International Journal of Plant & Soil Science

Volume 35, Issue 19, Page 630-643, 2023; Article no.IJPSS.103964
ISSN: 2320-7035

Millets Based Integrated Farming System for Food and Nutritional Security, Constraints and Agro-Diversification Strategies to Fight Global Hidden Hunger: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i193593

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/103964

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Review Article

Received: 05/06/2023
Accepted: 09/08/2023
Published: 24/08/2023

ABSTRACT

Globally, there is an increase in hidden hunger; a type of malnutrition brought about by a lack of certain micronutrients (Mg, Na, K, Cu, Mn, Mb, Zn, Cr, Su, and Cl). This review tries to investigate the possibilities of millet-based integrated farming system as a tool to tackle this global menace. Small-seeded grains known as millets are renowned for their great nutritional value and resistance to a variety of agro-ecological situations. Millets are high in fibre, protein and micronutrients However, there has been a drop in consumption and cultivation of millets in many countries despite their nutritional potential because of a variety of issues which include: limited access to better seed varieties, a lack of post-harvest infrastructure, shaky market relations, and insufficient policy backing millet production and sales. This review tends to offer important suggestions for overcoming these limitations and encouraging agro-diversification initiatives. These suggestions are: stepping up research and development to improve the adaptability and nutritional value of millet varieties, putting policies in place that support millet marketing and production, setting up a productive post-harvest infrastructure, and raising consumer awareness of and demand for millet-based products. Moreover, encouraging cooperation among many stakeholders, which includes: farmers, researchers, policymakers, and consumers, is essential to create a favourable climate for the adoption and expansion of integrated agricultural systems based on millets. Conclusion: Embracing millets as a cornerstone of integrated farming systems will allow diversification of agricultural methods, which will improve ecosystem services such as soil health and biodiversity which can considerably help to combat hidden hunger and ensure global food and nutritional security.

Keywords: Hidden hunger; malnutrition; millet; micronutrient; nutritional security.

1. INTRODUCTION

"Tackling hunger and feeding the world population are two of the biggest challenges of the modern world. Reasons contributing to this issue range from deficiencies in the supply of micro- and macro-nutrients, shortage in production of foods leading to supply–demand imbalances, and conflicts, which destabilize various parts of the world. Although several of these triggers for hunger can be addressed leading to a slight reduction in the population suffering from hunger and malnutrition from almost one billion in 1990–1992 to 850 million in 2010–2012, the threat of climate change and global warming still lingers" (Kumar et al. 2022).

"One of the largest problems facing the modern world is feeding everyone on the planet. The lack of micro- and macronutrients, shortages in food production that cause supply-demand mismatches, and conflicts that destabilize different regions of the world are all factors that contribute to this problem. Even though some of these causes of hunger can be addressed, the threat of climate change and global warming still exists. As a result, the number of people who experience hunger and malnutrition which decreased slightly from approximately one billion in the years 1990–1992 to 850 million in the years 2010–2012" [1] may experience a sharp increase which may lead to about 2-3 billion people experiencing nutritional insecurity as a result of reduced food production rates and the additional strain of feeding a population that will top 9 billion by 2050 [2].

Food and nutritional security remain a critical global challenge in the 21st century. With the world population projected to reach 9 billion by 2050, ensuring adequate and nutritious food for all has become a pressing concern. Concurrently, the issue of hidden hunger, characterized by micronutrient deficiencies despite sufficient caloric intake, poses a grave threat to the well-being and development of millions of people worldwide. To address these challenges, a sustainable and diversified approach to agriculture is imperative, aiming to improve not only food production but also nutritional content.

Millets come in a variety of small-seeded species, including finger millet (*Eleusine coracana*), proso millet (*Penicum miliaceum*), little millet (*Panicum sumatrense*), foxtail millet (*Setaria italic*), and pearl millet (*Pennisetum glaucum*). Moreover, sorghum (*Sorghum bicolor*), maize (*Zea mays*), barley (*Hordeum vulgare*), and oats (*Avena sativa*), are referred to as coarse cereal [3] are also important in addressing the global challenge of nutritional content.

India is the largest producer of millet grains in the world, with an annual production of 334500 tonnes (43.85 %), Millet provides food, economical, and animal feed stability. Millets, a group of small-seeded cereal grains, have garnered increasing attention as a potential solution to food and nutritional security. These crops have been cultivated for millennia and have shown remarkable resilience to harsh environmental conditions, making them well-suited for diverse agro-climatic regions.

Moreover, millets possess high nutritional value. It is rich in protein, dietary fiber, essential minerals, and vitamins. Integrating millet-based farming systems offers a unique opportunity to combat hidden hunger while ensuring sustainable agricultural practices [4].

“Agriculture productivity is adversely affected with serious impact on production and productivity due to uneven weather conditions, increased temperature, and less availability of irrigation water. Global climate change together with the rapidly increasing population is mounting considerable pressure on agriculture sector to produce more food from less land. The anticipated increase in temperature will mostly affect the hot tropics, mainly populated by developing countries as they are likely to suffer maximum loss in food production” [5]. “Even in temperate regions, several strategies need to be devised for the adaptation of agricultural crops against erratic climate conditions such as changing temperature, erratic rainfall, and onset of severe floods and droughts” [6]. According to Agriculture Organization of the United Nations. Economic, & Social Department, [7], “there is an anticipation that climate change may severely impact food production and food security in several drought-prone regions across the globe”. “This water paucity may lead to shrinking of dietary range and reduction of total food consumption that could possibly lead to malnutrition problems and food insecurity” [8]. “A key issue is whether we will be able to feed the projected global population of 9 billion in 2050 equitably, healthily and sustainably” [9]. “Even if a person consumes enough calories, it is likely that he may have an inadequate consumption of vital micronutrients such as vitamins, minerals and trace elements leading to micronutrient undernourishment or what can be termed as hidden hunger. Pests and diseases are also likely to be greatly impacted by changing temperatures” [10].

“Thus, development of varieties with enhanced nutraceutical value and improved stress tolerance has been one of the priority areas of research these days. Modern crop improvement techniques such as genomics-assisted breeding and genetic engineering play important role in understanding the complexities of stress response and tolerance as well as in providing measures for enhanced crop productivity. However, one of the possible solutions to counter these tribulations can be identifying and improving native crops that are highly adaptive to local climate, have high nutritive value and can efficiently withstand biotic and/or abiotic stresses. Although it is difficult to find a single staple food crop that fulfils all the major criterions, the wide variety and diversity of local food crops (such as minor millets) provide us a choice of such climate resilient crops” [11].

“As India’s agriculture suffer hugely from the vagaries of monsoon, millets which are also known as “famine reserves” for their prolonged and easy storability under ordinary are of great relevance. They are most suitable for mixed and intercropping, thus offer sustainable resources use, food and livelihood security to farmers. Millets, which are grown for both food and fodder, increase farming's economic efficiency and enhance the safety of food and livelihood for millions of households, especially small and marginal farmers and people living in remote tribal areas with limited access to water”. (Tiwari et al., 2022) According to research by Tiwari et al. [12], “a 1% increase in Millet production might cut poverty by 0.65%. As rain- fed areas are 30% less productive than irrigated areas, increasing production is especially crucial in these areas. Therefore, Millets appear to hold the key to fighting poverty, malnutrition, and climate change”.

Table 1. Nutrient composition of millets (per 100 g)

Millets	Carbohydrates (g)	Protein (g)	Fat (g)	Energy (kcal)	Crude fibre (g)	Mineral matter (g)	Ca (mg)	P (mg)	Fe (mg)
Finger	72.0	7.3	1.3	328	3.6	2.7	344	283	3.9
Kodo	66.9	8.3	1.4	309	9.0	2.6	27	188	0.5
Proso	70.4	12.5	1.1	341	2.2	1.9	14	206	0.8
Foxtail	60.9	12.3	4.3	331	8.0	3.3	31	290	2.8
Little	67.0	7.7	4.7	341	7.6	1.5	17	220	9.3
Barnyard	65.5	6.2	2.2	307	9.8	4.4	20	280	5.0
Sorghum	72.6	10.4	1.9	349	1.6	1.6	25	222	4.1
Bajra	67.5	11.6	5.0	361	1.2	2.3	42	296	8.0

Table 2. Vitamin profile of millets

Millets	Thiamin(mg)	Niacin (mg)	Riboflavin	Vit B6 (mg/100 g)	Folic acid (mg/100 g)	Vit B5 (mg/100 g)	Vit E (mg/100 g)
Foxtail	0.59	3.2	0.11	–	15.0	0.82	31.0
Proso	0.41	4.5	0.28	–	–	1.2	–
Finger	0.42	1.1	0.19	–	18.3	–	22.0
Little	0.3	3.2	0.09	–	9.0	–	–
Barnyard	0.33	4.2	0.1	–	–	–	–
Kodo	0.15	2.0	0.09	–	23.1	–	–
Sorghum	0.38	4.3	0.15	0.21	20.0	1.25	12.0
Bajra	0.38	2.8	0.21	–	45.5	1.09	19.0

Table 3. Essential amino acid profile of millets (mg/g of N)

Millets	Arginine	Histidine	Lysine	Tryptophan	Phenyl alanine	Tyrosine	Methionine	Cystine	Threonine	Leucine	Isoleucine	Valine
Foxtail	220	130	140	60	420	–	180	100	190	1040	480	430
Proso	290	110	190	50	310	–	160	–	150	760	410	410
Finger	300	130	220	100	310	220	210	140	240	690	400	480
Little	250	120	110	60	330	–	180	90	190	760	370	350
Barnyard	270	120	150	50	430	–	180	110	200	650	360	410
Sorghum	240	160	150	70	300	180	100	90	210	880	270	340
Bajra	300	140	190	110	290	200	150	110	140	750	260	330

Table 4. Micronutrient profile of millets (mg/100 g)

Millets	Mg	Na	K	Cu	Mn	Mb	Zn	Cr	Su	Cl
Foxtail	81	4.6	250	1.40	0.60	0.070	2.4	0.030	171	37
Proso	153	8.2	113	1.60	0.60	–	1.4	0.020	157	19
Finger	137	11.0	408	0.47	5.49	0.102	2.3	0.028	160	44
Little	133	8.1	129	1.00	0.68	0.016	3.7	0.180	149	13
Barnyard	82	–	–	0.60	0.96	–	3	0.090	–	–
Kodo	147	4.6	144	1.60	1.10	–	0.7	0.020	136	11
Sorghum	171	7.3	131	0.46	0.78	0.039	1.6	0.008	54	44
Bajra	137	10.9	307	1.06	1.15	0.069	3.1	0.023	147	39

Table 5. Fatty acid composition and amylose and amylopectin content profile of millets

Millets	Palmitic	Palmeolic	Stearic	Oleic	Linoleic	Linolenic	Amylose (%)	Amylopectin (%)
Foxtail	6.40	–	6.30	13.0	66.50	–	17.5	82.5
Proso	–	10.80	–	53.80	34.90	–	28.2	71.8
Finger	–	–	–	–	–	–	16.0	84.0
Little	–	–	–	–	–	–	-	-
Sorghum	14.0	–	2.10	31.0	49.0	2.70	24.0	76.0
Bajra	20.85	–	–	25.40	46.0	4.10	21.1	78.9

(Source: Tiwari et al. [13])

Fig. 1. Characteristic features of millets
(Source: Tiwari et al.[14])

2. ETHNOBOTANICAL VALUES OF MILLETS

"Millets have a profound significance in our cultural heritage and until now have played significant roles in temple festivals. These activities are preserved as traditional knowledge in the regulations put forth by PPVFRA, 2001" [15]. These traditions demonstrate that these grains were recognized by our ancestors for their nutraceutical and therapeutic values (Fig. 2).

"One common practice in small grains was their presentation as a wedding gift to the bridegroom. The number of grains gifted was treated as a prestige. The grains were also cooked, especially during puberty and childbirth celebrations" [16].

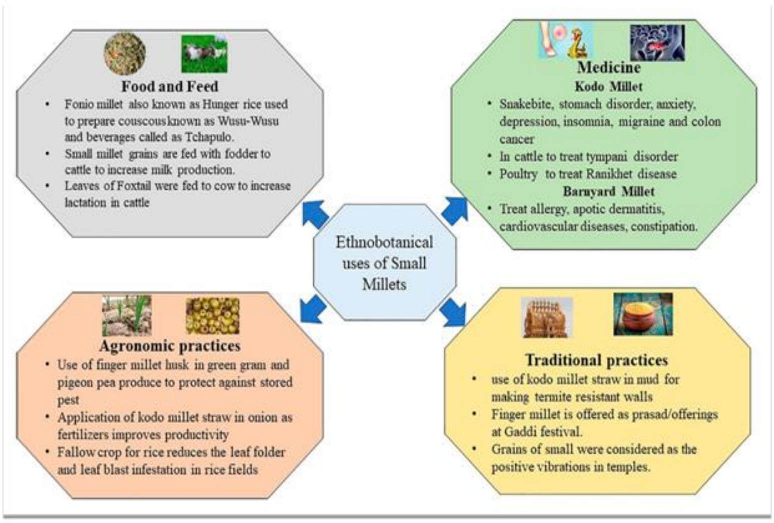

Fig. 2. Ethnobotanical values of millet
(Source: Lydia et al. [17])

3. NUTRITIONAL VALUE OF MILLETS

Millets are rich in folic acid; therefore, they were treated as a special entity for women to overcome anaemic disorders. In Africa, fonio millet, commonly known as "hungry rice," has similar importance. These grains are predominantly used to prepare couscous known as wusuwusu. Fonio is best used in the preparation of beverages called Tchapulo, which is rich in minerals. Finger millet are used in the processing of beer, and its malted products are often used in African tribal communities [18]. "Arake, a distilled liquor, is prepared in Ethiopia with finger millet flour. Furthermore, people residing in Sudan predominantly consume a hot porridge of finger millet with banana or sugar juice, which is a staple dish in tribal zones. A sour bread known as injera is made from teff and is used in spicy stews by well-off tribal individuals. Teff has a unique role in Africa after fonio millet. Due to its cold tolerance in higher altitudes, Teff is popularly known as love grass.The major morphotypes in fonio millet are Yoro, Ipordapia, Ipordawoun, Ipoagoa, and Iporni which are conserved by communities including the Hausa and pagans in West African regions" [19,20].

4. CONSERVATION OF MILLETS

"Regarding the conservation of cultural heritage in India, the Malayali in Eastern Ghats continue to cultivate and conserve small millet landraces" [21]. "The landraces of little, foxtail, and proso millets are conserved by the Kolli Hill tribes; the characteristics of these millets suggest the presence of novel alleles for future breeding programs" [22,23].

5. OTHER USES OF MILLETS

"Tracking the records of the utilization of millets in Chhattisgarh, India has revealed the use of Kodo millet straw in mud to make termite-resistant walls. The farmers of this region also used Kodo millet straw as fertilizers in onion fields to increase productivity. Another traditional practice was the application of finger millet husk in green gram and pigeon pea products to protect these grains from pest infestation during storage. The pot makers in Northern India also are using Kodo

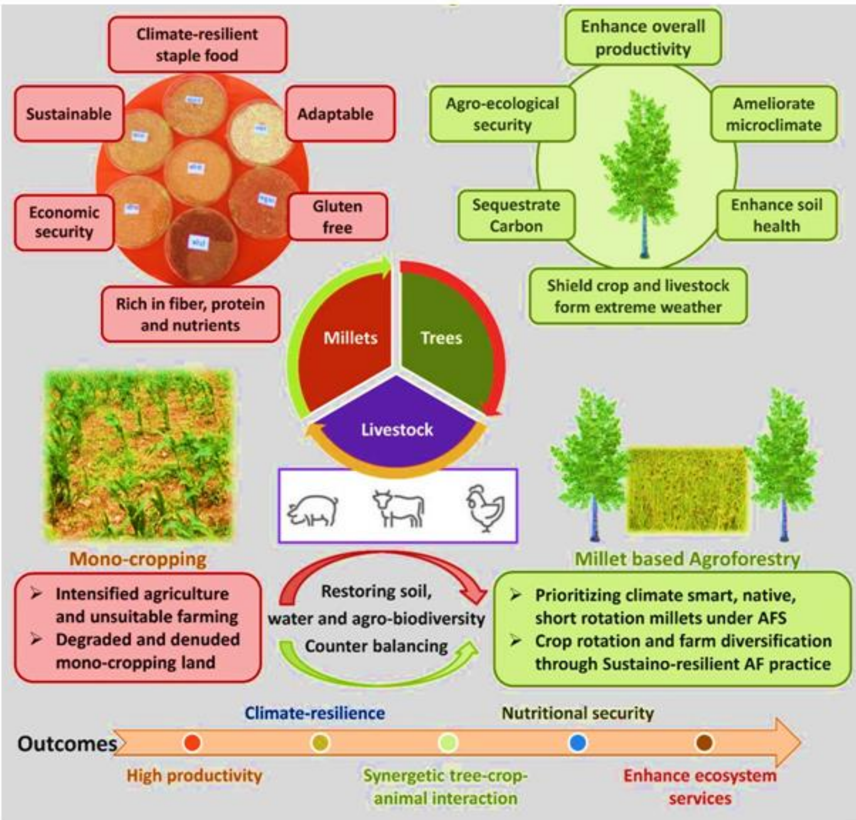

Fig. 3. Millets Based Integrated Farming System
Source: Teli, [24]

millet straw when baking pots. Moreover, the leaves of Kodo millet possess lecithin and are used for the treatment of snakebites, stomach disorders, and joint pain. In cattle, Kodo millet straw had a significant impact on treating tympani disorder. Additionally, the older grains of Kodo millet (3–4 years) were used to cure Ranikhet disease in poultry" [25].

" In Africa and India, Kodo millet was a fallow crop after rice; in other rice fields, Kodo millet straw is usually spread in the fields to protect against leaf folder and blast" [16]. "The millet grains were also previously mixed with fodder to increase milk production in cows. Several recent agro-start-ups in India for cattle feed also practice this technique to enhance milk production in rural dairy farms" [26]. **"**In traditional practice, finger millet is often a prasad/offering in the Gaddi festival. This is believed to enhance the fruiting of non-flowering mango and tamarind trees. Furthermore, thick pastes of finger millet flour are used to treat fire burns, and these grains are considered to offer positive energy in temples" [27].

"Furthermore, barnyard millet is used to treat allergies, atopic dermatitis, cardiovascular diseases, constipation, and blood related disorders. Moreover, Kodo millet is preferred for overcoming anxiety, depression, insomnia, migraine, and colon cancer. Foxtail millet is used to treat chicken pox, heart attack, fever, cholera, and gastric problems. The leaves of foxtail millet are also fed to cattle to increase lactation. These practices underscore the nutritional and therapeutic value of small millets in our heritage. The genetics underlying these traits could be explored and used to develop sustainable diets" [28].

Millet-based Integrated Farming System (Mb IFS) is a climate resilient and sustainable system that combines tree-crop-livestock on the same area of land [29]. Growing crops along with trees offer numerous economic advantages since the trees support crops and livestock as well as a variety of ecological services. Along with its primary economic advantages, MbIFS may also contribute to nutritional security and mitigation of climate change [30,31].

6. TECHNOLOGY INTERVENTIONS

There is a large scope for increasing productivity and profitability for farmers through scaling-up of climate resilient agriculture; however, it calls for concerted efforts, and adoption of location-specific and cost-effective technologies. The new technologies should also be less input intensive, cost-effective, less labour intensive and economically viable. According to Chapke and Tonapi, [32], "Based-on experience of millets cultivation, some promising interventions are underlined as follows:"

6.1 Promotion of Allied Enterprises as Integrated Farming System

Since, the mono-cropping and traditional farming are not viable, addressing only a component of the farming system, e.g., crop variety, fertilizer use or even crop husbandry is not expected to bring about a significant increase in the productivity as witnessed in irrigated areas. The soil, plant, and animal cycle is the basis for all feed used by the animals. The livestock in the rain fed regions are weak. Farmers in this area often sell their cattle due to the scarcity of fodder. The land holdings are being reduced with increased population pressure. There is large unexploited scope to harness system level productivity and value chains, wherein women have income generating opportunities through women-focused activities. Therefore, the millets-based integrated farming system approach with introduction of poultry, dairy, goat farming, piggery and apiculture at each household will help to supplement the farmers' income and women empowerment.

6.2 Millets-based Intercropping

To achieve appropriate land use, efficient inter- and sequence-crop systems were recommended based-on soil type, rainfall and length of growing seasons. Intercropping sorghum with legumes not only produces higher yields per unit area and time, but also provides nutritional security, economic benefits and improves soil health. Sorghum + pigeon pea (2:1/3:1/6:2) and sorghum+ soybean (3:6/2:4) are the two most common intercropping systems. Medium duration sorghum genotypes are most suitable for intercropping. Soybean - rabi sorghum has been found more productive and economically viable system in areas receiving annual rainfall above 700 mm and medium to deep soils having high water retention capacity, and sorghum (kharif)-chickpea, safflower and mustard (rabi) under limited irrigation conditions. Many other millets-based intercrop and sequence cropping are found to be more profitable.

6.3 New Niches of Millets Cultivation (In Rice Fallows)

Although millets are known to be climate resilient crops, their cultivation in traditional areas is reducing. New niches like in rice fallows; sorghum or millets cultivation plays significant role in economic security of the farmers. "According to research carried out, Sorghum hybrid; CSH 16 (7.50 t ha-1) yielded significantly better than the locally popular hybrid Mahalaxmi 296 (5.86 t ha-1) in rice fallows in Guntur district of Andhra Pradesh, in four years from 2012 to 2016. The significant increase of 27% was observed in grain and ultimately it was resulted into 73% higher monetary benefit to the farmers" [33]. "The district yield average of sorghum is 6.80 t ha-1 during 2014-15 which is around seven times more than the national yield average (0.90 t ha-1). Such success story can be replicated in the areas where, the scope is to introduce sorghum and other millets in rice fallows which, assures additional income to the farmers" [33].

6.4 Millets-based Pulses Crop Systems

"The pulse-based cropping systems are environmentally sustainable also, as they require lower use of fertilizers, pesticides and irrigation in addition to enhancing the productivity of cropping systems by increasing yield of subsequent crops" [34,35]. To achieve appropriate land use, efficient inter- and sequence-crop systems were recommended based-on soil type, rainfall and length of growing seasons.

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Many other millets-based intercrop and sequence cropping are found to be more profitable namely: intercropping of sorghum (CSH 16) with pigeon pea in 2:1/2:2 row ratio and sorghum + soybean in 3:6 row ratio. Medium duration sorghum cultivars like CSH 16, CSH 18, CSH 25, CSV 15 and CSV 20 were most suitable for intercropping with green gram and black gram. Crop sequence with black gram / green gram /soybean / cowpea (fodder) in kharif followed by rabi sorghum, and soybean-rabi sorghum sequential cropping was found more feasible and profitable.

Moreover, mix-cropping of sorghum and chickpea is well established and prominent in most of the rainfed areas of the Maharashtra and Karnataka. Promising intercropping with other minor millets were like, Pearl millets + Green gram, Pearl millets + Groundnut, Finger millets + Pigen pea, FM + Black gram, FM + Field bean, Barnyard millets + Rice bean, Foxtail millets + Pigen pea, Foxtail millets + Field bean, Kodo millets + Pigeon pea, oilseeds, little millets + Pigen pea, green gram, Soybean, and Proso millets + Green gram. Crop sequence with Pearl Millets-Chickpea and Finger Millets-Black gram, green gram is also recommended (Table 6 and Fig. 4).

Table 6. List of recommended dosed for Intercropping systems

Intercropping systems	Recommendation
Sorghum + pigeon pea	Metolachlor 0.75-1.5 kg/Fluchloralin 0.50/Pendimethalin 1.0 /Alachlor at 1.0 kg/ha + 1inter-row cultivation/h and weeding
Sorghum + cowpea/green gram/black gram	Isoproturon at 0.50 kg/ha or butachlor at 0.75-1.0 kg/ha or metolachlor 1.0 kg + 1 HW
Cropping systems	
Sorghum-cotton	Pre-emergence application of atrazine 0.25 kg/ha in sorghum and pendimethalin 1.0 kg/ha in cotton; Poor establishment of green gram and groundnut after atrazine treated sorghum.
Sorghum-safflower	Pre-emergence application of atrazine at 0.75 kg/ha in sorghum

(Chapke et al. [36])

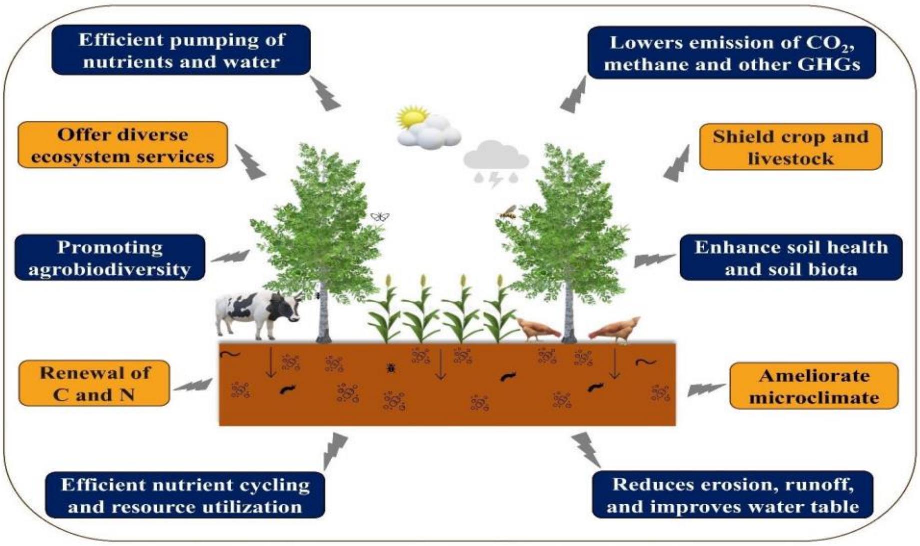

Fig. 4. Role of Millet Based IFS in Restoring Agroecology
(Source: Teli [24])

The combination of millets trees, and livestock restores soil health and renews food security through closed nutrient cycling and effective resource utilization. Integration of trees along with crops can withstand adverse weather conditions [37,29].

Climate change has caused significant challenges in recent years, reducing crop productivity, favouring the spread of weeds, pests, and other diseases, and altering the nutritional value and composition of crops [38,39,40]. Thus, there is a need for climate-resilient farming techniques that may increase agricultural output and withstand changing climatic conditions. Integrated farming system (IFS) and millets can both contribute significantly to the provision of numerous agro ecosystem services. It can be scaled out even further by combining both crucial components and growing millets under various IFS. The Millet-based integrated farming system (MbIFS) can become a climate smart system and a workable option to address the current challenges of food, nutrition, energy, employment, and environmental security by regulating microclimate, protecting natural resources, and modifying hydrology, biogeochemistry, and agro biodiversity [41].

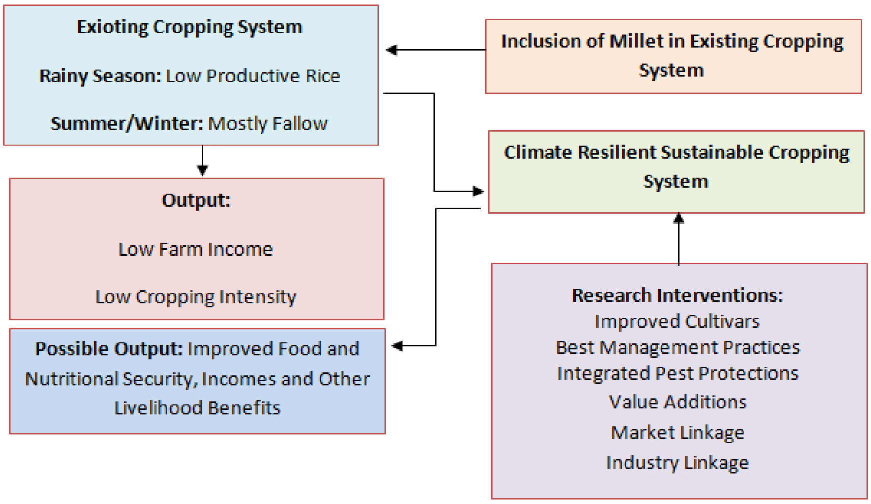

Fig. 5. Strategy to promote millet in existing cropping system
(Source: Brahmachari et al., [42])

7. GLOBAL PERSPECTIVE OF MILLETS

"Internationally, the demand for millet based processed products is snowballing day by day. The economic gains through the adoption of millet-based cropping system may be augmented by addressing envisaged benchmarks resulting in significant improvement in productivity, profitability and even export earnings. Millets can be successfully grown in drought prone and unfertile soil where most other crops often failed to grow. Cultivated millets not only contribute to the economic efficiency of farming but also provide food and livelihood security to millions of downtrodden communities of the different parts of the world. Major millets producing counties are concentrated in the pockets of southern and western Africa and Asia. Similar growth environment like drought prone and red laterite region of eastern India, predominates in different parts of the Globe like southern and western Africa and Asia west-central High Plains of the USA and Western Australia are conducive for millet production. Therefore, millet-based crop production model possibly equally applicable to these regions" [42].

8. CHALLENGES FOR MILLET PRODUCTION

"Despite the breeding efforts, most of breeding programs fail to deliver hybrids due to a vast variation in microclimate (day and night temperature and humidity) and soil apart from rainfall, which requires proper quantification" [27]. Furthermore, narrow cultivar diversity in drought-prone ecology also is another factor for this. Thus, there is a high need to give higher priority to the below mentioned areas to promote its production and utilization:

- Development of hybrids/varieties of millet with better regenerative capacity on reversal of dry spell for harsh environment/drought-prone areas (for A1 zone in India).
- Development of hybrids/varieties resistant/tolerant to salt/high temperature.
- Shift in focus of breeding from productivity improvement to the identification of end product-specific traits.
- Mainstreaming of bio-fortification in millet for iron and zinc.
- Enhancement of shelf life of millet flour and overcome rancidity to promote its products.
- Development of screening protocols and control measures against different diseases such as downy mildew, blast, rust, ergot, smut.
- Generating authentic data on nutritional benefits of millet and bioavailability studies.
- A study on demand survey for millet.

9. CONCLUSION AND FUTURE PERSPECTIVES

Millet is no longer referred to as a coarse cereal, but rather as a nutri-cereal or a nutraceutical crop, and it is viewed as a possible solution to malnutrition and hidden hunger around the world. Apart from its high nutritional value, its capacity to tolerate diverse abiotic stresses and fight infections makes it an ideal model for investigating the immense genetic and genomic potential of this otherwise essential crop and allied cereal grasses. These properties on the whole make millet an ideal model for studying genomics and a plausible source for gene mining for complex traits [43].

Molecular biology and biotechnology have proven to be a potential technique for instilling stress tolerance in commercially significant plants; nevertheless, progress in millets has been limited thus far, owing to a lack of adequate genomic resources in these crops. However, with the availability of sorghum, foxtail millet and *Brachypodium* genome sequence, and on-going genomics program in millet and millet will be of great help for the abiotic and biotic stress tolerance research in these minor cereals. High throughput sequencing platforms will not only be able to overcome the complexity of the millet genome, but will also aid in the understanding of stress tolerance regulation at the transcriptional, post-transcriptional, and epigenetic levels. An integration of various advanced high throughput omics strategies will definitely revolutionize millet research with the large-scale identification of stress responsive genes/proteins/metabolites that could potentially be used for crop improvement. Potential candidate genes responsible for high yield, biotic and abiotic stress tolerance and those involved in high mineral accumulation isolated from millet can also be utilized for improving other cereal crops through transgenic approaches or genomics assisted breeding and pave way for the development of designer crops for a better and sustainable future.

Production of transgenic crops expressing functional foreign genes has to be expanded to millets as well in order to produce transgenic millet varieties expressing foreign genes of agronomic importance, which will be very helpful in improving millet production by conferring resistance to both biotic and abiotic stresses. In the future, developing a super grain may be conceivable by combining multiple agronomically relevant features into the genome of a single millet genotype. Thus, combining current developments in molecular breeding and genetic engineering with advanced Omics technologies will undoubtedly help to improve the current state of millet research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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