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LETTER TO THE EDITOR

Potential of underutilized crops to introduce the nutritional diversity and achieve zero hunger

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Underutilized crops are genetically diverse group of plants

Several crops with enormous nutritional values were once largely consumed by mankind. However, due to selective domestication, most of them had become marginally cultivated in a confined region. It is an estimate from various studies on the evaluation of mankind that about 80,000 plant species have been directly used by humans for food, fodder, fibre, medicine, and industrial purposes. Among these, more than 25,000 are edible and about 7000 have either been domesticated or collected from the wild for food at one time or another (Muthamilarasan et al. 2019). At present, merely 30 species are being cultivated for food, among which 6 crops including rice, wheat, maize, potato, soybean, and sugarcane share more than 75% of total plant-derived energy intake. Green revolution in Asia occurred due to the introduction of high-yielding rice and wheat varieties with excess soil nitrogen application has uplifted the undernourished incidences from one in three people being hungry during 1960 to roughly one out of ten in the present date. However, the advent of green revolution has negatively impacted crop diversity in developing countries. Narrowing down of crop diversification together with consumption of highly processed food and sedentary life resulted in double-burden nutritional challenges with nearly 2 billion people still suffering from malnutrition and additional 1.9 billion people suffering from obesity and non-communicable diseases due to higher caloric intake (Sreenivasulu and Fernie 2022; Tiozon et al. 2021). Switching to crops with higher caloric yields has ended the cultivation of super-nutrient crops and general awareness of broader climatic adaptation of several native species to be grown in marginal environments.

Underutilized food crops can be broadly divided into 5 categories including pseudocereals and millets; grain legumes; root and tubers; leafy vegetables; and fruits (Table 1). Most species belonging to pseudocereals and millets are of Chinese or African origin with a long history of cultivation. Broomcorn (*Panicum miliaceum*) and foxtail millet (*Setaria italica*) were the first domesticated species before rice or any other crops (Robbeets et al. 2021). An indigenous African legume bambara groundnut (*Vigna subterranea*) is known for its adaptability in poor soils of hot and arid environments where other crops fail to grow. It also fixes an enormous amount of nitrogen to the soil (~90 kg/h) which boosts production of intersessional crops (Bernard et al. 2018). Excessive diversity of the traditional farming system reflects human innovation, multifarious food preferences, and cultural diversity across the regions. The underutilized crops possess dense nutrients with higher micronutrients, rich in dietary fibre, resistant starch, protein and bioactives with low glycemic index properties, while being highly adapted to agro-climate niches (Table 1). Due to their poor yields and lack of national policy to link with value chain for promoting agro-business, these underutilized crops were not mainstreamed. Their ignorance has led to erosion of genetic diversity and unique gene pools from cultivation areas.

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Table 1 List of some underutilized edible species with immense nutritional potential and suitable under water deficit conditions

Category	Name of the species	Major area of cultivation	Nutritional merits	Estimated genome size
Pseudocereals and millets	Job's tears (*Coix lacryma-jobi*)	East and Southeast Asia	Rich in Ca, Fe, and vitamin content	1684 Mb
	Fonio (*Digitaria exilis*)	West Africa	Starch-rich seeds with high protein and essential amino acids including methionine	668–707 Mb
	Pearl millet (*Pennisetum glaucum*)	Semi-arid and warm regions of Asia, Africa, and America	Grains with high resistance starch; minerals including Fe, Ca, K, Mg, Zn; vitamins; and fibres	2352 Mb
	Finger millet (*Eleusine coracana*)			1196 Mb
	Proso millet (*Panicum miliaceum*)			NA
	Foxtail millet (*Setaria italica*)			490 Mb
	Broomcorn (*Panicum miliaceum*)			923 Mb
	Barnyard millet (*Echinochloa colona*)			NA
	Kodo millet (*Paspalum scrobiculatum*)			NA
	Quinoa (*Chenopodium quinoa*)	South America, Europe, and Asia	Seeds with high protein, dietary fibre, B vitamins, Mg, K, and Ca	1453 Mb
	Buckwheat (*Fagopyrum esculentum*)	Hilly regions of Southeast Asia	High-calorie seeds, rich source of soluble and insoluble dietary fibre, vitamins, Fe, and Zn	1200 Mb
	Chia (*Salvia hispanica*)	Central and Southern Mexico and Southwest America	Rich source of fibre, minerals, omega fatty acids, and minerals	347.6 Mb
	Teff (*Eragrostis tef*)	Ethiopia and Eritrea	Rich in protein, fibre, magnesium, zinc, calcium, and vitamin B6	730 Mb
Grain legumes	Groundnut (*Arachis hypogaea*)	Tropical and subtropical countries in the world	Rich source of protein, vitamin E, foliate, Mg, and Cu	2813 Mb
	Grass pea (*Lathyrus sativus*)	Asia, East Africa, and South America	Rich source of protein, essential amino acids, and vitamins	NA
	Bambara groundnut (*Vigna subterranea*)	West Africa	Rich source of protein, carbohydrate, and fibre	535 Mb
	Horse gram (*Macrotyloma uniflorum*)	Southeast Asia	Rich source of protein, carbohydrate, vitamins, iron, and molybdenum	NA
	Petai (*Parkia speciosa*)	Southeast Asia	Rich source of protein, fibres, minerals, vitamins, and flavonoids	NA
Root and tubers	Yam (*Dioscorea alata*)	West Africa, Southeast Asia, and New Guinea	Rich in carbohydrate, proteins, vitamin B6, Cu, and Mn	454 Mb
	Mashua tuber (*Tropaeolum tuberosum*)	Peru, Bolivia, Colombia, and Ecuador	Rich in carbohydrate, proteins, vitamin C, and ß-carotene	NA
	Yan bean (*Pachyrhizus erosus*)	Mexico and South America	Rich in carbohydrate, proteins, minerals, and vitamin B, and carotene	560 Mb

Table 1 (continued)

Category	Name of the species	Major area of cultivation	Nutritional merits	Estimated genome size
Leafy vegetables				
	Wild watermelon (*Citrullus lanatus*)	South America, Africa, Middle East, and South Asia	Rich in Ca, Fe, P, Mg, vitamins, and carotenoid including lycopene	NA
	Chinese leek (*Allium tuberosum*)	Southeast Asia	Rich in essential flavonoids, amino acids, and has therapeutic value	NA
	Malabar spinach (*Basella alba*)	Southeast Asia and Australia	Rich in vitamins, Fe, Ca, antioxidants including ß-carotene, and lutein	NA
	Sparrow grass (*Asparagus officinalis*)	Asia and Europe	Rich in vitamins, Mn, Mg, P, and K	1308 Mb
Fruits	Bayberry (*Myrica esculenta*)	Southeast Asia	Rich in vitamin C and polyphenolic compounds, has therapeutic values	NA
	Sugar apple (*Annona squamosa*)	South America, Australia, and Asia	Rich in essential amino acids, fibres, vitamins, and Mg	NA
	Indian jujube (*Ziziphus mauritiana*)	Southeast Asia and Eastern Africa	Rich in carotene, vitamins A, vitamin C, and fatty oils	418 Mb

Crop diversification to ensure food security

Ensuring food and nutritional security for a population of approximately 10 billion by 2050 is the foremost important challenge, given that crop production under changing climates with severity in facing several abiotic and biotic constraints with limited agricultural land. It was estimated that approximately 690 million people were hungry in 2019 and the number had sharply elevated to 720–811 million in 2020 under the obscurity of the COVID-19 pandemic (FAO 2021). It also projects that if the situation remains the same, it would be difficult to achieve zero hunger by 2030. Most of the underutilized crops are meagrely cultivated in hunger-prone regions and have potential to alleviate food and nutrient deficiency of a larger population if produced in combination with staple crops, for example the rice-fallow system in Eastern India. The rice-fallow intensification system is introduced by leaving residue much after rice harvest helps to maintain the soil moisture to introduce diversified pulses and alternatively by introducing the appropriate irrigation system vegetables be grown after rice cropping (Behera et al., 2014; Singh et al., 2020a). These underutilized crops have not gained much attention due to limited commercial gain and lack of awareness among consumers. Re-diversification of crops has now been essential to eradicate triple burden nutritional challenges such as malnutrition, non-communicable diseases, and zero hunger under sustainable agricultural production. This requires holistic strategies of global policy, research priorities to increase the productivity of underutilized crops, deploying various modern technologies for trait improvement (precision breeding through genomic selection and marker-assisted selection methods and modernizing the breeding programmes), implementing crop rotation systems, improve the value chain and marketability, and most importantly building confidence among local farmers. In a case study during the middle of the last decade, diversification of the cropping system has enhanced productivity and climate resilience in Zambia (FAO et al. 2019). Rotation of underutilized crops with existing crop systems may disrupt the disease and pest cycle, replenish soil nutrients, and diversify the presence of pollinators. Rotations with Indian mustard (*Brassica juncea*) and wild rocket (*Diplotaxis tenuifolia*) has significantly reduced the cucumber wilt disease caused by *Fusarium oxysporum* (Jin et al. 2019). The rotation system resulted in enhanced soil bacterial diversity and abundances of potential plant-beneficial microorganisms including *Pseudomonas* spp. and 2,4-diacetylphloroglucinol (an antifungal) producers.

Nutritional merits of underutilized crops

The major advantage behind promoting the use of underutilized crops is their immense nutritional value for eradicating hidden hunger. Most of the underutilized crops are superior to staple crops in terms of their nutritional properties. For example, millets and super-nutrient crops such as quinoa, chia, and teff (https://www.greenovateboston.org/nutritiondata/nutrition-data-of-quinoa-chia-seed-wraps-with-teff-seeds-flaxsee/) are recognized with several folds' higher carbohydrate quality with rich dietary fibre sources and high-quality protein sources with enriched essential amino acids than modern varieties of rice and wheat (Sushree Shyamli et al. 2021). Due to vigorous genetic rearrangement and selection pressure, most of our staple crops have lost several valuable genes. It is worth noting that quite a range of genetic variation is identified for nutritional content within the landraces and wild relatives of cereals, which could be tapped to further improve the nutritional content of cereals in the elite breeding pool (Anacleto et al. 2019). Higher resistant starch content in grains of foxtail millet has higher therapeutic values for type II diabetic patients (Muthamilarasan and Prasad 2021). Millet grains are also rich in minerals and dietary fibres. Similarly, in legumes, protein content and essential amino acids in seeds and vegetative parts of grass pea (*Lathyrus sativus*) are manifolds higher than other legumes including alfalfa (*Medicago sativa*), garden pea (*Pisum sativum*), and broad bean (*Vicia faba*). Further, through symbiotic nitrogen fixation with *Rhizobium leguminosarum*, they also add up to 125 kg/ha nitrogen to the soil. This improves productivity of non-legume crops growing in the inter-season. Several lesser-known leafy vegetables including *Asparagus officinalis*, *Citrullus lanatus*, *Basella alba*, *Ipomoea aquatica*, *Moringa oleifera*, and others are rich sources of fibres, vitamins, and minerals. Altogether, it is realized that underutilized crops are nutritionally superior as compared to regular crops which demonstrate their potential in attaining United Nation's Sustainable Development Goal (SDG) 2, that is zero hunger.

Conservation aspect

Extinction of natural habitats either due to rapid urbanization or commercial gains is one of the major threats to wild vegetation. Several underutilized species that are well adapted in those sites need to be conserved to provide social and economic needs of rural poor. Therefore both ex situ conservation and in situ conservation are required to be implemented without further delay. This would lead to preventing the identity loss of many neglected though highly valuable species. It has also been indicated that a very limited collection of underutilized species is maintained in genebanks worldwide. However, in the past few years, various national and international programmes organized by the Food and Agriculture Organization (FAO), African Orphan Crop Consortium (AOCC), International Plant Genetic Resources Institute (IPGRI), International Institute of Tropical Agriculture (IITA), International Crops Research Institute for Semi-Arid Tropics (ICRISAT), and others have been carried out in Southeast Asia, some part of Africa, and Australia to make general awareness among their people. Specific crop industries should also take the responsibility to nourish and meet the supply of underutilized crops as per national needs. Apart from these, new crops with good economic returns also need to be identified and conserved. In addition to the germplasm conservation of underutilized crops, local knowledge on traditional uses of these crops should also be conserved and propagated to the wider population.

Mainstreaming underutilized crops

Although the monoculture cultivation of staple crops with higher application of chemical fertilizer and pesticides ensured the current food security, these approaches are severely causing environmental degradation and affecting human health. Underutilized crops when promoted together with staple crops contribute to sustainable development not only through ensuring food and nutrition security, but also ecosystem stability, enhanced income for smaller farmers, and cultural diversity. Therefore, promoting their cultivation, roadmap to improve beneficial traits, optimizing storage, and post-harvest processing should be on the agenda of policy makers. Mapping of crop suitability in a given region is a prerequisite for crop selection and sustainable land management. However, most of the underutilized crops are resistant to pests and diseases, and display a high level of tolerance towards unfavourable environmental constraints. For example, millets, sorghum, groundnuts, lentil, and grass pea can easily be cultivated under nutritionally poor soil with low water availability. Mainstreaming these crops at the global scale can benefit farmers with low income and limited agricultural resources who suffer the consequences of climate change. Several of the underutilized crops might not be suitable for challenging environmental conditions; however, their production can be enhanced in their favourable conditions and marketed globally. Promoting orphan crops can contribute to livelihood security and economic empowerment of socially vulnerable communities.

Enabling breeding technologies deployed for the genetic improvement

The choice of species for research and improvement largely depends on economic investments and regional priorities of crop. Wider applications of emerging genomics and biotechnological tools regarding preservation, genetic diversity analysis, and further improvement of underutilized crops may provide an avenue to enhance the genetic gains of yield and mainstreaming their cultivation. Prior concern should be efficient collection and preservation of all the available germplasms; enhancement of genetic material availability for micropropagation; identification and elimination of pests and diseases; and mining of novel genes to enhance the productivity, retaining the good grain quality and nutritional value. A genome editing, especially CRISPR/Cas-based technologies, has already shown its potential in restoring domestication-related traits in wild tomato (*Solanum pimpinellifolium*) (Zsögön et al. 2018; Li et al. 2018). Technology has already been applied to foxtail millet and cassava (Gomez et al. 2019; Zhao et al. 2020). Targeted editing of novel cap-binding proteins (nCBP-1 and nCBP-2) reduces severity of cassava brown streak disease (Gomez et al. 2019). The application of genome editing technology is needed to be extended to other underutilized crops. However, most of these crops lack good reference genomes and annotations, functional genomic studies, and transformation methods. A substantial research investment would pave the way to enable these orphan crops of targeted genetic improvements.

Marker-assisted breeding is extensively utilized in staple crops and has begun to be employed in some of the underutilized crops including barley, cassava, millets, pigeon pea, grass pea, peanuts, and some perennial plants. Recently, marker-trait association studies targeting nutritional traits have been carried out in some of the nutritionally rich underutilized crops (Nida et al. 2021; Singhal et al. 2021; Jaiswal et al. 2019). However, it remains to be performed in a large number of orphan crops. Significant investments made in the large-scale genome sequencing of legumes and millets and exploring the intra-species diversity in cereals allowed annotating genomes and link with wide array of phenotyping data through genome-phenome associations to identify the key candidate genes and unravel the superior haplotypes containing donors across these crops. Extensive genomic studies and identification of novel genetic determinants controlling beneficial traits from underutilized crops can be systematically mined to design future breeding strategies to overcome the stagnation of yield while maintaining the nutrient density and overcome the agro-climatic and post-harvest challenges (Fig. 1). Application of speed breeding would hasten the pace of crop improvement if applied in combination with genetic modification/genome editing or marker-assisted selection (Singh et al. 2020b).

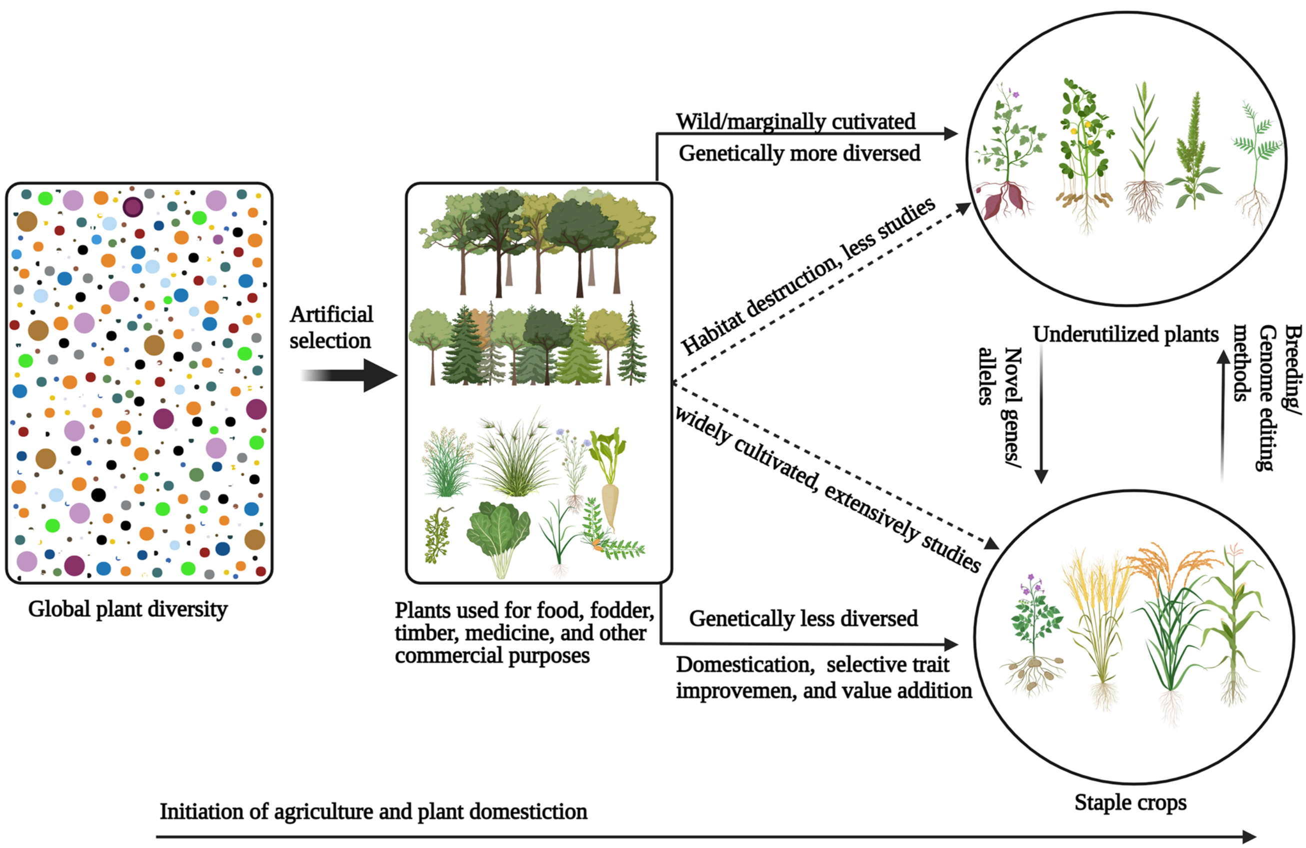

Fig. 1 Schematic representation of cultivation status of plant species. Major crops were selectively domesticated among the diverse plant species, whereas a large number of plants that were neglected and marginally cultivated are termed as underutilized species. Underutilized crops can be a donor of genetic resources for major crop improvement. Similarly, breeding methods and biotechnology-based genetic improvement technologies applied for staple crops can be employed to the improvement of underutilized species. Image created using Biorender.com

Conclusion and way forward

Uniformity in crop selection over the larger areas has strained modern agriculture in the era of changing climates with emerging diseases, and pests. Therefore, (a) bringing in modern breeding technologies to improve the genetic gain for increased productivity with novel nutritional value in minor crops, (b) reintroduction of missing alleles for enriched nutritional content in the staple crops, and (c) undertaking re-diversification of food crop cultivation under crop rotation systems have now been essential to ensure nutritional security and establishment of a sustainable agriculture system. De novo domestication of wild crops is also needed to be initiated through genome editing technologies and speed breeding techniques for their impact for enhancing nutritional quality for some of the underutilized crops and major cereals to improve the livelihood of small-income farmers. In addition, coupling best agronomic practices together with mechanization is desired. Integration of new crops into the existing cropping system might also require the application of different types of machinery for sowing and harvest and also depending on the crop, after harvest processing procedures, which should be provided for the farmers. Extensive research investments and appropriate policies are required to mainstream their cultivation. At the same time, it is also necessary to create awareness among people regarding benefits of consumption of nutritious crops. For an initiative, recognizing nutritional and socio-economic values of millet crops, the Food and Agriculture Organization (FAO) of the United Nations has announced the year 2023 as "International Year of Millets". However, several questions still remained unanswered as: (i) how longer duration it will take to market value addition and linking farmers cultivating underutilized crops? (ii) Could intercrop breeding systems ever be implemented to share genetic benefits among closely related crops? (iii) What should be national and international policies required ensuring the sustainable use of these wild resources?

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Declarations

Conflict of interest The corresponding author is one of the editors of this journal.

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