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A review on problem and prospects of millets production in India

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Abstract
Millet crops are small grain cereal crop beside rice, wheat and barley and are rich source of proteins, nutrients, minerals, organic compounds which are important to overcome food insecurity, malnutrition, and several common and lethal diseases. However, despite its enormous potential, India's millet production still faces a number of problems such as poor research and development, lack of high yielding varieties, labour intensive and low productivity and lower minimum spot price (MSP) and unfavourable government policies that must be assured to overcome guarantee its continued expansion. Additionally, the government can be very helpful in helping smallholder farmers boost their productivity and output by giving them financial and technical support. As a result, the review looks at the adoption and development of millet cultivation as well as its key constraints. The assessment also emphasised the potential for expanding millet farming. Increasing governmental and private funding for research and extension services, boosting farmer associations and market connections, endorsing millet-based goods and value chains, and incorporating millets into the country's food policy are some of these. The review concluded that millets could assist achieve the sustainable development goals (SDGs) and promote fair and sustainable agricultural expansion, which would enhance the availability of nutritious foods worldwide. However, realising this opportunity will call for coordinated efforts from several stakeholders, such as legislators, academics, and farmers.

Keywords: Millets, problems, prospects, nutrition security, sustainable agricultural

Introduction
Millets are nutri cereals comprising of sorghum, pearl millet, finger millet (Major millets) foxtail, little, kodo, proso and barnyard millet (minor millets) (Figure 1). These are one of the oldest foods known to humanity. These are one of the several species of coarse cereal grasses in the family poaceae, cultivated for their small edible seeds. Pseudo millets are so called because they are not part of the Poaceae botanical family, to which 'true' grains belong, however they are nutritionally similar and used in similar ways to 'true' grain (Tripathi *et al*., 2023) [63]. People are more concerned about sustainability and adequate nutrition these days in their mills, as a result, millets must be produced in order to meet the need of the food and nutritional security of growing population (Chapke *et al*., 2018) [11]. Millets are high in nutrition and dietary fibre. They serve as good source of protein, micronutrients and phytochemicals and antioxidants. The millets contain 7-12% protein, 2-5% fat, 65-75% carbohydrates and 15-20% dietary fibre. The essential amino acid profile of the millet protein is better than various cereals such as maize, rice, wheat, and barley. Millets contain fewer cross-linked prolamins, which may be an additional factor contributing to higher digestibility of the millet proteins (Patra *et al*., 2023) [54]. In addition to its nutritional advantages, it is climate resilient (RE) and suited to the dry-land agro-ecologies of the semi-arid tropics, particularly areas with little precipitation and low soil health. India is the world's greatest grower of millets, accounting for around 40% of global output, and ranks second in terms of supplying millets (Gowri and Shivakumar, 2020) [17].
Millets are cultivated in arid and semi-arid regions where major cereals are unable to produce considerable yields worldwide, especially in the undernourished countries such as Ethiopia, South Africa, India, Sudan, Senegal, and Bangladesh etc. (Kumar *et al*., 2018) [32]. (Adekunle, 2012; Yang *et al*., 2012) [1, 71].

Therefore, the United Nations (U.N.) has chosen to designate 2023 as the international year of millets in recognition of the possible critical role that millets could play in improving the health status of a sizable section of the world's malnourished population (Muthamilarasan and Prasad, 2020) [45]. This declaration was made in an effort to raise awareness of the various advantages that millet crops offer in terms of health, nutrition security, and food security as well as their potential long-term contribution to sustainable agriculture, adaptation to climate change, and the decrease of malnutrition (Kane-Potaka *et al*., 2021, Joseph *et al* 2023) [22, 21]. Besides that, Millets can be a part of crop rotation systems that help break pest and disease cycles.

This review also focused on tactics and prospects for growing millet cultivation. These include strengthening ties between farmers' groups and the market, endorsing products and value chains based on millet, integrating millets into the nation's food policy, and increasing public and private funding for extension and research activities. As per the evaluation conducted by Kheya *et al*. (2023) [27-28], millets have the potential to contribute towards the attainment of significant Sustainable Development Goals (SDGs) such as SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-Being), SDG 12 (Sustainable Consumption and Production), and SDG 13 (Climate Action). This is because they can foster fair and sustainable crop growth. By doing this, food and nutrition security would be improved globally. The review emphasises the significance of using an all-encompassing, multidisciplinary, inclusive strategy that gives innovation and sustainability priority. The main objective of this is to illuminate the opportunities and problems that farmers encounter in this situation.

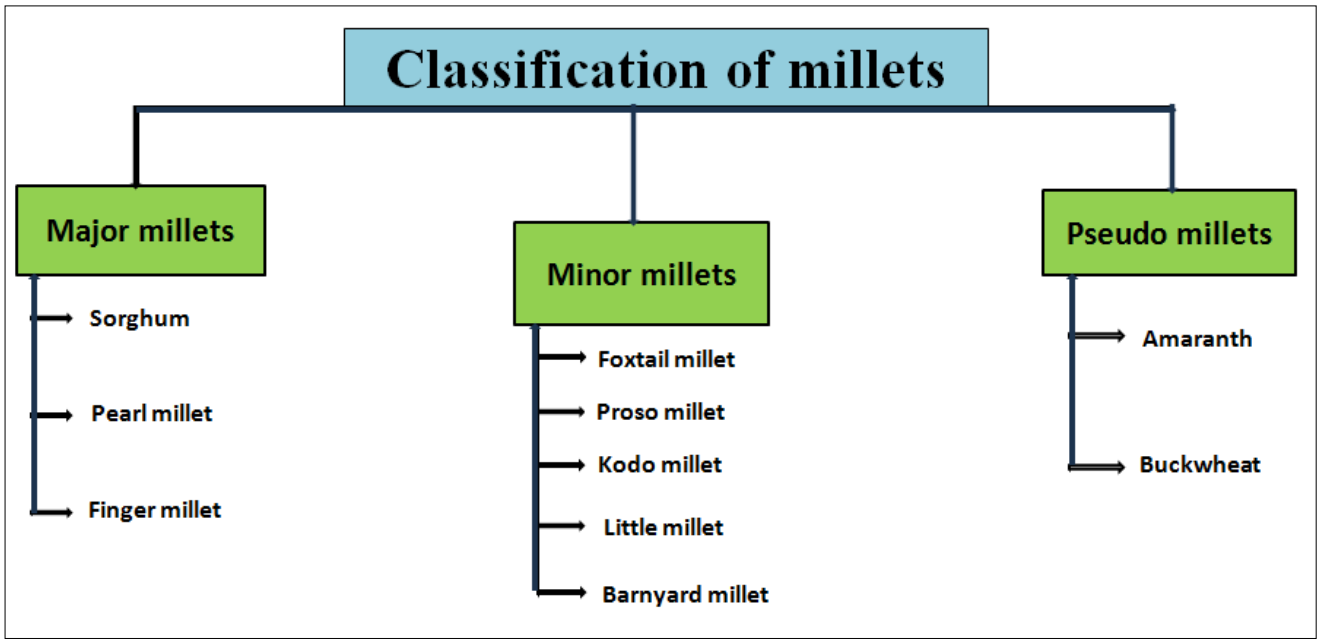

Fig 1: Classification of millets.

2. Current Trends in Millet Production

Millets are grown in over 100 nations thought the world. India is the worlds's largest producer of millets of 2022 with the total share of 11.8 Mt followed by Niger (3.7 Mt) and China (2.7 Mt) and many more countries (Figure 1). In Africa, millets are the second most widely grown cereal particularly important in semi-arid regions where they are grown as rained crop Kheya *et al*. (2023). In recent years, millets have been recognized as important substitutes for major cereals crops to hope up with the world foods storage and to meet the demands of increasing population of both developing and developed countries (Karuppasamy, 2015) [24]. Indian government has also been promoting millet production as part of its National Food Security Mission. As a result of these factors, millet production in India is expected to continue to grow in the coming years. In India almost 21 states of the country are producing millets and out of which Rajasthan (27%), Maharashtra (15%), Uttar Pradesh (14%), Karnataka (13%), Madhya Pradesh (8%), Gujarat (7%), Haryana (7%), Tamil Nadu (4%), Andhra Pradesh (2%), Uttarakhand (1%) and other states (2%) are major millets producing states in India as presented in Figure 3. Millet production accounts significant contribution country's agricultural economy, national and food security as well as employment to millions of people in the country (Sukanya *et al*., 2023). The country's principal products include pearl millet (60%) sorghum (27%), finger millet (11%) and other small millets (2%).

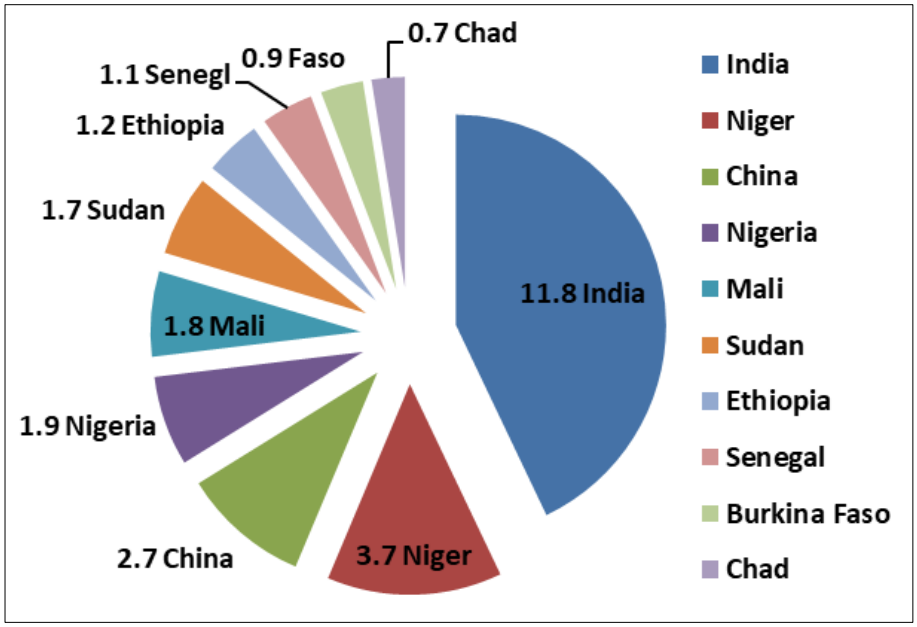

Fig 2: Country wise millet production in million tonnes (FAOSTAT, 2022).

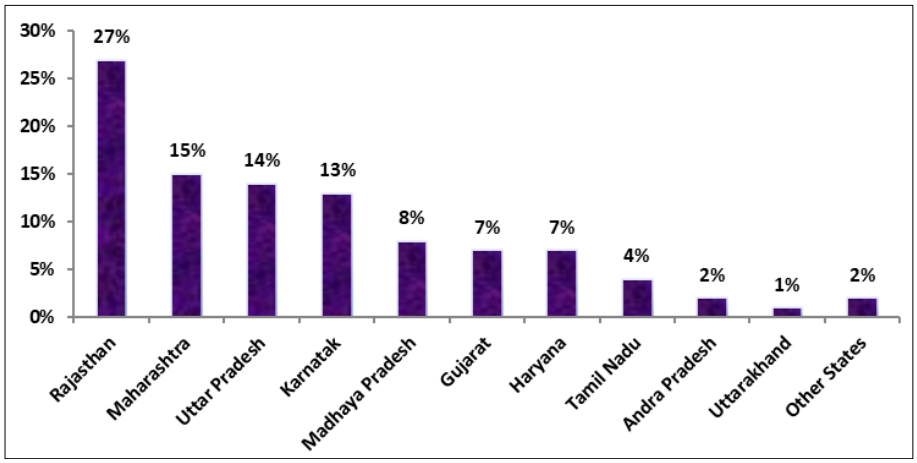

Fig 3: State wise millet production (%) in India (FAOSTAT, 2021-2022).

Problems of Millet Production

Millets have many benefits for sustainable agriculture, but before they can be a practical choice, a number of issues must be resolved. According to Yadav *et al.* (2012) [68], millets typically demand more labour and specific agricultural practices than other crops. Millets are also not as accessible as other crops, so farmers might not have access to the resources and supplies needed to cultivate them. It is also challenging for farmers to turn a profit because millets have a poor market value (Patra *et al*., 2023) [54]. The problems and prospects are enlisted briefly as below:

Limited availability of quality seed

The scarcity of high-quality seeds is a significant obstacle for millet growers in India. Market-available seeds are frequently of lower quality or tainted with disease or weeds. Because of this, farmers find it challenging to acquire the yield they want from their crops.

Lack of high yielding variety

The absence of better varieties and production methods is one of the primary obstacles to millet farming. Local landraces account for most millet cultivars cultivated (Kheya *et al*., 2023) [27-28].

Pest, disease and weed pressure

The productivity of millet crops can be significantly impacted by pests and illnesses (Motagi *et al*., 2014) [44]. Farmers may experience lower incomes and decreased yield because of this. According to the survey, one of the biggest problems facing farmers is the absence of efficient methods for managing diseases and pests. It is important to note that diseases and pests have become more common recently due to the detrimental effects of climate change, particularly the rise in temperature. Weeds that frequently appear in millet fields are associated with the following families: Poaceae, Convolvulaceae, Asteraceae, Amaranthaceae, Commelinaceae, Compositae, Nyctaginaceae, apparridaeceae, portolacaceae, ehphorbiaceae, tiliaceae, alizoaceae, zygophyllaceae, asclepiadaceae, cyperaceae, and scrophulaceae (Mishra *et al*., 2018) [42]. Millet and weed compete for resources including water, space, and nutrients. Sorghum yields between 15 to 83% less when uncontrolled weed infestation is present, compared to 16 to 94% for pearl millet, 55 to 61% for finger millet. These crops are typically regarded as traditional and specialised, with little market

potential and poor costs. This restricts farmers' ability to profitably grow millet, according to the study (Mishra *et al*., 2018) [42]. Other factors that affect this include crop cultivars, weed infestation type and intensity, management techniques, and environmental conditions.

Labour intensive and low productivity

According to Yadav *et al*., (2019) [69] millets are generally thought of as low-yielding crops with lower productivity when compared to other cereal grains crops like wheat and rice. Numerous factors, including as the lack of improved varieties, inadequate inputs, and inadequate agronomic practices, contribute to low yield. An important yield gap exists between farmer's practices and crop potential yields due to poor crop, soil, and water management as well as continued land degradation. Further factor contributing to low productivity is the lack of infrastructure and programmes for the production and distribution of premium seeds and other agricultural inputs to farmers. Another issue that Indian millet growers deal with is low yield. Farmers may experience lower earnings and profits as a result of low productivity. Millets are primarily grown on hillsides or slopes, and there is little chance that they will be mechanised to lessen the labour-intensiveness of production and post-harvest processes (Gyawali, 2021) [19].

Lack of infrastructures and proper marketing facilities

It may be challenging for farmers to reach markets and buyers due to inadequate infrastructure, such as transportation services and roads. Farmers might experience a decrease in revenue as a result. There are no adequate infrastructures or facilities in place to store millets or prevent post-harvest losses. Poor transportation infrastructure makes it difficult to move millet in a timely manner throughout the nation's many regions. There are inadequate irrigation infrastructure and a scarcity of water in many parts of the nation. According to Gyawali (2021) [19], the crop has become unprofitable due to inadequate marketing facilities and significant price fluctuations.

Low prices

It could be challenging for farmers to turn a profit on their harvests due to the low rates that millet buyers are willing to pay. This may make one less inclined to grow millet.

Lower MSP and Lack of price information

Many times, farmers are unaware of the actual worth of the millet they produce. The government provides minimum support prices (MSPs), loan subsidies, and other incentives, but the area under millet cultivation has not risen in large part due to lower income from millets. It could be challenging for farmers to turn a profit on their harvests due to the low rates that millet buyers are willing to pay. This may make one less inclined to grow millet.

3.8. Lack of adequate storage facilities

India's millet growers also have to deal with inadequate storage facilities. Reduced farmer revenues and early crop spoiling are two consequences of inadequate storage facilities.

Unfavourable government policies

The production of millet may be negatively impacted by unfavourable government policies such exorbitant taxes and subsidies. Because of this, it could be challenging for farmers to turn a profit on their crops.

Lack of extension services

In India, extension services are frequently insufficient, despite the fact that farmers need them to obtain up-to-date information and guidance on millet cultivation. This may result in subpar crop management and lower yields.

Limited access to inputs and credit

The insufficiency of timely and high-quality agricultural input supply is another obstacle to Bangladesh's cereal crop development. It states that smallholder millet farmers frequently struggle to get loans to invest in their farms and to obtain inputs like seeds, fertiliser, and insecticides. According to the analysis, this hinders their capacity to raise yield and productivity. According to Mondal (2010) [43], only 18% of the seeds needed in the country may be obtained from government and commercial sources that have undergone certification and adequate labelling. The remaining 82% of seeds are stored by farmers themselves. It should be noted that one of the main issues thought to be restricting agricultural productivity is farmers' poor-quality seed. The commercial sector's and non-governmental organisations' contribution to the production of high-quality seeds remains negligible due to the lack of facilities for seed processing and preservation (Mondal 2010) [43]. About 90% of farmers in the country are small and marginal farmers who often struggle with financial limitations that hinder them from covering significant management expenses. Their access to institutional finance is severely restricted because of the collateral requirement. Because of their conditions, these farmers are forced to utilise inputs far less frequently than is recommended, which ultimately results in low output-particularly costly P and K fertilisers.

Lesser Shelf-life

The shelf life of millet flour is limited to 1-2 months, thus businesses who want to add value to the grain and sell products made from it need to charge more for them. Since the impoverished and middle class cannot afford the pricey items, the crop has evolved into the logical choice for the wealthy and powerful.

Lack of investment in millets research and development

Research on millet is underfunded, which impedes technology development and knowledge transfer to farmers who want to grow millets but lack the necessary skills. Additionally, there is a lack of high-quality seeds and little research and development being done on better millet kinds. Low financing has resulted in subpar performance from the National Agricultural Research System (NARS). In several fields, there are less opportunities to nurture and advance young scientists as a result of funding constraints.

Prospects of Millet Production

Prospects suggest potential future opportunities. According to farmers and extension agents, millets have significant potential because they require little to no input and can withstand biotic stress.

Health benefits

Millets are utilised by people with celiac disease since they are a gluten-free grain. The anti-diabetic feature of millet is

its ability to lower blood glucose response and glycosylated haemoglobin, hence lowering the glycemic index and lowering the risk of developing diabetes mellitus. The phenolic chemicals included in millet grains eliminate free radicals, hence lowering oxidative stress (Lokesh *et al*., 2022) [36]. Similar to how millet extracts inhibit the proliferation of cancer cell lines, it possesses anti-cancer qualities. produce phase-2 detoxifying enzymes and prevent DNA damage. Reduced incidence of hypertension is achieved by millets' ability to stop low-density lipoproteins from oxidising.

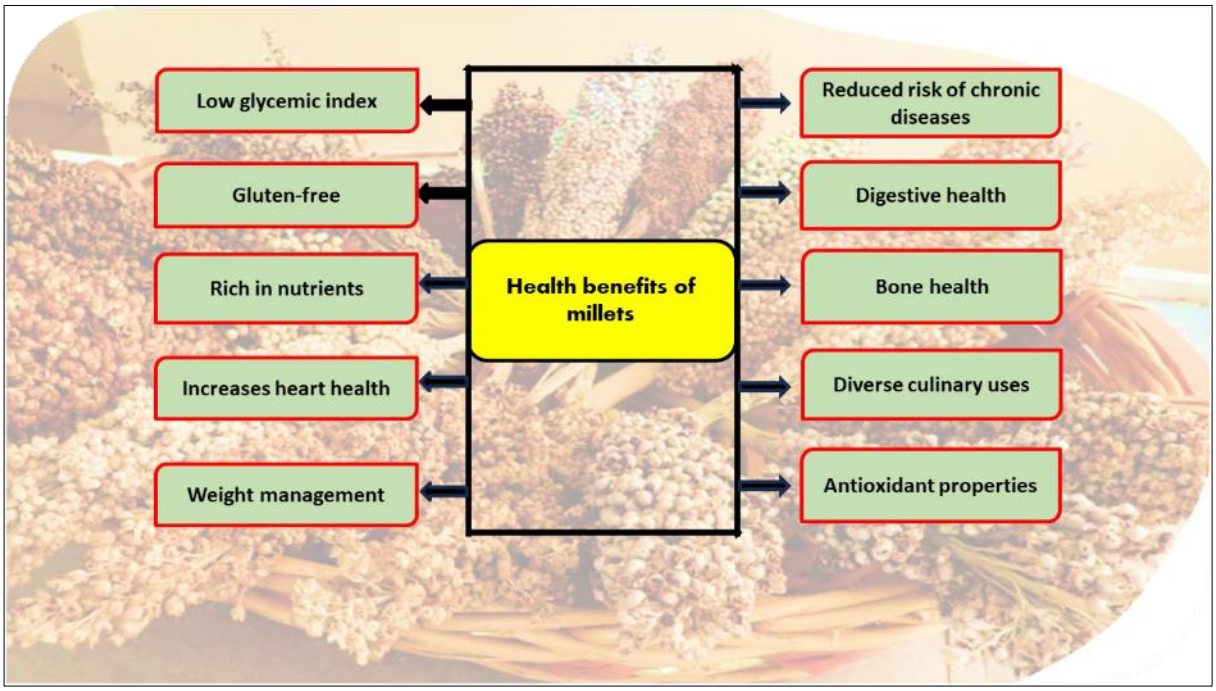

Fig 4: Various health benefits of millets.

Food security and climate change

Due to its impact on the availability and quality of soil and water resources, climate change places significant strain on these resources. The preservation and enhancement of the world's soil resources to the extent necessary to supply food, fibre, and freshwater is referred to as soil security (Koch *et al*., 2013) [30]. 97% of the food produced in the world is said to be grown in soil, which is also home to 98% of terrestrial biodiversity. There has been relatively little attention paid to the worrisome rate at which soil quality is deteriorating. This has caused disruptions to the food systems, imbalances in the supply and demand, deficits in macro- and micronutrients, and a decline in the production of major crops including maize, wheat, and rice (Saxena *et al*., 2018) [58]. Given that the world's population is estimated to reach 9 billion people by 2050 and that 2-3 billion of them would likely be malnourished and experience hunger, the current situation has prompted important concerns about how to meet the world's growing food demand Godfray *et al*., 2014 [16], Wheeler and Von Braun, 2013) [65]. Agriculture's sustainability and food security are put at risk by rising global average temperatures brought on by greenhouse gas emissions, which also directly lower agricultural yields and productivity (Kang *et al*., 2009) [23]. Other minor cereal crops, such sorghum, and millets, have relatively small carbon footprints. Millets have the potential to be a crop that helps lower global carbon emissions for this reason, among other main ones (Prasad and Staggenborg, 2009) [54]. Because millets are resistant to both biotic and abiotic challenges and may produce a sizable yield on poor quality soil with little input, they can be grown in semi-arid and arid climates (Awika, 2011) [5]. Millets are both thermophilic—they can grow at higher temperatures and xerophilic they can proliferate when there is a shortage of water. Unlike sorghum or maize, pearl millet, finger millet, barnyard millet, and kodo millet can grow on poor sandy soils and thrive in arid climates with low annual rainfall (200-500 mm). This is because they can use the available moisture more effectively (Guigaz, 2002; Wallace *et al*., 2015) [18, 64]. In parts of Africa and India, it is regarded as a crucial crop for ensuring food security (Passot *et al*., 2016) [52]. Because of its high photosynthetic efficiency, foxtail millet reaches maturity early, making it an ideal choice for use as a catch crop. Owing to their brief lifespan, multiple crops can be harvested from a single plot of land during a single year. In addition, it has a high nutritional content and strong pest and disease resistance (Dwivedi *et al*., 2012) [13]. With just one pre-sowing precipitation, this crop yields well (Zhang *et al*., 2007) [72]. Each of these characteristics highlights how crucial millets are to both sustained agriculture and food security.

Climate smart crop

The main effects of climate change are rising temperatures, erratic precipitation patterns, and an increase in greenhouse gas emissions, especially carbon dioxide. The country will also frequently face cyclones, salinities, droughts, and floods because of climate change. The yield of key cereals has been significantly impacted by climate change, which is a serious worry in the modern era. In these conditions, millets are a sustainable crop that can endure the negative effects of climate change and global warming. Due to their low carbon footprint in agriculture, ability to withstand hot and dry conditions, and environmental soundness, millets are referred to as climate-smart crops. Millets are widely recognised for their climate-resilient attributes, such as their

capacity to adjust to diverse ecological circumstances, decreased requirement for irrigation, enhanced development and yield in the presence of limited nutrient input, and low susceptibility to environmental perturbations (Kole et.al., 2015) [31]. An estimated 2 MT of agricultural production would be lost because of sea level rise brought on by climate change, which would also cause the flooding of 16% of all farmed land, the eviction of 10% of the population, salt buildup in the coastal zone, and worse crop yields. According to M. Begum *et al.* (2017) [9], millets can thrive in highly salinized soils. According to the study, foxtail millet has some salinity tolerance and can be grown using better agronomic techniques and cultivars. Different types of millets climate resilient traits are list out in table 1.

Table 1: Various types of millets with climate resilient traits.

Crops	Climate resilient traits
Pearl millet	Highly adaptable wide range of heat and drought can be cultivated in very poor soils and responsive to high input management
Finger millet	Adapted to wide altitude range, moderately resistant to drought, heat stress, and humidity
Foxtail millet	Adapted to high altitude and low rainfall conditions
Proso millet	Short duration crops, adapted to high altitude and rainfall conditions
Little millet	Famine food, adapted to poor soils, low rainfall, and can also withstand waterlogging to some extent
Kodo millet	Very hardy crops with long duration, adapted to low rainfall, poor soils, and shows good response to improved agronomic practices
Barnyard millet	Short duration crop, well adapted to high altitudes and low rainfall conditions

Source: from (Paschapur *et al*., 2021; Kheya *et al*., 2023) [52, 27-28].

Potential for processing industry

The processing sector can expand and flourish significantly at the local and national levels with the help of millet crops. Given that millets meet most of the requirements to be considered a staple food crop, they are likely to be acknowledged as an inexpensive supply of minerals and protein, which are lacking in staple food crops like wheat and rice, which primarily provides energy. Millets, particularly sorghum malt, are mostly used in industry as raw materials to make beer, lactic acid, and alcoholic fermented beverages (Adekunle, 2012) [1], confections, and foods for weaning (Anukam and Read, 2009) [4]. Grain millet has good processing properties. Since millet is a staple crop that is consumed at the household level, it must be processed at the household and industrial levels. This processing should involve small, medium, and large-scale enterprises (Obilana and Manyasa, 2002; Hamad, 2012) [48, 20]. Wetting, dehulling, and milling are the three main primary processing steps and fermentation, malting, extrusion, flaking, roasting, and popping are the secondary processing steps. Soaking, germination, and drying are the primary steps in conventional malting, which is primarily carried out in underdeveloped nations.

Value added products

Millet crop value-added products, such as baked and extruded ready-to-eat meals, can be sold, and acknowledged as a suitable replacement for the so-called health drinks that are sold as fortified supplements for kids. The reliability of these drinks is frequently questioned by health experts due to their high sugar and artificial flavouring content. The most essential ingredient for creating and manufacturing value-added and functional foods is composite flour, which is made from the grains of millet crops like kodo millet in great demand (Kaushik *et al*., 2021) [25]. These hybrid flours from non-millet staples (rice, maize, and wheat) and millets (sorghum, kodo, and pearl millet) are essential for making delicate biscuits and cookies. Meanwhile, scientists are investigating the nutritional content of breads made with millet flours, whether hybrid or not, and their findings are remarkable (Akeredolu *et al*., 2005; Laminu *et al*., 2011; Vidya *et al*., 2012, Eduru *et al*., 2021) [3, 33, 64, 14]. Grain products, meals, and flour are among the popular millet items available in the market.

Millet based crop diversification or millet-based cropping system

The farming system's mono-cropping practice is linked to a number of problems, including declining farm profits, climate change, and food poverty, all of which make agricultural output unsustainable. An option to profit maximisation with improved fertility status is crop diversification, which offers a greater range of crops. In the future, switching to various agricultural methods might be necessary since they support sustainable intensification and yield several advantages from a single plot of land. An option for improved nutrition provision, less greenhouse gas emissions, drought tolerance, improved soil fertility, and increased biodiversity is to include millets in the cropping system. Millets are a crop that can tolerate and withstand a wide range of climatic conditions, even though Indian agriculture faces several challenges such as climate change and unpredictable rainfall. The area used for millet production has been declining, even though these cereals offer greater nutritional and health benefits (Sharmili *et al*., 2021) [59]. Intercropping in millets can help to address this issue, which is mostly caused by the low yield of millets relative to other cereal crops. When multiple crops are grown together on the same piece of land, an intercropping system makes use of the soil's nutrients (Xue *et al*., 2016; Yang *et al*., 2018; Maitra, 2020) [67, 70,], soil moisture (Singh *et al*., 2020), greenhouse gas flux (Adler *et al*., 2007; Signor and Cerri, 2013; Collins *et al*., 2017) [2, 61, 12], sunlight (Mahallati *et al*., 2015; Kermah *et al*., 2017; Raza *et al*., 2019) [37, 26, 56], and runoff (Zougmore *et al*., 2000; Banik *et al*., 2006) [74, 6]. In addition to this, intercropping improves diversity and regulates runoff water and erosion (Padhi *et al*., 2010; Maitra *et al*., 2019) [49, 39-40]. Complementarity between the species being grown is a crucial factor to take into account when choosing crops for an intercropping system in order to increase crop yields (Ngwira *et al*., 2012; Pappa *et al*., 2012) [46, 50]. Furthermore, intercropping has been shown to improve functional diversity, boost resource efficiency, and lower risk from biotic and abiotic sources (Franco *et al*., 2015) [15]. Therefore, in addition to improving soil health, intercropping pulses with millets will lead to increased millet productivity (Maitra *et al*., 2001) [38]. In addition to the benefits of sustaining crop productivity (Siddique *et al*., 2012; Yogesh *et al*., 2014; Chai *et al*.,

2014; Bantie *et al*., 2014) [60, 72, 10, 8] and enabling diversity of beneficial soil microorganisms (Li and Wu, 2018; Maitra and Ray, 2019) [39-40], crop diversification is also required to obtain higher yield and return. Additionally, little millets can be grown in monoculture or intercropping, which allows small holders in drylands to have secure livelihoods, food, and nutrition while using resources sustainably (Kiwia *et al*., 2019) [29]. Cereal-legume intercropping systems have been found to be superior to monocropping (Banik and Sharma, 2009) [9]. Rusinamhodzi *et al*. (2012) [57] state that smallholders in drylands benefit from the mix of cereal and legumes as a source of food and nutrition. The increased yield of finger millet when grown as an intercropping with pigeonpea was also attributed by Maitra *et al*. (2001) [38] to this practice. According to Nigade *et al*. (2012) [47], the highest yield of grain and straw was obtained by intercropping finger millet (*Eleusine coracana*) in an 8:2 or 4:1 row proportion with blackgram or mothbean (*Vigna aconitifolia*). When little millet was interplanted at an 8:2 ratio with pulses like blackgram and greengram, the yield parameters of the plant, such as the number of productive tillers per hill and test weight, increased. In additional research, reported that higher grain and straw yields were obtained by intercropping small millet (*Panicum sumatrense*) with pigeonpea (*Cajanus cajan*) in a 6:1 row ratio, followed by the sequential planting of horsegram. It is advantageous to intercrop small millet and pigeon pea at a ratio of 6:1 or 6:2. According to Padhi *et al*. (2010) [49], finger millet and pigeonpea raised in a 4:2 ratio under rainfed conditions during the rainy season was more productive, financially feasible, and energetically efficient than plantings of each plant alone.

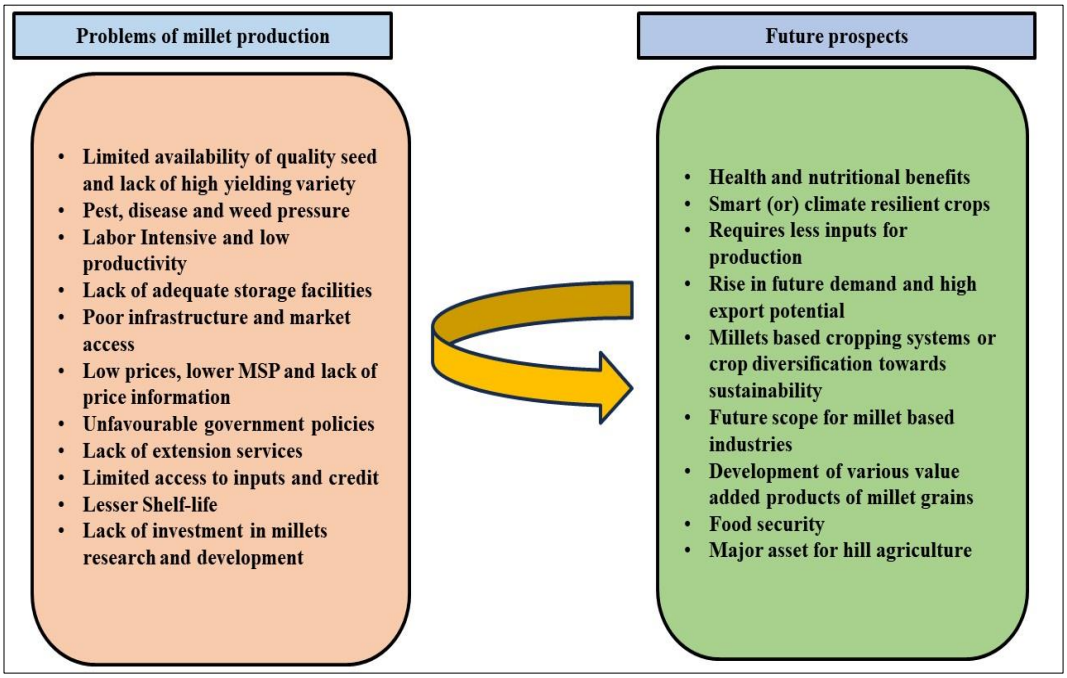

Fig 5: Problems and prospects of millet production

5. Conclusion

Millets have the potential to play a significant role in sustainable agricultural and contribute to meeting the food demand growing world. Currently millet production facing various issues such as diseases and pest infestation, poor infrastructure and market access, lack of investment in millet research and development. This can be accomplished by supporting millet consumption, implementing better growing practices, development of improved varieties and giving smallholder farmers financial and technical support as well as collaboration and participation of many stakeholders.

6. Acknowledgements

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7. References

1. Adekunle AA. Agricultural innovation in sub-Saharan Africa: experiences from multiple stakeholder approaches. Forum for Agricultural Research in Africa; c2012. Accra (Ghana). ISBN 978-9988-8373-2-4.
2. Adler PR, Del Grosso SJ, Parton WJ. Life cycle assessment of net greenhouse-gas flux for bioenergy cropping systems. Ecological Applications. 2007;17:675-691.
3. Akeredolu IA, Addo AA, Akeredolu OA. Clinical evaluation of pearl millet Technolconophor weaning mix as supplementary food for Nigerian children. Brazilian Archives of Biology and Technology. 2005;48(4):531-536.
4. Anukam KC, Reid G. African traditional fermented foods and probiotics. Journal of Medicinal Food. 2009;12(6):1177-1184.
5. Awika JM. Major cereal grains production and use around the world. In: Advances in Cereal Science: Implications to Food Processing and Health Promotion. Washington, DC: ACS Publications; c2011. p. 1-13.
6. Banik P, Midya A, Sarkar BK, Ghosh SS. Wheat and chickpea intercropping systems in an additive series experiment: advantages and weed smothering. European Journal of Agronomy. 2006;24:325-332.
7. Banik P, Sharma R. Yield and resource utilization efficiency in baby corn-legume intercropping system in

the eastern plateau of India. Journal of Sustainable Agriculture and Environment. 2009;33:379-395.
8. Bantie Y, Fetien A, Tadesse D. Competition indices of intercropped lupine (local) and small cereals in additive series in West Gojjam, Northwestern Ethiopia. American Journal of Plant Sciences. 2014;5:1296-1305.
9. Begum M, Islam MR, Hossain MM, Rahman MM, Alam MF. Millet, A climate-smart crop for saline-prone areas of Bangladesh. Journal of Climate Change and Health. 2017;3(1-2):33-38.
10. Chai Q, Qin A, Gan Y, Yu A. Higher yield and lower carbon emission by intercropping maize with rape, pea and wheat in arid irrigation areas. Agronomy for Sustainable Development. 2014;34:535-543.
11. Chapke RR, Shyamprasad G, Das IK, Tonapi VA. Improved millets production technologies and their impact. Technology Bulletin ICAR-Indian Institute of Millets Research. 2018, 1-4.
12. Collins HP, Fay PA, Kimura E, Fransen S, Himes A. Intercropping with switchgrass improves net greenhouse balance in hybrid poplar plantations on a sand soil. Soil Science Society of America Journal. 2017;81:781-795.
13. Dwivedi SUH, Senthilvel S, Hash CT, Fukunaga K, Diao X, Santra DBD. Genetic and genomic resources. Plant Breeding Reviews. 2012;35:246-375.
14. Eduru A, Kamboj A, Reddy PM, Pal B. Nutritional and health benefits of millets, present status, and future prospects: A review. The Pharma Innovation Journal. 2021;10(5):859-868.
15. Franco JG, King SR, Masabni JG, Volder A. Plant functional diversity improves short-term yields in a low input intercropping system. Agriculture, Ecosystems & Environment. 2015;203:1-10.
16. Godfray HCJ, Garnett T. Food security and sustainable intensification. Philosophical Transactions of the Royal Society B: Biological Sciences. 2014;369(1639):20120273.
17. Gowri MU, Shivakumar KM. Millet scenario in India. Economic Affairs. 2020;65(3):363-370. DOI: 10.46852/0424-2513.3.2020.7.
18. Guigaz M. Memento Del'agronome. Montpellier (France): CIRAD-GRET and Ministère des Affaires Étrangères; c2002.
19. Gyawali P. Production trend, constraints, and strategies for millet cultivation in Nepal: A study from review perspective. International Journal of Agriculture and Applied Sciences. 2021;2(1):30-40.
20. Hamad SH. The microbial quality of processed date fruits collected from a factory in Al-Hofuf City, Kingdom of Saudi Arabia. Emirates Journal of Food and Agriculture. 2012;24(2):105-112.
21. Joseph J, Panathady AM, Pouchepparadjou A. Status of Millets in India: Trends and Prospects. 2023;10.
22. Kane-Potaka J, Anitha S, Tsusaka TW, *et al*. Assessing millets and sorghum consumption behavior in urban India: A large-scale survey. Frontiers in Sustainable Food Systems. 2021;5:680777.
23. Kang Y, Khan S, Ma X. Climate change impacts on crop yield, crop water productivity and food security-A review. Progress in Natural Science. 2009;19(12):1665-1674.
24. Karuppasamy P. Overview on millets. Trends in Biosciences. 2015;8(13):3269-3273.
25. Kaushik N, Yadav P, Khandal RK, Aggarwal MK. Review of ways to enhance the nutritional properties of millets for their value addition. Journal of Food Processing and Preservation. 2021;45(4):213-222.
26. Kermah M, Franke AC, Adjei-Nsiah S, Ahiabor BDK, Abaidoo RC, Giller KE. Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea of northern Ghana. Field Crops Research. 2017;213:38-50.
27. Kheya SA, Talukder SK, Datta P, Yeasmin S, Rashid MH, Hasan AK, Islam AKMM. Millets: The future crops for the tropics-Status, challenges, and future prospects. Heliyon. 2023;3.
28. Kheya SA, Talukder SK, Datta P, Yeasmin S, Rashid MH, Hasan AK, *et al*. Millets: The future crops for the tropics-Status, challenges, and future prospects. Heliyon. 2023;3. https://doi.org/10.1016/j.heliyon.2023.e22123
29. Kiwia A, Kimani D, Harawa R, Jama B, Sileshi G. Sustainable intensification with cereal-legume intercropping in Eastern and Southern Africa. Sustainability. 2019;11:1-18.
30. Koch A, McBratney A, Adams M, Field D, Hill R, Crawford J. Soil security: Solving the global soil crisis. Global Policy. 2013;4(4):434-441.
31. Kole M, Muthamilarasan R, Henry D, Edwards R, Sharma M, Abberton M, *et al*. Application of genomics-assisted breeding for generation of climate resilient crops: progress and prospects. Frontiers in Plant Science. 2015;6:563. https://doi.org/10.3389/fpls.2015.00563
32. Kumar A, Tomer V, Kaur A, Kumar V, Gupta K. Millets: A solution to agrarian and nutritional challenges. Agriculture and Food Security. 2018;7(1):1-15. https://doi.org/10.1186/s40066-018-0183-3
33. Laminu HH, Modu S, Numan AI. Production, in vitro protein digestibility, phytate content and acceptability of weaning foods prepared from pearl millet (*Pennisetum typhoideum*) and cowpea (Vigna unguiculata). International Journal of Nutrition and Metabolism. 2011;3(9):109-113.
34. Léder I. Sorghum and millets. Cultivated Plants Primarily as Food Sources. 2004;1:66-84.
35. Li S, Wu F. Diversity and cooccurrence patterns of soil bacterial and fungal communities in seven intercropping systems. Frontiers in Microbiology. 2018;9:15-21.
36. Lokesh K, Dudhagara CR, Mahera AB, Kumar S. Millets: The future smart food. The Pharma Innovation Journal. 2022;11(4):75-84.
37. Mahallati MN, Koocheki A, Mondani F, Feizi H, Amirmoradi S. Determination of optimal strip width in strip intercropping of maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) in Northeast Iran. Journal of Cleaner Production. 2015;106:343-350.
38. Maitra S, Ghosh DC, Sounda G, Jana PK. Performance of intercropping legumes in fingermillet (*Eleusine coracana* L.) at varying fertility levels. Indian Journal of Agronomy. 2001;46:38-44.
39. Maitra S, Palai JB, Manasa P, Kumar PD. Potential of intercropping system in sustaining crop productivity. International Journal of Agriculture Environment & Biotechnology. 2019;12:39-45.

40. Maitra S, Ray DP. Enrichment of biodiversity, influence in microbial population dynamics of soil and nutrient utilization in cereal-legume intercropping systems: a review. International Journal of Bioresource Science. 2019;6:11-19.
41. Maitra S, Shankar T, Banerjee P. Potential and Advantages of Maize-Legume Intercropping System. Intech Open, London, UK; c2020. doi:10.5772/intechopen.91722.
42. Mishra JS, Kumar R, Upadhyay PK, Hans H. Weed management in millets.
43. Mondal MH. Crop agriculture of Bangladesh: challenges and opportunities. Bangladesh Journal of Agricultural Research. 2010;35(2):235-245.
44. Motagi BN, Krishnappa M, Biradar BD. Pests and Diseases of Finger Millet: Biology and Management. Springer; 2014.
45. Muthamilarasan M, Prasad M. Small millets for enduring food security amidst pandemics. Trends in Plant Science. 2021;26(1):34-40.
46. Ngwira AR, Aune JB, Mkwinda S. On-farm evaluation of yield and economic benefit of short-term maize legume intercropping systems under conservation agriculture in Malawi. Field Crops Research. 2012;132:149-157.
47. Nigade RD, Karad SR, More SM. Agronomic manipulations for enhancing productivity of finger millet based on intercropping system. Advance Research Journal of Crop Improvement. 2012;3:8-10.
48. Obilana AB, Manyasa E. Millets. In: Belton PS, Taylor JRN, eds. Pseudocereals and less common cereals: grain properties and utilization potential. Springer Verlag; 2002:177-217.
49. Padhi AK, Panigrahi RK, Jena BK. Effect of planting geometry and duration of intercrops on performance of pigeonpea - finger millet intercropping systems. Indian Journal of Agricultural Research. 2010;44:43-47.
50. Pappa VA, Rees RM, Walker RL, Baddeley JA, Watson CA. Legumes intercropped with spring barley contribute to increased biomass production and carryover effects. The Journal of Agricultural Science. 2013;150:584-594.
51. Paschapur AU, Joshi D, Mishra KK, Kant L, Kumar V, Kumar A. Millets for life: a brief introduction. Millets Millet Technology. 2021:1-32.
52. Passot S, Gnacko F, Moukouanga D, Lucas M, Guyomarc'h S, Ortega BM. Characterization of pearl millet root architecture and anatomy reveals three types of lateral roots. Frontiers in Plant Science. 2016;7:829.
53. Patra A, Singh RP, Kundu MS, Kundu A, Mukherjee S. Biotica Research Today, planting geometry and row proportion. Karnataka Journal of Agricultural Sciences. 2023;27:1-4.
54. Prasad PV, Staggenborg SA. Growth and production of sorghum and millets. In: Soils, Plant Growth and Crop Production. Oxford, UK: EOLSS Publishers Co., Ltd.; 2009.
55. Raza MA, Feng LY, Van der Wref W, Iqbal N, Khan I, Hassan MJ, *et al*. Optimum leaf defoliation: a new approach for increasing nutrient uptake and land equivalent ratio of maize soybean relay intercropping system. Field Crops Research. 2019;244:doi:10.1016/j.fcr.2019.107647.
56. Rusinamhodzi L, Corbeels M, Nyamangara J, Giller KE. Maize-grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in Central Mozambique. Field Crops Research. 2012;136:12-22.
57. Saxena R, Vanga SK, Wang J, Orsat V, Raghavan V. Millets for food security in context of climate change: a review. Sustainability. 2018;10(1):1-31.
58. Sharmili K, Yasodha M, Rajesh P, Rajendran K, Thankappan S, Minithra R. Millet and pulse-based intercropping system for agricultural sustainability-A review. Crop Research. 2021;56(6):369-378.
59. Siddique KHM, Johansen C, Turner NC, Jeuffroy MH, Hashem A, Sakar D, *et al*. Innovations in agronomy for food legumes: A review. Agronomy for Sustainable Development. 2012;32:45-64.
60. Signor D, Cerri CPE. Nitrous oxide emission in agricultural soils: a review. Pesquisa Agropecuária Tropical. 2013;43:322-38.
61. Singh D, Mathimaran N, Boller T, Kahmen A. Deep-rooted pigeon pea promotes the water relations and survival of shallowrooted finger millet during drought-Despite strong competitive interactions at ambient water availability. PLoS ONE. 2020;15:doi:10.1371/journal.pone.0228993.
62. Tripathi G, Jitendrakumar PH, Borah A, Nath D, Das H, Bansal S, *et al*. A review on nutritional and health benefits of millets. International Journal of Plant and Soil Science. 2023;35(19):1736-1743.
63. Vidya S, Ravi R, Bhattacharya S. Effect of thermal treatment on selected cereals and millet flour doughs and their baking quality. Food and Bioprocess Technology. 2012;6:1218-1227.
64. Wallace JG, Upadhyaya HD, Vetriventhan M, Buckler ES, Tom Hash C, Ramu P. The genetic makeup of a global barnyard millet germplasm collection. Plant Genome. 2015;8(1):1-15.
65. Wheeler T, Von Braun J. Climate change impacts on global food security. Science. 2013;341:508-513.
66. Xue Y, Xia H, Christie P, Zhang Z, Li L, Tang C. Crop acquisition of phosphorus, iron, and zinc from soil in cereal/legume intercropping systems: a critical review. Annals of Botany. 2016;117:363-77.
67. Yadav OP, Rai KN, Rajpurohit BS, Hash CT, Mahala RS, Gupta SK, *et al*. Twenty-five years of pearl millet improvement in India. ICAR- All; c2012.
68. Yadav SS, Reddy B, Kumar VS, Kumar RV. Millets: Crop Production Science in Horticulture. Academic Press; c2019.
69. Yang C, Fan Z, Chai Q. Agronomic and economic benefits of pea/maize intercropping systems in relation to N fertilizer and maize density. Agronomy. 2018;8:doi:10.3390/agronomy8040052.
70. Yang X, Wan Z, Perry L, Lu H, Wang Q, Hao C, *et al*. Early millet uses in northern China. Proceedings of the National Academy of Sciences of the United States of America. 2012, 1-5.
71. Yogesh S, Halikatti SI, Hiremath SM, Potdar MP, Harlapur SI, Venkatesh H. Light use efficiency productivity and profitability of maize and soybean intercropping as influenced by planting geometry and row proportion. 2014.
72. Zhang JP, Liu TS, Zhang JP, Liu TS, Zheng J, Zhang JP. Cloning and characterization of a putative 12-

oxophytodienoic acid reductase cdna induced by osmotic stress in roots of foxtail millet. DNA Sequencing. 2007;18(2):138-144.
73. Zougmore R, Kambou FN, Ouattara K, Guillobez S. Sorghum-cowpea intercropping: An effective technique against runoff and soil erosion in the Sahel (Saria, Burkina Faso). Arid Land Research and Management. 2000;14:329-42.