Chapter

Exploring the Impacts of Climate Change on the Nutritional Properties and Food Security of Various Cereal Grains

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Abstract

Climate change substantially influences agriculture, affecting food security and agricultural production. To address the current concerns, it is essential to address climate-smart agricultural methods, such as crop rotation, integrated pest control and enhanced nitrogen fertilisation techniques, to assist farmers in adjusting to a shifting climate. Furthermore, an ongoing review is being conducted to investigate the potential effects of climate change mitigation and the contribution of agriculture to reducing greenhouse gas emissions abroad. This investigation encompasses various aspects such as agricultural practice and crop varieties, particularly crop relocation, soil nutrient management and innovative nitrogen fertiliser techniques. Restricting the discourse to the crop and N fertiliser selection options and the implementation of various strategies, such as identifying the most resilient crop for climatic fluctuations, implementing a crop relocation system as conventional and modern agricultural practices, minimising the reliance on pesticides and enhancing the nutritional qualities of better cultivars, in addition to the grain drying process and storage, may influence the nutritional composition of cereal grains. All the above adaptation mechanisms depend on the local context, area or country. Ecologically, low-impact solutions that modernise agriculture include biodiversity-based and climate-smart farming. These initiatives aim to effectively enhance agricultural incomes and production while addressing the interrelated challenges of climate change and food security.

Keywords: agriculture practice, grains, buckwheat, crop rotation, proso millet, nutritional contents

1. Introduction

Fluctuations in climate patterns, including factors such as temperature, rainfall and the occurrence of frosts, can either enhance or deteriorate agricultural conditions throughout different regions of the globe. Increased temperatures and elevated CO_2 levels may enhance crop yields in some areas or vice versa [1]. Nevertheless, changes in precipitation patterns, severe weather occurrences and decreased water availability might lead to a decline in agricultural production [2]. The yearly emissions from the global food system, mostly attributed to methane and nitrous oxide emissions from agriculture, account for around 21–37% of total emissions [3, 4]. To ensure food security and sustainable production amidst significant environmental changes, farmers and the agricultural sector may use many ways to adjust to these emerging circumstances [1]. Research suggests that a temperature increase of 2.0°C might result in a 20–40% decrease in cereal grain output due to the impact of climate change, particularly in Asia and Africa [5]. The growth of grains such as wheat, maize and rice is very susceptible to temperature variations [6]. Several management strategies are suggested to guarantee food security and sustainable production in the face of climate change. These include the development of innovative crop varieties, the implementation of efficient cropping systems and the optimisation of nutrient management [5]. Developing climate-resilient crops is a commonly employed approach to breed and grow crop varieties that can withstand the negative impacts of climate change, such as flooding, drought and extreme heat, which can help farmers adapt to changing environmental conditions [7, 8]. Implementing diversified cropping systems and crop rotation techniques in agriculture contributes to ensuring food security and advancing sustainable production in response to the challenges posed by climate change [9, 10]. Prior European study investigated the occurrence of pest insects in different agricultural environments by the use of a multiple-choice methodology [11]. The study evaluates the suitability of crops, the impact of weed species and the effectiveness of crop rotation as a management strategy [12]. By using agricultural diversification practices such as implementing varied crop rotations, utilising cover crops and practising intercropping, it is possible to enhance ecosystem services, minimise environmental damage and maintain crop yields while safeguarding quality [13]. The simulation results demonstrate that the application of nitrogen fertilisation, the timing of planting and the provision of irrigation substantially influence the production of sorghum and millet. These findings indicate that implementing appropriate crop management strategies could effectively reduce the risks associated with climate change [14]. Sorghum, millets and pseudocereals are crucial grains for establishing resilient and sustainable food systems in the context of climate change. These grains possess the ability to withstand harsh weather conditions and are highly suitable for dry and semi-arid agroecosystems [15, 16]. Previous research has shown that a crop rotation consisting of wheat, maize and millet and fallow periods during a 4-year cycle in Colorado yields better results than traditional methods to enhance food security and build resistance to climate change [17]. Another investigation performed in Canada discovered that cultivating forage sorghum within a traditional rotation of wheat and grain sorghum and fallow land resulted in enhanced productivity and profitability of the cropping system [18]. Research done in Western Ethiopia revealed that the practice of rotating sorghum and finger millet crops was widespread in the study region [19]. In South Africa, sorghum is often irrigated in rotation with other crops, exacerbating nutrient and water depletion [20]. In Europe, Hungary has optimal conditions for cultivating early and intermediate-maturity sorghum hybrid. Sorghum production is advantageous for crop rotation [21]. The European Union’s Green Deal sought to achieve climate neutrality in Europe by 2050. This will be accomplished via the promotion of sustainable food systems, the advancement of organic farming practices and the facilitation of market entry for alternative crops. The European Union’s Green Deal aims to achieve climate neutrality in Europe by 2050. Promoting sustainable food systems, advancing organic farming methods, and facilitating market entry for alternative crops will help accomplish this goal, besides utilizing conventional and regionally tailored cultivars of crops [22]. In southern

Hungary, implementing crop rotation systems has the ability to enhance soil health, fertility and nutrient balance, hence favourably impacting the nutritional quality of the crops [23, 24]. Sorghum and millets offer potential for improving food nutritional value, health and sustainable food systems. Biofortification strategies and unique protein functionality are essential [25]. By carefully choosing sorghum and millet types for a rotation system, farmers may establish a more sustainable and productive agricultural system that is specifically suited to their location and market circumstances [26]. The studies emphasised the potential for enhancing productivity and profitability via the significance of grain quality and planting strategies in the choice of crop varieties [27]. Grain storage ensures food security, market stability and profitability. Government agencies store grains to uphold quality standards and minimise losses [3].

The objective of the book chapter was to evaluate the impact of agricultural practices such as grain drying and storage on the resilience of proso millet, sorghum, and buckwheat cereal grains in the face of climate change. Additionally, the chapter examines how these practices affect these grains' nutritional and quality aspects and their potential contribution to high-quality production for human food security.

The scientists and breeders have carefully examined the potential implications of multiple factors on agricultural practices, which may significantly affect production and food security. These considerations are further discussed below.

2. The implications of climate change on agriculture

Climate stress may harm cereal grains' nutritional value, reducing nutrient absorption and assimilation. The repercussions vary according to the crop's classification, the stress level and the prevailing environmental circumstances. Therefore, it is crucial to consider the impact of climatic stress on grain quality while selecting crops and implementing farming practices [28]. The biosecurity toolkit developed by the Food and Agriculture Organisation (FAO) provided strategic guidance for safeguarding food security, commerce and agricultural practices. It specifically addresses global challenges such as environmental and biodiversity difficulties [29].

The diversity of the varieties in agricultural exchange programmes may provide useful insights into the abundance of crop diversity region. It also highlights the need to conserve and use these varieties for the purpose of sustainable agriculture [29–31].

Climate change is significantly impacting Europe's agriculture, affecting crop and livestock production and posing challenges for farmers in adapting to changing conditions, which can present several negative impacts, as are detailed in the following points:

Climate change has prompted significant adaptations in US agriculture, with farmers employing strategies to mitigate crop yields and losses [32]. China's climate change adaptation techniques for maize output are being studied to enhance understanding of the challenges of changing climatic patterns in agriculture [33]. France is known for its rich history of cultivation diversity in Western Europe. Based on the RCP8.5 warming scenario and assuming no changes in growing regions or technology, our model ensemble indicates that winter wheat output would fall by 21.0%, winter barley yield will decline by 17.3% and spring barley yield will decline by 33.6% by the end of the century [34]. Furthermore, climate change will increase the susceptibility of the EU's agri-food business to drought in non-EU nations, with over 44% of the EU's agricultural imports projected to be at high risk of drought in the coming years [35]. China's evidence earlier predicted climate change impacts global agriculture and food production. However, the connection between climate change and national food security must be adequately understood [36]. A study from Africa examined the difficulties and potential advantages of sorghum growing techniques in the humid agroecology of Western Ethiopia [19].

2.1 Alteration and insertion of adaptive crops for climate change

The FAO/OECD Workshop focused on addressing the problems posed by climate change in different agro-ecological and socio-economic settings and building resilience for adaptation in the agriculture sector. The workshop explored resilience from several angles, including biophysical, economic and social dimensions and spanning different levels of analysis, from individual farms to the global scale [37]. A European exploration study has proposed many techniques that might assist farmers and policymakers in formulating suitable adaptation strategies to tackle the problems presented by climate change in the agricultural sector [38, 39]. These strategies are of the utmost importance, such as:

2.1.1 Climate resilience

Employing climate resilient techniques to improve the capacity of agricultural systems to forecast, prepare for, adjust to, withstand and recuperate from the effects of climate change and severe weather events [40].

2.1.2 Climate-resilient practices

The collection of climate-resilient practices may help developers and other stakeholders, and the strategies can be customised to address the individual hazards, levels of exposure and vulnerabilities identified throughout the climate risk assessment process [41]. Policymakers have discovered the optimal crops that can acclimatise to climatic changes and are devising efficient measures to bolster the agricultural industry in response to a shifting climate [42].

2.1.3 Crop switching and relocation

The strategic shifting and relocation of profitable crops for agricultural purposes to adapt to climate change is a crucial component of climate change resistance programmes [26, 43]. Implementing crop switching may mitigate agricultural losses caused by climate change, while relocation can facilitate the identification of appropriate crop adaptation prospects for farmers and policymakers [9]. Implementing a diverse crop rotation may be a very successful approach to enhancing the availability of soil nutrients and preserving soil health in no-till systems. Conversely, windrow-burning waste could harm soil fertility [43], as was explained by **Figure 1**.

3. Incorporating *P. millet, Sorghum bicolor*, and common buckwheat into crop rotation strategies

P. millet and *S. bicolor* are scientifically known as the kind of grains that are notable for their capacity to thrive in dry and hot environments, making them valuable for ensuring food security in desert locations, given the anticipated pattern of increasing drought intensity in the Mediterranean region [22, 44]. Buckwheat is a rapidly growing

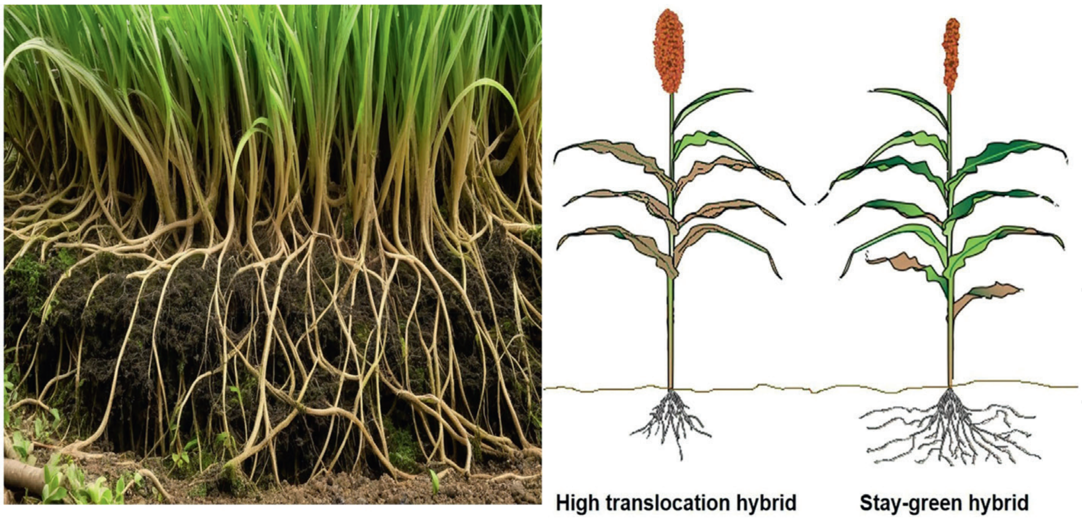
Figure 1.
Switching and relocation system in the agriculture.

crop that is well-suited for various crop rotation systems, and its nutritional needs should be considered when designing such systems [45]. *P. millet* has been shown to enhance overall production and may serve as a substitute for summer fallow in winter wheat-fallow rotations within crop rotation systems [44]. Studies have shown that *S. bicolor* is a valuable crop in crop rotation systems since it is more likely to achieve the highest yield in certain rotations [14]. Which can provide several advantages, including in the following section details.

4. Implication of *P. millet, S. bicolor* and common buckwheat rotation system on soil fertility

Crop rotation, via the cultivation of several crops in a particular area, may mitigate the depletion of specific nutrients in the soil, resulting in a more equitable and sustainable absorption of nutrients [46].

Crop rotation, which involves the cultivation of *P. millet*, *S. bicolor* and buckwheat, effectively disrupts patterns of nutrient depletion or surplus by modifying the need for certain nutrients. In addition, varied crop rotations enhance microbial diversity, which in turn improves soil structure, nutrient accessibility and breakdown of organic waste [43, 47, 48]. In addition, implementing crop rotation systems using *P. millet*, *S. bicolor* and buckwheat has boosted soil fertility by stimulating microbial populations, improved soil aggregation and facilitated water infiltration, aeration and root development. Consequently, this results in enhanced assimilation of plant nutrients and heightened agricultural output [22, 49]. Buckwheat, classified as a legume, can capture atmospheric nitrogen via the action of nitrogen-fixing bacteria, resulting in the enhancement of soil fertility with this vital nutrient [37]. The wide fibrous root structure of *S. bicolor*, capable of growing to great depths, improves soil aggregation and water penetration, facilitating nutrient absorption and enhancing soil fertility [50, 51]. *P. millet*'s shallow root system is advantageous for nutrient absorption and soil structure enhancement, particularly in less fertile soils [52, 53]. Research conducted by Frontier examined the performance of sorghum hybrids with enhanced terminal senescence under optimal environmental circumstances, resulting



* Source [131].

Figure 2.
The role of root structure in facilitating nutrient absorption, letters refer to (a) Sorghum root structure in the soil (b) Sorghum hybrids under favourable environmental conditions (left) and sorghum hybrids grown under resource-poor conditions (right). Source: Copyright © 2022 Ostmeyer, Bahuguna, Kirkham, Bean and Jagadish. This open-access article is distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms. Correspondence: S. V. Krishna Jagadish, kjagadish@ksu.edu.

in higher nitrogen transfer from leaves to improve both production and grain quality (left), as compared to stay-green sorghum hybrids cultivated in resource-limited situations [53]. Sorghum hybrids that possess rapid nitrogen transfer and exhibit accelerated senescence in less challenging settings may not need a complex root structure [53], as displayed in **Figure 2** (left).

Buckwheat has the capacity to improve soil fertility [54]. In addition, the root exudates have the capacity to mobilise nutrients, particularly phosphorus, by solubilising them, making them more available [55]. Furthermore, the high efficacy of these crops in reducing wireworm populations and promoting soil health is noteworthy [54, 55].

Soil composition, pH levels, and nutrient levels influence cereal grain nutritional composition. Additionally, breeding techniques and agricultural methods significantly enhance grain quality under different environmental conditions, impacting productivity, food security, and human consumption [56]. **Table 1** shows that crop tissues can absorb essential plant nutrients.

5. Pesticide and residue utilisation concepts

The excessive use of pesticides can cause environmental pollution and pose risks to human health. The Food and Agriculture Organisation (FAO) of the World Health Organisation (WHO) establishes maximum residue limits and oversees the use of pesticides in food production to mitigate health and environmental risks [57]. Pesticide usage in food production should be monitored to reduce health and environmental concerns [11]. Research was conducted to analyse the impact of pesticide residues on food safety and the environment to protect consumers' interests and maintain the food supply's stability [58].

Elements	Chemical symbol	Chemical forms uptake by crop
Primary nutrients		
Nitrogen	N	NO_3^-, NH_4^+
Potassium	K	K
Phosphorus	P	HPO_4^-, HPO_4^{2-}, PO_4^{3-}
Secondary nutrients		
Sulphur	S	SO_4^{2-}
Calcium	Ca	Ca^{2+}
Magnesium	Mg	Mg^{2+}
Micronutrients		
Copper	Cu	Cu^+, Cu^{2+}
Iron	Fe	Fe^{3+}
Zinc	Zn	Zn^{2+}
Manganese	Mn	Mn^{2+}
Boron	B	BO_3^{3-}
Molybdenum	Mo	MoO_4^{2-}
Nickel	Ni	Ni^{2+}
Chlorine	Cl	Cl^-

Source: [31].

Table 1.
The elemental nutrients which crops can obtain from the soil source.

Some foods may retain pesticide residues after washing or peeling. Buying organic fruit and growing veggies using Integrated Pest Management (IPM) are the best strategies to limit pesticide exposure in food [58].

5.1 Pesticide utilisation in case of *P. millet, S. bicolor* and common buckwheat

The dynamic crop simulation model focuses on optimising the dynamics of pesticide residues in plant-environment systems, with a particular emphasis on *P. millet*. Drought and heat are excellent methods for minimising residues in *P. millet* crops, making them robust to environmental conditions [59].

Several insecticidal measures were used to control *Melanaphis sacchari*, which may provide useful impacts on pesticide usage in sorghum cultivation. These strategies can help create efficient approaches to managing the aphid and minimise its detrimental impact on sorghum crops [60, 61].

Based on a comparative investigation, buckwheat showed resistance to weed pressure and insect pest damage, making it a good alternative plant for conducting semi-field pesticide toxicity evaluations, such as impatiens flowers [62, 63].

6. Organic and conventional fertiliser concepts in case of *P. millet, S. bicolor* and common buckwheat

Optimised organic manures, chemical fertilisers and bio-priming can enhance soil physicochemical characteristics and *P. millet* yield production [64, 65]. It was proposed that using integrated nutrition sources and seed priming techniques may enhance the development, production and overall quality of nutri-cereal *P. millet* [66]. The combined use of organic amendments and chemical fertilisers has been shown to enhance *S. bicolor*'s growth, productivity and nutritional value. Organic additions are a viable substitute for inorganic fertilisers in improving crop yield and soil quality [65]. Moreover, using organic supplements has enhanced productivity and superior quality of *S. bicolor* in semi-arid tropical locations, exceeding the advantages of mineral fertilisers. This intriguing method can improve soil health and boost crop yield [67].

Favourable results were carried out to evaluate the impact of different farming techniques (organic and conventional) on the nutritional properties of buckwheat varieties grown in Poland [68, 69].

7. Concepts of nitrogen fertiliser impact on nutrient absorption

Crop rotation facilitates nitrogen cycling, hence enhancing nutrient uptake by crops [69]. However, agricultural land use leads to soil nutrient extraction, affecting yield; insufficient replenishment can lead to low nutrient availability. Solutions include fertilisers and crop breeding to overcome this issue [70]. Crop nutrient improvement may be accomplished by diverse breeding techniques and genetic variation, resulting in enhanced productivity, disease resistance, and adaptability to different climates [71].

Nitrogen fertiliser is a crucial component in contemporary agriculture since it has been scientifically shown to enhance plant growth and production [72]. Despite worries about its environmental consequences, including pollution and carbon emissions, and the need for more sustainable alternatives, the prevailing agreement is that, until superior choices become accessible, farmers necessitate unrestricted availability of nitrogen fertiliser to guarantee food security [53]. Nitrogen fertilisers have played a crucial role in contemporary agriculture, facilitating fast development and enhancing productivity in farming [73]. Nevertheless, there are continuous endeavours to discover alternate and more sustainable methods, such as nano-enabled fertilisers, that may enhance nutrient utilisation efficiency and minimise environmental repercussions in contrast to conventional synthetic fertilisers [74]. Although there are difficulties and worries, the need for nitrogen fertiliser in contemporary agriculture is generally acknowledged, and continuous research and innovation strive to tackle its ecological consequences while guaranteeing an uninterrupted food supply [75]. Phenotyping technologies play a crucial role in breeding strategies for sustainable agriculture. They are used to evaluate the capacity of cover crops to withstand changes in the environment and identify genetic ways for enhancing root properties. One such strategy is using buckwheat as a cover crop [76].

The nutritional needs of various crop kinds are determined by their intended use and might vary significantly depending on the adaptability of the crop. Comprehending these essential nutrient needs is vital for efficient nutrient control and for enhancing the ideal development and productivity of various crops [77].

7.1 The employed technologies for efficient N fertiliser utilisation

Modern phenotyping technology and innovative breeding techniques in cover crops have the potential to increase these functions. These tactics focus on enhancing nitrogen fixation, nutrient absorption and stress resistance, among other characteristics, to maximise root growth and performance in agricultural contexts. By incorporating root features into breeding programmes, we want to increase the ability of cover crops to provide ecosystem services, which will eventually contribute to sustainable agriculture and boost soil health [77, 78]. For example, **Figure 3** illustrates: Nano N fertilisers may be administered to crops via three different methods: by being enclosed inside nanomaterials, by being covered with a thin protective polymer coating or by being supplied as particles or emulsions of nanoscale dimensions [79].

Rotating N_2-fixing grain legumes with cereals may provide advantages such as enhanced seed productivity and quality, augmented family monetary revenue and decreased dependence on artificial nitrogen fertilisers [47]. Developing nitrogen fixation in cereals has been a persistent research obstacle; however, advancements have been achieved in the identification of nitrogen-fixing bacteria that have the potential to serve as crop inoculants. Scientists are investigating methods to genetically modify cereal crops to independently produce nitrogen, potentially decreasing reliance on synthetic fertilisers [78].

7.1.1 Optinyte technology

Optinyte technology, developed by Corteva Agriscience, is a nitrogen stabiliser that safeguards nitrogen fertiliser and minimises environmental loss by impeding the nitrification process and limiting the conversion of ammonium to nitrate. It is used in N-Serve and Instinct NXTGEN nitrogen stabilisers to guarantee that the nutrient remains in the root zone throughout crucial periods of growth development [80–82].

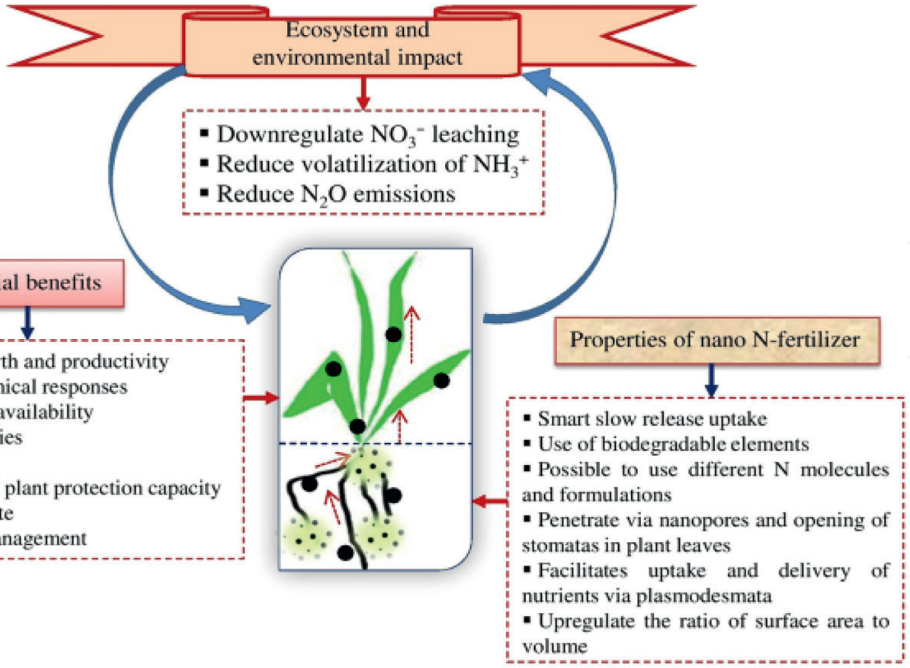


Figure 3.
Advantages of employing the modern technology of nitrogen fertiliser [79]. Source: Springer Nature. Date: Oct 12, 2023. Copyright © 2023, The Author(s) Creative Commons. This open-access article is distributed under the terms of the Creative Commons CC BY license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. You are not required to obtain permission to reuse this article. CC0 applies for supplementary material related to this article, and attribution is not required.

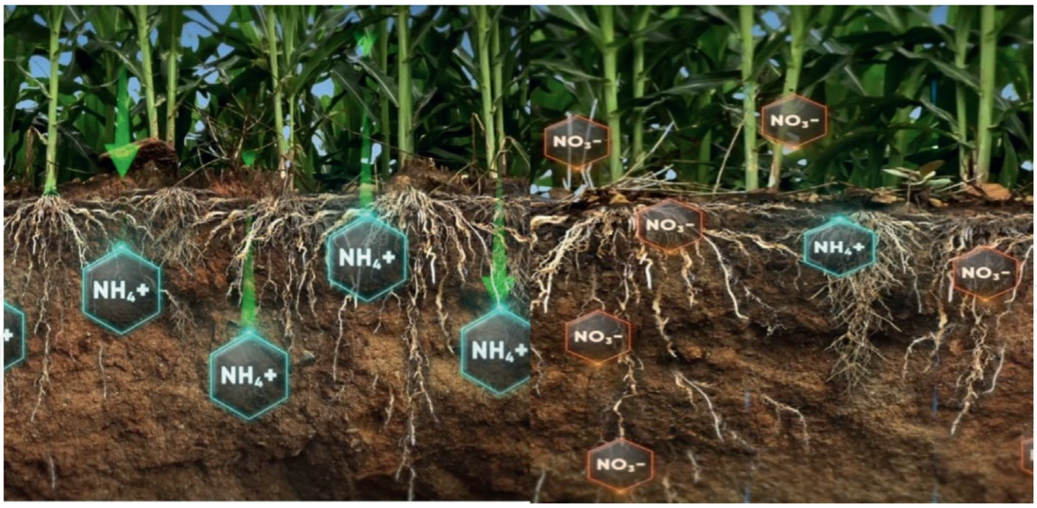


Figure 4.
Mechanism of the Optinyte technology for efficient nitrogen fertiliser utilisation [81]. Source: https://www.thedailyscoop.com/news/retail-industry/two-takeaways-nitrogen-stabilizer-research.

The Optinyte technology has several advantages in agriculture concerning environmental sustainability and agricultural productivity [81, 82]. Several notable advantages are demonstrated in **Figure 4**.

7.1.2 Soilgenic Technologies

Soilgenic Technologies, LLC, has developed a pioneering method that enhances nitrogen fertiliser efficiency and decreases emissions. Additional technologies include the use of slow-release fertilisers, precision agriculture, and cover crops [82].

Slow-release fertilisers gradually release nitrogen over an extended duration, hence minimising the chances of leaching and volatilisation. Precision agriculture uses data and technology to enhance the efficiency of fertiliser application by optimising rates and timing, thereby minimising wastage and enhancing crop absorption. Cover crops may effectively scavenge residual nitrogen in the soil and mitigate leaching [80, 83, 84].

8. Implication of N fertiliser on *P. millet, S. bicolor* and common buckwheat

8.1 Nutrient management

Multiple literature sources have examined the effects of different degrees of nitrogen fertilisation on *S. bicolor* yield and quality characteristics [85, 86]. These studies emphasised the utilisation of nitrogen fertilisation in sorghum production and its ability to enhance yield and quality features [86]. Nevertheless, it is crucial to consider nitrogen fertiliser's environmental ramifications and long-term viability [86, 87].

The 60 kg/ha^{-1} rate of N fertiliser was recommended for *S. bicolor* crops after the rotation of cowpea and soybeans [87]. The physicochemical qualities of *S. bicolor* are influenced by elevated amounts of nitrogen fertiliser, which vary depending on the application stage and the sorghum's specific variety. These effects have a significant impact on the main constituent of *S. bicolor* grains [88–90].

Studies on *P. millet* indicated that a lack of nitrogen has a detrimental effect on grain production, decreasing nitrogen utilisation efficiency and increasing the carbon/nitrogen ratio by lowering the overall nitrogen content and the levels of soluble proteins and sugars [52]. Nitrogen fertilisation rates significantly influenced the development and yield of *P. millet*. In the past, the production and consumption of small millets declined. Nevertheless, they have a crucial function in guaranteeing both the availability of food and a stable source of income, particularly in locations vulnerable to climate change and with limited resources [10, 91]. In contrast, now benefiting from superior morphological and molecular traits of *P. millet* crop as an emergency crop for human consumption is a target in Mediterranean countries [92–94].

The maximum yield was achieved with the highest nitrogen fertilisation rate, highlighting its importance for promoting sustainable agriculture and ensuring food security in Mediterranean areas [94]. Another Mediterranean research demonstrated a distinct impact of nitrogen fertilisation rates on *P. millet* morphology, productivity and phenology. Utilising nitrogen impacted protein content and all other variables, except for the weight of 1000 seeds [94].

Common buckwheat (*Fagopyrum esculentum* M.) is a pseudocereal that plays a crucial role as a catch crop in crop rotation systems [76]. Buckwheat, a crop grown by traditional farmers, has the potential to support smallholder farmers and rural communities [3]. Buckwheat is vital as catch crops can enhance nutrient cycling in cropping systems and reduce nitrogen leaching [48]. The choice of catch crop species and mixture can impact nutrient uptake and carry-over potential, and the growth conditions can also affect nutrient conservation and losses [49, 95]. Legumes can undergo nitrogen fixation by forming a mutually beneficial relationship with rhizobia, while cereals often rely on synthetic nitrogen fertilisers [95].

The utilisation of buckwheat in cover cropping and sorghum grains presents both opportunities and challenges in sustainable agriculture systems in Southern Australia, specifically in Mediterranean climatic conditions. Further evaluation and identification of appropriate cover crop species for the region are necessary [47, 96].

9. Implication of variety diversity role on nutrient management

Various crop varieties have distinct capabilities for absorbing and utilising nutrients, which might influence the effectiveness of nutrient management techniques. Legume crops may effectively mitigate the excessive reliance on chemical fertilisers, particularly nitrogenous fertilisers, in cereal-based cropping systems [97, 98]. The sustainable preservation of genetic resources is essential for enhancing the resilience of the ecosystem, boosting food production and ensuring nutritional security. That requires extensive initiatives to gather and save cultivated varieties, landraces and wild accessions.

Each crop has a distinct nutritional need for achieving optimum development and exhibits different nitrogen, phosphorus and potassium requirements [98], as shown in **Table 1**.

Grain crops such as wheat, barley, oats, rye, and triticale possess unique nutritional demands, with various cultivars within the same crop category sometimes exhibiting diverse requirements, varying from millets and pseudocereal requirements [77].

9.1 Implication of *P. millet, S. bicolor* and common buckwheat variety diversity on nutrient management

S. bicolor germplasm exhibits high genetic diversity, offering potential for cultivar development, breeding strategies and conservation efforts. Genetic regions under selection may contain genes for improved production and adaptation [99, 100]. The discussed factors can contribute to understanding the plasticity and stability of grain sorghum varieties, which can be valuable for developing new cultivars and improving sorghum production in different climatic conditions [100]. The genetic diversity and heritability of sorghum traits provide insights into breeding and conservation efforts and contribute to the knowledge of sorghum genetic resources in the region [101, 102].

Prior investigation indicated that the growing site does not significantly influence the features of *P. millet*. However, the selection of a certain variety may impact its nutritional and functional qualities, which can benefit farmers and researchers [52, 103, 104]. The *P. millet* exhibits a wide range of nutritional characteristics, including protein content (9.5–17%) and vital vitamins and minerals such as vitamin B, iron, calcium, potassium, zinc and magnesium. The farmers and breeders were encouraged to improve the cultivation and development of *P. millet* varieties with specified nutritional needs [105–107].

Previous findings focused on the physical diversity of buckwheat landraces that originated from Northeast India. The research included collecting buckwheat landraces from various elevations, ranging from 103 to 2971 m. The results indicated significant genetic variation within the germplasm of both common buckwheat (*Fagopyrum esculentum* M.) and Tartary buckwheat (*Fagopyrum tataricum*) [97]. In addition, researchers from Europe and Asia used simple sequence repeats (SSR) markers to examine the genetic diversity of several buckwheat species, such as *Fagopyrum esculentum* and *Fagopyrum tataricum*. For the examination of plant genetic diversity, the creation of genetic maps, gene mapping, and cloning are essential due to their locus specificity and co-dominant inheritance, facilitating precise identification and manipulation of target genes [108, 109]. Diverse crop varieties enhance farmers' productivity and sustainability by adapting to changing environmental conditions, as seen in higher yielding common buckwheat varieties with determinate growth habits [110].

9.2 Distinction between the varieties through morphological properties

The variety of the crops is a significant factor to consider when evaluating the multi-element composition of cereal and legume crops [111]. The distinction between cereal grains and a variety may be made by examining their morphological qualities, including grain size, shape, colour and texture [112]. Furthermore, considering the presence of endosperm tissue, kernel hardness and other physical characteristics could help identify cereal grain varieties. The plant's morphological traits are determined by its genetic composition and environmental variables [95, 109].

Geographical origin, variety, harvest season and their interactions are just a few variables that may impact the authenticity of grain and legume crops. These variables may influence the elemental composition of crops, and their impacts can differ based on the particular crop and environment. Gaining comprehension of these aspects and their interplay may aid in evaluating the quality and verification of these agricultural products [95, 109].

10. Comparing the essential nutritional composition of *P. millet, S. bicolor* and common buckwheat

The nutritional makeup of *P. millet*, *S. bicolor* and buckwheat may vary depending on the specific type. However, all three are nutrient-rich grains with a well-rounded combination of macronutrients, vitamins, minerals, and antioxidants. As such, they are beneficial complements to a balanced diet.

Table 2 shows the ranges of the essential nutritional contents in *P. millet*, *S. bicolor* and buckwheat in the whole grains.

11. Implication of handing and storge process on nutritional properties and grain security

The process of drying and storing cereal grains is essential for preserving their quality and preventing any deterioration. The drying process minimises losses caused by factors such as time, infestations or storage and also prolongs the duration during which the crop may be used. The following are key factors to consider while drying and storing cereal grains [96, 113].

Dryness: The dehydration procedure eliminates moisture from cereal grains, guaranteeing optimal safety and minimising agricultural losses. Grain dryers use heated air to provide optimal drying of grains, avoiding the potential for decay and the development of mould or aflatoxins. The drying process must reduce the moisture content of the grain to a range of 10–15% to ensure safe storage [114].

Storage conditions: To store cereal grains safely and for an extended period, it is essential to maintain proper storage conditions. The warehouse should be adequately ventilated and have a moisture level below 50%. Temperature and moisture changes during storage can affect the quality of cereal grains [96, 113].

Nutrient	Proso millet	Sorghum	Buckwheat
Energy (kcal/100 g)	354	339	355
Fat (g/100 g)	3	3.3	7.4
Protein (g/100 g)	12.5	10.4	12
Carbohydrates (g/100 g)	70	75	72.9
Dietary fibre (g/100 g)	2.2	6.3	10
Phosphorus (mg/100 g)	285	287	330
Potassium (mg/100 g)	195	350	450
Magnesium (mg/100 g)	114	165	390
Calcium (mg/100 g)	8	28	110
Iron (mg/100 g)	0.8	4.4	4
Zinc (mg/100 g)	1.5	1.8	0.8

Source: [52, 95, 109].

Table 2.
The essential nutritional content in P. millet, S. bicolor and common buckwheat based on the whole grains.

Packaging: Clean and dry cereals may be kept for 3 years, provided they have undergone appropriate drying treatment; it is important to use specialised agricultural technology to eliminate moisture, which may harm the storage process. Grain dryers use heated air to achieve optimal drying of grains, hence guaranteeing utmost safety and minimising crop wastage [115].

Drying and storage methods: Various methods are used to dehydrate and preserve grain crops for commercial purposes. The choice of the suitable technique relies on variables such as the cereal variety, the accessible resources, and the required level of excellence in the end product [96, 113].

Effective grain storage is crucial for maximising income for farmers and guaranteeing a steady food supply. It is also crucial for maintaining optimal grain quality and minimising storage losses, which are vital to ensuring food security. Hence, managing storage conditions, particularly in preserving quality and minimising losses, is crucial in guaranteeing food security [106].

12. Conclusion

Ancient cereal grains, such as *P. millet*, *S. bicolor* and common buckwheat, have several obstacles in their production, including a dearth of enhanced seed variants, inadequate infrastructure and fluctuating demand in affluent nations. The crop rotation system, including catch crops like buckwheat, *P. millet* and *S. bicolor*, can effectively replace the negative effects of climate change, pesticide residues and nitrogen fertilisers. This strategy is successful in managing nutrients and preserving soil fertility. Additionally, using modern technologies such as Optinyte technology and innovative nitrogen fertiliser methods can further enhance the efficacy of nutrient management—efficient agricultural techniques on a wide scale benefit crop quantity and quality, leading to food security. In addition, developing agricultural practice standards might be further complicated by the limited expertise and resources available to smallholder farmers.

However, drying and storage are also crucial issues since conventional approaches are often demanding in labour and time. *P. millet*, *S. bicolor* and buckwheat are vulnerable to insect infestations and sensitive to mould development, making them less prevalent in rural regions. Consumer acceptability and cultural preferences also impact demand since ancient alternative grains are typically considered inexpensive food options in metropolitan settings. Policy and market restrictions also affect the agricultural techniques for cereal grain production, storage, packaging and consumption of grains with appropriate nutritional compositions. Government policies often prioritise staple crops such as rice and wheat, resulting in restricted allocation of resources towards research and development. The fragmented structure of millet markets and the absence of standardised quality and price generate confusion and distrust among consumers and suppliers.

Conflict of interest

The authors declare they have no conflict of interest.

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