases in staple cereal concentrations of a few milligrams of essential minerals, which can improve their health and productivity [66, 67, 68].

Due to its high mineral and nutritional content, wheat grain plays a significant role in human nutrition. For the sake of global food security, wheat production must therefore double by 2050 [26]. The mineral contents of wheat germplasm, including Fe, Zn, Se, Mn, Mg, proteins, and vitamins, have been thoroughly screened [34]. Phytic acid was also screened; this is significant because it limits the amount of nutrients that are bioavailable. In recent decades, breeding as well as agronomic and genetic solutions have been examined with the goal of wheat biofortification. Breeding competitive bread wheat cultivars with 40% higher Zn concentration in South Asia [69, 70]. Five biofortified wheat cultivars - in India - have been made available as a result of this process [72]. In a group of high yielding genotypes, ranges of Fe concentrations of 20-60 mg kg^{-1} and Zn concentrations of 15-35 mg kg^{-1} were reported [44].

Table 2: Intervention strategies, target population and tools

Interventions	Target population	Tools, strategies and supporting technologies
A. Targeted interventions: farm sector 1. Cropping system Intervention (crop calendar, crop types and technology) in existing cropping system to enhance farm output and input usage efficiency. Introduction of nutrient-dense biofortified crops in the crop calendar (for example, iron-rich sorghum and vitamin A-rich orange fleshed sweet potato) Introduction and popularization of locally grown naturally fortified and locally consumed nutritious foods (greens, amla, moringa, tubers, etc.)	Farmers with operational landholdings	Participatory Rural Appraisal (PRA) and Focus Group Discussion (FGD) Front Line Demonstration (FLD) Farmer Field School (FFS) technique
2. Livestock system Intervention in scientific goat rearing, backyard poultry and fisheries for income enhancement and consumption Improved silvipastoral system (forestry, pasture, livestock) for optimizing the land use pattern	Farmers with experience of raising livestock with special preference to the most vulnerable group without operational landholdings	PRA and FGD Awareness generation about Feed and Breed Improvement Program (FBIP) Creation of fodder and pasture cafeteria on farmers' plot
3. Vegetables and fruits Establishing nutri-garden in backyard of each farm family to promote vegetables and fruits rich in iron and vitamins A and C	Farmers with homestead land and experience of growing vegetables and fruits	PRA and FGD FLD FFS technique Scientific crop/nutri-garden architecture
B. General interventions: farm and nonfarm sector 1. Nutrition literacy and awareness at various levels	Level-1: Household Level-2: Community Level-3: Institution	Content development on nutrition Information and Communication Technology (ICT)
2. Agronomic best practices	All farm households, on all field crops, vegetables and fruits	Agriculture extension services Training and visit (T and V) Lab to land and land to Lab
3. Introduction of low-cost technology (e.g. fertilizer use efficiency, new varieties/crops, water use efficiency)	All farm households	Fertilizer deep placement technology (FDP) High density planting system (HDPS) Small agriculture implements
4. Livestock health care services (e.g. health check-up camp, de-worming, vaccination)	All households having animal resources	Vaccination/de-worming/artificial insemination techniques
5. Improved feed and fodder	All farm households	Fodder silage technology

This demonstrated that there is enough genetic variation in the wheat gene pool to investigate the possibility of significantly raising grain micronutrient concentrations. Moreover, it has been documented that foliar and soil application techniques can increase the concentrations of zinc and iron in wheat grains by up to three times [74].

Educating farmers in developing nations about the importance of balanced fertilization will help them reach targets for micronutrient concentration, which will help fight hidden hunger.

It is difficult to increase the concentration of Zn and Fe in the endosperm, which is the portion that is most edible, using agronomic techniques; however, reports have indicated that soil application can increase the concentration of Fe and Zn.

Rice

Rice is one of the main staple food crops grown worldwide, it is especially highlighted for micronutrient improvement. This means that rice biofortification has a significant potential to reduce malnutrition worldwide. With 20-22 mg kg^{-1} Zn in brown rice, the first high Zn rice cultivar was distributed in 2013 by Harvest Plus and the Bangladesh Rice Research Institute. According to reports by [47], there have been increases in rice for Zn, Se, and Fe of 17.4, 0.123, and 14.2 mg kg^{-1}, respectively. Where rice is the main crop, after screening 484 rice lines [49], discovered co-localized QTL regions for Zn and Fe in addition to high yield characteristics. In order to increase the bioavailability of micronutrients in rice and, in turn, the nutrition and health of consumers, it is necessary to take into account the composition of rice grains, including the localization of Fe and Zn as well as their chelators, transporters, promoters, and inhibitors [49]. The Zn content of the grains in aromatic rice has also been markedly enhanced by zinc management in the soil.

Corn

Although maize is frequently seen as a cash crop, it is also a staple in many nations and a major source of food for both people and animals worldwide. Zinc can be applied exogenously in the form of seed priming, foliar spraying, or soil incorporation to improve maize seed germination, seedling vigor, and stress tolerance [15, 16]. Following the application of ZnO nanoparticulates, Maqbool and Bashir [17] reported a high accumulation of zinc in maize grains, measuring 36 mg kg^{-1}. Previous reports have indicated a significant genome-wide correlation between the concentration of micronutrients in maize kernels and yield. This suggests that biofortification of maize can be achieved through the use of specialized phenotyping tools and conventional plant breeding techniques [68, 70]. Among 1000 CIMMYT maize lines, concentration ranges of Zn, Fe, and provitamin A have been reported, and maize lines with 15-35 mg kg^{-1} Zn, an average of 20 mg kg^{-1} Fe, and about 0-15 mg kg^{-1} total provitamin A concentration have been identified.

Additionally, pearl millet has demonstrated excellent genetic variation that can be utilized in breeding (30-140 mg kg^{-1} Fe and 20-90 mg kg^{-1} Zn). Novel cultivars with high yields and high Zn and Fe contents. The Pujar group [72] discovered a strong positive correlation between Fe/Zn and overall performance. Density of populations of pearl millet. Including parental lines with a significant amount of Average heterosis may be advantageous in breeding initiatives that aim to improve Pearl millet's Fe/Zn ratio.

Biofortification of Non-Cereals

Numerous crops other than cereals are making a significant contribution to global food security, particularly in numerous African nations. Non-cereal crops can benefit from genetic and agronomic biofortification as well. Only a handful have been discussed thus far; however, biofortification of other crops, like pulses, holds great promise, including the biofortification of chickpeas [50].

Cassava

Cassava (Manihot esculenta) is a staple crop in many African nations, but its zinc, iron, and vitamin A contents are very low. In order to lessen micronutrient deficiencies, it is necessary to biofortify this crop for Fe, Zn, I, and vitamin A in low-resource nations. Cassava is grown as a staple crop in Latin American and Caribbean nations in addition to Africa. It is thought to be a crucial crop to biofortify with beta-carotene in order to raise the vitamin A content of its users [19]. Because it can withstand a variety of stresses and poor soil conditions, cassava is an important crop in tropical and subtropical climates [76, 77, 78].

Potato

Potato also known as *Solanum tuberosum*, potatoes are a valuable vegetable that provide calories and energy to people of all ages. Due to its widespread use, it offers a great deal of potential to enhance human nutrition through different biofortification techniques. The PSY gene has been added to potatoes using transgenic methods to increase their beta-carotene content [73].

Through the foliar application of zinc fertilizers, field experiments were carried out to significantly increase the zinc content of potato tubers. Additionally, zinc sulfate and zinc oxide were found to be more effective than zinc nitrate for foliar applications meant to increase zinc concentrations and boost yield [55]. In summary, potatoes have considerable genetic diversity for micronutrient concentration that can be utilized for conventional breeding of varieties with enhanced Fe and Zn concentrations for human nutrition.

Sweet potato

Sweet Potato Varieties with orange flesh (*Ipomoea batatas* L., Lam) contain more beta carotene than those with white flesh. The initiative to biofortify sweet potatoes aims to replace white-fleshed varieties with orange-fleshed plants. The Harvest Plus project has set a target level of beta carotene for sweet potatoes of 32 mg kg^{-1}, however reports from HarvestPlus [20] and Nestel *et al.* [59, 69] have shown that cultivars with higher concentrations of up to 100 mg kg^{-1} exist. Sweet potatoes have many phytochemicals, vitamin C, carbohydrates, anthocyanin, and dietary fibre.

The nutritive value of sweet potato can be improved by enhancing the contents of lutein, carotene, and total carotenoids, through overexpression of “orange” IbOr-Ins genes in white fleshed sweet potato [8]. The orange fleshed sweet potato beta carotene content can also be enhanced by irrigation and chemical fertilizer applications.

Common Beans

Humans worldwide eat the common bean (*Phaseolus vulgaris*), which is an essential grain legume. The dry grains of this annual herbaceous plant are edible. Although the beans have high concentrations of the essential amino acids methionine and cysteine, their nutritive value is inadequate despite their abundance in leucine, isoleucine, lysine, valine, and threonine. However, methionine-rich storage albumin protein from Brazil nut seeds can be expressed, increasing the amount of methionine in beans [1]. By applying zinc fertilizer topically, common beans may also benefit from zinc biofortification. According to reports, applying organic and chemical fertilizers can increase the concentrations of N, P, K, Mn, Cu, and Zn in common beans. Furthermore, it has been demonstrated that by employing various techniques, the Fe and Zn concentrations in common beans can be increased by 60-80% and 50%, respectively. For Fe and Zn concentration, common beans have been found to have high genetic diversity, and genes linked to Zn accumulation have been reported in navy beans.

Conclusion

In essence, the FSN model will show that a broad, long-term, nutrition-sensitive agricultural intervention is feasible. The methodology for the study will record the level of profitability and productivity improvement in the agricultural system that leads to increased household expenditure on a balanced diet more consumption of foods high in nutrients, and the degree to which the design of a pro-nutrition farming system can be embraced by households with varying asset bases. The study's evidence of successful models linking agriculture to nutritional outcomes can be utilized to frame farming systems that are sensitive to nutrition and gender in various agro-ecological zones across the nation. Additionally, the study will contribute to the evaluation of the potential contribution of crop biofortification to the reduction of micronutrient malnutrition.

References

1. Christiaensen L, Demery L, Kühl J. The (evolving) role of agriculture in poverty reduction - An empirical perspective. J Dev Econ. 2011;96:239-254.
2. Alderman H. In: von Braun J, Kennedy E, eds. Agricultural Commercialization, Economic Development, and Nutrition. Baltimore: Johns Hopkins University Press; c1994.
3. Haddad L, Hoddinott J, Alderman H. Intrahousehold Resource Allocation in Developing Countries: Models, Methods and Policy. Baltimore: Johns Hopkins University Press; c1997.
4. Kim SH, Kim YH, Ahn YO, Ahn MJ, Jeong JC, Lee HS, *et al*. Downregulation of the lycopene β-cyclase gene increases carotenoid synthesis via the β-branch-specific pathway and enhances salt-stress tolerance in sweet potato transgenic Calli. Physiol Plant. 2012;147:432-442.
5. Low J, Arimond M, Osman N, Cunguara B, Zano F, Tschirley D, *et al*. A food-based approach: Introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in Mozambique. J Nutr. 2007;137(5):1320-1327.
6. Masset E, Haddad L, Cornelius A, Isaza-Castro J. A systematic review of agricultural interventions that aim to improve nutritional status of children. EPPI-Centre, Social Science Research Unit, Institute of Education, University of London. 2011;137(5):1320-1327.
7. McKenzie D. Beyond baseline and follow-up: The case for more T in experiments. J Dev Econ. 2011;99(2):210-221.
8. Miller DD, Welch RM. Food system strategies for preventing micronutrient malnutrition. Food Policy. 2013;42:115-128.
9. Mullins G, Wahome L, Tsangari P, Maarse L. Impacts of intensive dairy production on smallholder farm women in coastal Kenya. Hum Ecol. 1996;24:231-253.
10. Susan H. Opportunities for investments in nutrition in low income Asia. Asian Dev Rev. 1999;17(1, 2):246-273.
11. Berti P, Krasevec J, FitzGerald S. A review of the effectiveness of agriculture interventions in improving nutrition outcomes. Public Health Nutr. 2004;7(5):599-609.
12. Distelfeld A, Cakmak I, Peleg Z, Ozturk L, Yazici AM, Budak H, *et al*. Multiple QTL-effects of wheat Gpc-B1 locus on grain protein and micronutrient concentrations. Physiol Plant. 2007;129:635-643.
13. Monasterio I, Graham RD. Breeding for Trace Minerals in Wheat. Food Nutr. Bull. 2000;21:392-396.
14. Farooq M, Ullah A, Rehman A, Nawaz A, Nadeem A, Wakeel A, *et al*. Application of zinc improves the productivity and biofortification of fine grain aromatic rice grown in dry seeded and puddled transplanted production systems. Field Crop Res. 2018;216:53-62.
15. Imran M, Rehim A. Zinc fertilization approaches for agronomic biofortification and estimated human bioavailability of zinc in maize grain. Arch Agron. Soil Sci. 2016;63:106-116.
16. Liu DY, Zhang W, Pang LL, Zhang YQ, Wang XZ, Liu YM, *et al*. Effects of zinc application rate and zinc distribution relative to root distribution on grain yield and grain Zn concentration in wheat. Plant Soil. 2017;411:167-178.
17. Maqbool MA, Beshir A. Zinc biofortification of maize (*Zea mays* L.): Status and challenges. Plant Breed. 2018;138:1-28.
18. Subbaiah LV, Prasad TNVKV, Krishna TG, Sudhakar P, Reddy BR, Pradeep T, *et al*. Novel Effects of Nanoparticulate Delivery of Zinc on Growth, Productivity, and Zinc Biofortification in Maize (*Zea mays* L.). J Agric. Food Chem. 2016;64:3778-3788.
19. Signorell C, Zimmermann MB, Cakmak I, Wegmüller R, Zeder C, Hurrell R, *et al*. Zinc absorption from agronomically biofortified wheat is similar to post-harvest fortified wheat and is a substantial source of bioavailable zinc in humans. J Nutr. 2019;149:840-846.
20. Harvest Plus. Provitamin a Sweet Potato for Uganda and Mozambique; c2009. Available online: www.cipotato.org
21. Alam Cheema S, Rehman HU, Kiran A, Bashir K, Wakeel A. Progress and Prospects for Micronutrient Biofortification in Rice/Wheat. In: Plant Micronutrient Use Efficiency. Cambridge, MA: Academic Press; c2018. p. 261-278.
22. Alderman H, Hoddinott J, Kinsey B. Long-term consequences of early childhood malnutrition. Oxford Economic Papers. 2006;58(3):450-474.
23. Aslam MF, Ellis PR, Berry SE, Latunde-Dada GO, Sharp PA. Enhancing mineral bioavailability from cereals: Current strategies and future perspectives. Nutr

Bull. 2018;43:184-188.

24. Behrman J, Alderman H, Hoddinott J. Hunger and Malnutrition. Copenhagen Consensus Challenge Paper. Copenhagen Consensus. Copenhagen destiny. Agric. Res. 2004;2(3):183-188
25. Bouis HE, Hotz C, McClafferty B, Meenakshi JV, Pfeiffer WH. Biofortification: A New Tool to Reduce Micronutrient Malnutrition. Food Nutr. Bull. 2011;32:S31-S40.
26. Burgos G, Amoros W, Morote M, Stangoulis J, Bonierbale M. Iron and zinc concentration of native Andean potato cultivars from a human nutrition perspective. J Sci. Food Agric. 2007;87:668-675.
27. Cakmak I, Ozkan H, Braun HJ, Welch RM, Römheld V. Zinc and Iron Concentrations in Seeds of Wild, Primitive, and Modern Wheats. Food Nutr. Bull. 2000;21:401-403.
28. Cakmak I, Pfeiffer WH, McClafferty B. Review: Biofortification of Durum Wheat with Zinc and Iron. Cereal Chem. 2010;87:10-20.
29. Cuderman P, Kreft I, Germ M, Kovaˇceviˇc M, Stibilj V. Selenium Species in Selenium-Enriched and Drought-Exposed Potatoes. J Agric. Food Chem. 2008;56:9114-9120.
30. Headey D, Chiu A, Kadiyala S. Food Secur. 2012;4:87.
31. Dubock A. An overview of agriculture, nutrition and fortification, supplementation and biofortification: Golden Rice as an example for enhancing micronutrient intake. Agric Food Secur. 2017;6:59.
32. Ducreux LJM, Morris WL, Hedley PE, Shepherd T, Davies HV, Millam S, *et al*. Metabolic engineering of high carotenoid potato tubers containing enhanced levels of carotene and lutein. J Exp. Bot. 2004;56:81-89.
33. Esfandiari E, Abdoli M, Mousavi SB, Sadeghzadeh B. Impact of foliar zinc application on agronomic traits and grain quality parameters of wheat grown in zinc deficient soil. Indian J Plant Physiol. 2016;21:263-270.
34. Evenson RE, Msangi S, Sulser TB, Rosegrant MW. Green Revolution Counterfactuals. Paper presented at the annual meeting of the American Agricultural Economics Association. July 23-26, Long Beach, California; c2006.
35. Fang Y, Wang L, Xin Z, Zhao L, An X, Hu Q, *et al*. Effect of Foliar Application of Zinc, Selenium, and Iron Fertilizers on Nutrients Concentration and Yield of Rice Grain in China. J Agric. Food Chem. 2008;56:2079-2084.
36. FAO. The State of Food and Agriculture. Women in Agriculture. Closing the Gender Gap for Development. Food and Agriculture Organization. Rome; c2011.
37. FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition. Food and Agriculture Organization of the United Nations. Rome; c2018.
38. Gani G, Gulsar B, Bashir O, Bhat TA, Naseer B, Qadri T, *et al*. Hidden hunger and its prevention by food processing: A review. Int. J Unani Integr. Med. 2018;2:1-10.
39. Gillespie S, Harris J, Kadiyala S. The agriculture-nutrition disconnect in India - What do we know? IFPRI Discussion Paper. Washington DC: IFPRI; c2012. p. 01187.
40. Government of India. Economic survey 2012-13. New Delhi: Ministry of Finance; c2013. http://indiabudget.nic.in/budget 2013-2014/es2012-13/echap-01.pdf
41. Gupta PK, Balyan HS, Sharma S, Kumar R. Biofortification and bioavailability of Zn, Fe and Se in wheat: Present status and future prospects. Theor. Appl. Genet. 2020;134:1-35.
42. Hakki E, Hamurcu M, Khan MK, Pandey A, Akkaya M, Gezgin S, *et al*. Wheat biofortification - A potential key to human malnutrition. J Elementol. 2012;22:937-944.
43. MSSRF (M.S. Swaminathan Research Foundation). Notice Board. http://www.mssrf.org/notice-board.html. Accessed 22 Nov 2023.
44. Hughes J, Ortiz O. Biofortification Strategy. Proceedings of the Working together to consider the role of biofortification in the global food chain workshop. Nutr. Bull. 2018;43:416-427.
45. ILO (International Labour Organization). Employment by sector - ILO modelled estimates. International Labour Organization Geneva; c2017 Nov. Available at: http://www.ilo.org/ilostat. Accessed 17 November 2023.
46. Jha AB, Warkentin TD. Biofortification of Pulse Crops: Status and Future Perspectives. Plants. 2020;9:73.
47. Kadiyala J, Harris D, Headey D, Yosef S, Gillespie S. The Agriculture - Nutrition Disconnect in India What Do We Know? IFPRI Discussion Paper; c2014. p. 01187. IFPRI, Washington D.C.
48. Kiran A, Wakeel A, Sultana R, Khalid A, Ain QU, Mubaraka R, *et al*. Concentration and Localization of Fe and Zn in Wheat Grain as Affected by Its Application to Soil and Foliage. Bull Environ Contam Toxicol. 2021;106:852-858.
49. Kodkany BS, Bellad RM, Mahantshetti NS, Westcott JE, Krebs NF, Kemp JF, *et al*. Biofortification of pearl millet with iron and zinc in a randomized controlled trial increases absorption of these minerals above physiologic requirements in young children. J Nutr. 2013;143(9):1489-1493.
50. Kumar J, Saripalli G, Gahlaut V, Goel N, Meher PK, Mishra KK, *et al*. Genetics of Fe, Zn, β-carotene, GPC and yield traits in bread wheat (*Triticum aestivum* L.) using multi-locus and multi-traits GWAS. Euphytica. 2018;214:219.
51. Lachman J, Hamouz K. Red and purple coloured potatoes as a significant antioxidant source in human nutrition - A review. Plant Soil Environ. 2011;51:477-482.
52. Leroy J, Frongillo E. Can interventions to promote animal production ameliorate undernutrition? J Nutr. 2007;137(1):2311-2316.
53. Liu Z, Wang H, Wang X, Zhang G, Chen P, Liu D, *et al*. Phytase activity, phytate, iron, and zinc contents in wheat pearling fractions and their variation across production locations. J Cereal Sci. 2007;45:319-326.
54. Lockyer S, White A, Walton J, Buttriss JL. Proceedings of the Working together to consider the role of biofortification in the global food chain workshop. Nutr. Bull. 2018;43:416-427.
55. Low J, Arimond M, Osman N, Cunguara B, Zano F, Tschirley D, *et al*. A food-based approach: Introducing orange-fleshed sweet potatoes increased vitamin A

intake and serum retinol concentrations in young children in Mozambique. J Nutr. 2007;137(5):1320-1327.

56. Chaturvedi RK, Singh B, Singh VK. A review on impact of ceramic fertilizers with slow release of nutrient elements for agriculture applications. Int. J Agric. Food Sci. 2021;3(1):01-04. DOI: 10.33545/2664844X.2021.v3.i1a.42
57. Maluccio JA, Hoddinott JF, Behrman JR, Martorell R, Quisumbing AR, Stein AD, *et al*. The impact of improving nutrition during early childhood on education among Guatemalan Adults. Econ J. 2009;119(537):734-763.
58. Masset E, Haddad L, Cornelius A, Isaza-Castro J. A systematic review of agricultural interventions that aim to improve nutritional status of children. EPPI-Centre, Social Science Research Unit, Institute of Education, University of London; c2011.
59. Nestel P, Bouis HE, Meenakshi JV, Pfeiffer W. Biofortification of Staple Food Crops. J Nutr. 2006;136:1064-1067.
60. Oury F-X, Leenhardt F, Rémésy C, Chanliaud E, Duperrier B, Balfourier F, *et al*. Genetic variability and stability of grain magnesium, zinc and iron concentrations in bread wheat. Eur. J Agron. 2006;25:177-185.
61. Ozturk L, Yazici MA, Yucel C, Torun A, Cekic C, Bagci A, *et al*. Concentration and localization of zinc during seed development and germination in wheat. Physiol Plant. 2006;128:144-152.
62. Pinstrup-Andersen P. Eur. J Dev Res. 2012;25:5.
63. Poggi V, Arcioni A, Filippini P, Pifferi PG. Foliar Application of Selenite and Selenate to Potato (*Solanum tuberosum*): Effect of a Ligand Agent on Selenium Content of Tubers. J Agric. Food Chem. 2000;48:4749-4751.
64. Pradhan SK, Pandit E, Pawar S, Naveenkumar R, Barik SR, Mohanty SP, *et al*. Linkage disequilibrium mapping for grain Fe and Zn enhancing QTLs useful for nutrient dense rice breeding. BMC Plant Biol. 2020;20:1-24.
65. Rainer G, Hans S, Hans P, Hans-Joachim AP. The four dimensions of food and nutrition security: Definitions and concepts. European Union and FAO; c2000. http://www.foodsec.org/DL/course/shortcourseFA/en/pdf/P-01_RG_Concept.pdf.
66. Rainer G, Hans S, Hans P, Hans-Joachim AP. The four dimensions of food and nutrition security: Definitions and concepts. European Union and FAO; c2000. http://www.foodsec.org/DL/course/shortcourseFA/en/pdf/P-01_RG_Concept.pdf.
67. Gillespie S, Harris J, Kadiyala S. The Agriculture - Nutrition Disconnect in India What Do We Know? IFPRI Discussion Paper 01187, IFPRI, Washington D.C; c2012.
68. Sakai H, Iwai T, Matsubara C, Usui Y, Okamura M, Yatou O, *et al*. A decrease in phytic. acid content substantially affects the distribution of mineral elements within rice seeds. Plant Sci. 2015;238:170-177.
69. Spielman DJ, Pandya-Lorch R. Fifty years of progress. In: Spielman DJ, Pandya-Lorch R, eds. Millions Fed: Proven Successes in Agricultural Development. International Food Policy Research Institute (IFPRI). Washington, DC; c2009. p. 1-18.
70. Swaminathan MS. Genesis and growth of the yield revolution in wheat in India: lessons for shaping our agricultural destiny. Agric. Res. 2013;2(3):183-188.
71. Swaminathan MS. Launching a nutri-farm movement; c2013.
72. Telengech PK, Maling'A JN, Nyende AB, Gichuki ST, Wanjala BW. Gene expression of beta carotene genes in transgenic biofortified cassava. Biotechnology. 2014;5:465-472.
73. Ullah A, Farooq M, Nadeem F, Rehman A, Nawaz A, Naveed M, *et al*. Zinc seed treatments improve productivity, quality and grain biofortification of desi and kabuli chickpea (*Cicer arietinum*). Crop Pasture Sci. 2020;71:668-678.
74. United Nations. Zero hunger challenge; c2012. http://www.un.org/en/zerohunger/challenge.
75. United Nations Children's Fund, World Health Organization, the World Bank. UNICEF-WHO-World Bank Joint Child; c2012.
76. Welch RM, Graham RD, Cakmak I. Linking Agricultural Production Practices to Improving Human Nutrition and Health, expert paper written for ICN2. In Proceedings of the Second International Conference on Nutrition Preparatory Technical Meeting, Rome, Italy; c 2013. p. 13-15.
77. White PJ, Broadley MR. Biofortification of crops with seven mineral elements often lacking in human diets - Iron, Zinc, Copper, Calcium, Magnesium, Selenium and Iodine. New Phytol. 2009;182:49-84.
78. WHO. Micronutrient Deficiencies. World Health Organization; c2012. Available online: http://www.who.int/nutrition/topics/ida/en/ (accessed on 10 December 2012).
79. World Bank. Agriculture for development; c2008. http://siteresources.worldbank.org/INTARD/Resources/ESW_Sept5_final_final.pdf.
80. World Health Organization. Micronutrient deficiencies; c2012. http://www.who.int/nutrition/topics/ida/en/. Accessed 10 Dec 2012.
81. Bouis HE. The potential of genetically modified food crops to improve human nutrition in developing countries. J Dev Stud. 2000;40:1-22.
82. Magallanes-López AM, Hernandez-Espinosa N, Velu G, Posadas-Romano G, Ordoñez-Villegas VMG, Crossa J, *et al*. Variability in iron, zinc and phytic acid content in a worldwide collection of commercial durum wheat cultivars and the effect of reduced irrigation on these traits. Food Chem. 2017;237:499-505.