



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(7): 340-350
Received: 03-05-2026
Accepted: 05-06-2026

Md Hedayetullah
Department of Agronomy, Bidhan
Chandra Krishi Vishwavidyalaya,
Mohanpur, Nadia, West Bengal, India

Sabyasachi Patra
Param Nath Bhaduri Crop Research &
Seed multiplication Farm, Department
of Botany, The University of Burdwan,
Burdwan, West Bengal, India

Md Sahanowaz Hoque
Department of Agronomy, Bidhan
Chandra Krishi Vishwavidyalaya,
Mohanpur, Nadia, West Bengal, India

Rohan Sharma
Department of Agronomy, Bidhan
Chandra Krishi Vishwavidyalaya,
Mohanpur, Nadia, West Bengal, India

Mohammad Ilyas Khatibi
Department of Agronomy, University of
Agriculture Science, GKVK, Bangalore,
Karnataka, India

Uday Layek
Department of Agronomy, Bidhan
Chandra Krishi Vishwavidyalaya,
Mohanpur, Nadia, West Bengal, India

Gagan Mudi
Department of Agronomy, Bidhan
Chandra Krishi Vishwavidyalaya,
Mohanpur, Nadia, West Bengal, India

Sanchita Roy
School of Agriculture, DEV Bhoomi
Uttarakhand University, Dehradun,
Uttarakhand, India

Santanu Kayal
Department of Agronomy, Bidhan
Chandra Krishi Vishwavidyalaya,
Mohanpur, Nadia, West Bengal, India

Champak Kumar Kundu
Department of Agronomy, Bidhan
Chandra Krishi Vishwavidyalaya,
Mohanpur, Nadia, West Bengal, India

Corresponding Author:
Sabyasachi Patra
Param Nath Bhaduri Crop Research &
Seed multiplication Farm, Department
of Botany, The University of Burdwan,
Burdwan, West Bengal, India

Future scope of chia (*Salvia hispanica* L.) accommodation under rice-based cropping systems through crop diversification in a changing climate scenario

**Md Hedayetullah, Sabyasachi Patra, Md Sahanowaz Hoque, Rohan Sharma,
Mohammad Ilyas Khatibi, Uday Layek, Gagan Mudi, Sanchita Roy,
Santanu Kayal and Champak Kumar Kundu**

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i7e.5950>

Abstract

Climate change is one of the major problems threatening the sustainability of agriculture globally. Rising temperatures, erratic rainfall, frequent droughts, floods, and depleting natural resources have all had a negative effect on the productivity and profitability of traditional rice-based agricultural systems. Crop diversification is becoming more widely acknowledged as a successful tactic to boost farm income, increase resilience, and guarantee nutritional security. Chia (*Salvia hispanica* L.), one of the newest climate-resilient crops, has garnered a lot of interest due to its outstanding nutritional content, drought resistance, minimal input requirements, and strong market demand. Chia seeds are a significant functional food crop because they are high in protein, dietary fibre, antioxidants, omega-3 fatty acids, and vital minerals. By utilizing residual soil moisture, lowering production risks, enhancing resource use efficiency, and boosting cropping system profitability, the incorporation of chia into rice-based systems presents prospects for sustainable intensification. The significance of rice-based cropping systems, the effects of climate change, the agronomic traits of chia, its suitability for crop diversification initiatives, and the potential for integrating chia into rice-based systems in the future are all covered in this review. Major obstacles, research gaps, and policy actions necessary for widespread adoption are also highlighted in the essay.

Keywords: Chia, rice-based cropping system, crop diversification, climate change, nutritional security, sustainable agriculture

Introduction

Major regions of Asia, including India, Bangladesh, China, Thailand, and Southeast Asian nations, are dominated by farming systems centred on rice. The production of rice is the primary source of income for millions of smallholder farmers. However, climate unpredictability, groundwater depletion, deteriorating soil fertility, labour shortages, and volatile market pricing are putting increasing strain on these systems' viability. Rice productivity is expected to decline because of rising temperatures, water scarcity, and extreme weather events brought on by climate change. To apply better management practices and produce high-quality seed, Patra (2022) [82] states that farmers should be particularly aware of how temperature, relative humidity, extreme drought, soil salinity, soil temperature, and soil pH respond. Additional management practices, such as defence against diseases spread by seeds (Patra, 2023a) [83, 84, 85], defence against the effects of macro and micronutrients (Patra, 2023b) [83, 84, 85], preservation of seed vigour and viability (Patra, 2021; 2025a, 2025c, 2025e) [81, 86], and improved seed multiplication techniques (Patra, 2025d), are the primary factors affecting seed quality. Several studies (Mandal *et al.*, 2011a; 2011b; Patra *et al.*, 2012, 2013; 2026a, 2026b; Patra, 2017a, 2017b; Patra, S., & Burman, D., 2017; Garai, U., & Patra, S., 2024) [65, 66, 96, 79, 80, 92, 13, 95, 94] have documented the use of less toxic and organic seed treatments to improve seed quality and crop performance. Increasing traditional and aromatic rice production, quality, and economic viability while maintaining soil health for future generations requires adopting sustainable, balanced nutrient management practices (Patra *et al.*, 2026;

Hedayetullah *et al.*, 2026a; 2026c; 2026d; Hedayetullah and Patra, 2025; 2026) [93, 94, 95, 19, 33, 45, 46, 34, 40, 43, 44, 123]. Consequently, it is now crucial to diversify rice-based systems with high-value and climate-resilient crops (Roy *et al.*, 2025) [99].

Salvia hispanica L., an annual herbaceous plant belonging to the mint family (Lamiaceae), produces the delicious seed known as chia (Figure 1&2). Chia seeds are oval in shape, 1 to 2 mm in size, and can be black, grey, or white with black spots. Chia is a sign of power, and the tiny seeds have been used to boost vitality. Da Silva MR *et al.* (2014) [9] state that chia seeds can be used as whole seeds, oilseed, flour, or mucilage. The nutritional and therapeutic qualities of chia seeds make them extremely valuable. Healthy *omega*-3 fatty acids, polyunsaturated fatty acids, dietary fibre, protein (containing all required amino acids), vitamins, calcium, and other vital minerals are all present (Muñoz LA *et al.*, 2013; Ullah R *et al.*, 2016) [107, 72]. According to Coorey R *et al.* (2014) [8], chia seeds can be used to create a gel that can be used as a thickening, emulsifier, and stabilizer in food items. Chia seeds are said to be among the world's healthiest foods, full of nutrients and advantages for the body and brain. According to Ullah R *et al.* (2016) and Ali NM *et al.* (2013), chia seeds assist the digestive system, encourage good skin, strengthen bones and muscles, lower the risk of heart disease, diabetes, and indications of ageing, among other health advantages.

In recent years, it has emerged as a "superfood" due to its unique nutritional composition. Chia seeds contain approximately 30-35% oil, of which nearly 60-65% is alpha-linolenic acid (ALA), an important *omega*-3 fatty acid. The seeds also contain 18-25% protein, 30-40% dietary fiber, vitamins, minerals, and various antioxidant compounds (Kundu *et al.*, 2023) [59, 64]. The increasing demand for healthy foods and nutraceutical products has created new market opportunities for chia cultivation. In regions where rice is harvested before winter, chia can be grown as a shortduration alternative crop, making efficient use of residual soil moisture and available land resources. The principal aim of this review is a) To assess the potential of chia as an alternative crop in rice-based cropping systems for enhancing crop diversification, improving land-use efficiency, and increasing overall system productivity under varying agro-climatic conditions. b) To evaluate the role of chia cultivation in climate-resilient agriculture by examining its adaptability to water scarcity, temperature fluctuations, and other climate change-induced stresses in rice-growing regions. c) To analyze the agronomic, nutritional, and economic prospects of integrating chia into rice-based farming systems for improving farmer income, resource-use efficiency, and sustainable agricultural development.



Fig 1: Chia (*Salvia hispanica* L.) seed and Chia crop in leaf stage



Fig 2: Flowering stage of Chia

2. Rice-Based cropping systems: significance and difficulties

Rice-based cropping systems are the backbone of food security in many Asian countries, particularly India, where rice is cultivated in rotation with one or more crops throughout the year. Common cropping sequences include rice-wheat, rice-mustard, rice-lentil, rice-vegetables, rice-maize, and rice-chickpea systems (Hedayetullah *et al.*, 2018) [20, 21, 28, 29, 30, 31, 32, 35, 36, 47, 48, 49, 50]. These systems enhance land use efficiency, crop diversification, and farm income while ensuring a continuous supply of food and raw materials. However, their sustainability is increasingly threatened by several challenges. Climate change has led to rising temperatures, delayed monsoons, erratic rainfall patterns, droughts, floods, and heat stress during critical crop growth stages. Resource degradation, including declining groundwater levels, soil nutrient depletion, loss of soil organic carbon, salinity, and waterlogging, further reduces productivity (Burman, 2015) [7]. In this regard, integrated farming through land shaping models in low-lying and salinity-affected areas is suitable for enhancing farm income, especially for the eastern coastal region of India (Mandal *et al.*, 2015) [67]. Additionally, rising production costs, labor shortages, low profitability, and market uncertainties create economic pressure on farmers. Therefore, diversification toward low-input, climateresilient, and high-value crops is essential for sustaining rice-based farming systems.

3. Crop Diversification as a strategy for climate resilience

India's diverse agro-climatic zones support a wide range of cereal, pulse, and oilseed crops, which are cultivated under various cropping systems to optimize land use, enhance soil fertility, and improve farm income (Hedayetullah *et al.*, 2025, 2025a, 2025b) [34, 40, 43, 44]. These crops are categorized as major and minor based on area, production, and regional importance. Major cereal crops include rice (Rahaman *et al.*, 2022; Hedayetullah, 2022) [97, 17], wheat (*Triticum aestivum*), maize (*Zea mays*) (Kundu *et al.*, 2020) [63], and sorghum (*Sorghum bicolor*). These are grown predominantly in mono-cropping or rotation systems like rice-wheat (Indo-Gangetic Plains), rice-maize, and sorghum-chickpea in semi-arid regions (Hedayetullah *et al.*, 2014a) [37, 51, 52, 53]. Minor cereals such as millets (finger millet, foxtail millet, barnyard millet) are gaining attention under nutri-cereal-based diversified systems, especially in rainfed and tribal areas due to their drought tolerance and nutritional value (Hedayetullah and Giri, 2021) [24].

Groundnuts (*Arachis hypogaea*) (Giri *et al.*, 2014) [15], mustard (*Brassica juncea*) (Hedayetullah *et al.*, 2016) [6], and soybeans (*Glycine max*) are important oilseed crops that require less water. These are included into systems such as rice-mustard, groundnut-sorghum, and soybean-wheat (Zaman and Hedayetullah, 2018) [113, 114, 131, 133, 134, 135]. In dryland areas, minor oilseeds like safflower, linseed, and niger are typically planted as relay or intercrops. Diverse cropping systems that incorporate major and minor cereals, pulses, and oilseeds enhance productivity, guarantee food and nutritional security, and preserve soil health (Zaman and Hedayetullah, 2025c; Zaman and Hedayetullah, 2018b) [112, 115, 116, 117, 118, 119, 120, 121, 122, 113, 114, 131, 133, 134, 135]. Additionally, this kind of variety helps India achieve sustainable agricultural intensification and increases resistance to climatic variability (Hedayetullah *et al.*, 2014b) [37, 51, 52, 53]. India's cattle industry, which is essential to rural livelihoods and agricultural sustainability, depends heavily on fodder crops (Hedayetullah and Zaman, 2018, 2018a, 2018b, 2018c; Sadhukhan *et al.*, 2018) [29, 30, 31, 32, 35, 48, 49, 50, 100]. Fodder crops can be roughly divided into main and minor species based on farming systems and agroclimatic conditions (Hedayetullah, 2022) [17]. To guarantee

year-round forage supply, including ginger crops, they are included into various farming systems, such as crop-livestock or agroforestry systems (Mukherjee and Hedayetullah, 2018a; Singh *et al.*, b) [70, 71].

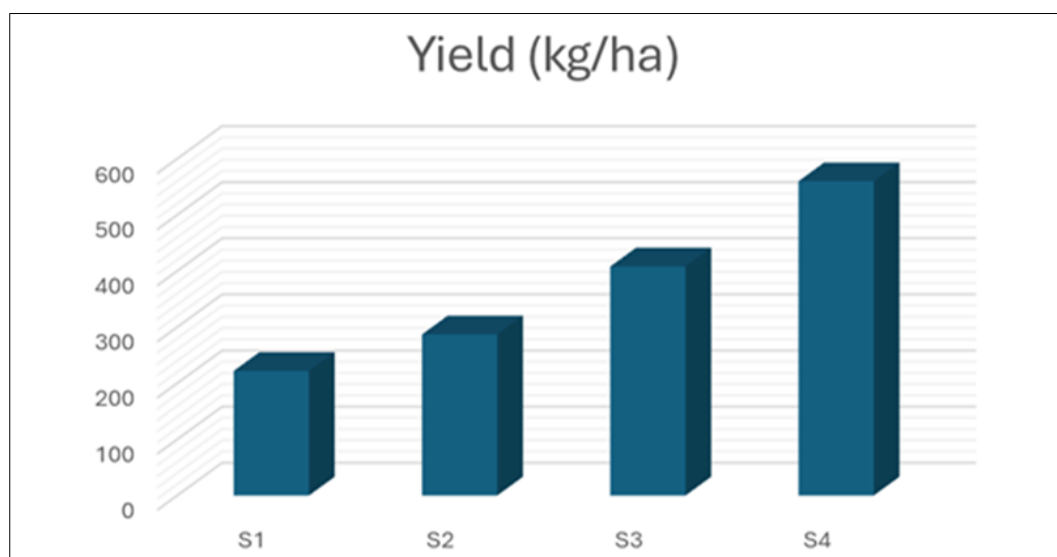
Sorghum (*Sorghum bicolor*), maize (*Zea mays*), berseem (*Trifolium alexandrinum*) (Barik and Hedayetullah, 2018) [3], oats (*Avena sativa*) (Hedayetullah and Barik, 2012) [22], napier-bajra hybrid (*Pennisetum glaucum* × *P. purpureum*), and guar (*Cyamopsis tetragonoloba*) are important fodder crops. Because fenugreek has a high biomass production and nutritional value, they are widely grown (Zaman *et al.*, 2018c) [113, 114, 131, 133, 134, 135]. In northern India, berseem and oats predominate during the rabi season, whereas sorghum, maize, and cowpea are typical during the kharif season. In year-round cut-and-carry systems, particularly in intensive dairy zones, Napier grass and perennial species like Guinea grass are utilised. Senji (*Melilotus* spp.), Rhodes grass (Hedayetullah and Banerjee, 2018) [21], lablab (*Lablab purpureus*), canary grass (Ahmed and Hedayetullah, 2018) [1], sunhemp (*Crotalaria juncea*) (Deenanath grass (Hedayetullah and Bandopadhyay, 2018) [20], stylo (*Stylosanthes* spp.), and silage maize varieties (Hedayetullah and Zaman, 2018; Kundu *et al.*, 2011, Kundu *et al.*, 2015) [29, 30, 31, 32, 35, 48, 49, 50, 60] are examples of minor fodder crops. These are frequently produced as intercrops in orchards and agroforestry systems, on marginal lands, or in bunds. Due to their drought resistance, lablab, senji, setaria, pangola, Salgom, and stylo are particularly useful in semi-arid regions (Hedayetullah *et al.*, 2018b; Hedayetullah *et al.*, 2018c; Hedayetullah *et al.*, 2018d, 2018e, 2018f, Zaman and Hedayetullah, 2018) [20, 21, 28, 29, 30, 31, 32, 35, 36, 47, 48, 49, 50]. Fodder crops are either grown as border crops (Johnson and doob grass) in horticulture-based systems or rotated or interplanted with cereals (such as berseem in wheat-rice systems) in integrated cropping systems (Hedayetullah and Zaman, 2018a; Hedayetullah and Zaman, 2018b) [29, 30, 31, 32, 35, 48, 49, 50]. In mixed agricultural systems, dualpurpose cereals, such multi-cut sorghum or maize, provide both grain and feed (Mukherjee and Hedayetullah, 2018; Hedayetullah *et al.*, 2018) [70, 71, 20, 21, 28, 29, 30, 31, 32, 35, 36, 47, 48, 49, 50]. Interplanting millets with fodder legumes improves soil fertility and feed quality (Ahmed and Hedayetullah, 2018) [1]. Hedayetullah and Zaman (2026) [123, 124, 125, 126, 127] and Zaman and Hedayetullah (2018, 2019, 2020a, 2020b) claim that carefully integrating major and minor fodder crops into cropping systems boosts feed availability, enhances soil health, and boosts livestock productivity all of which support resilient and sustainable farming systems in India.

4. Growth, yield attributes, nutritional and medicinal importance of chia

Chia (*Salvia hispanica* L.) is a short-duration, high-value medicinal crop with good adaptability and promising yield potential under diverse agro-climatic conditions (Hedayetullah *et al.*, 2014) [37, 51, 52, 53]. It is recognized globally as a functional food because of its exceptional nutritional and medicinal properties (Giri and Hedayetullah, 2020) [14]. Chia seeds contain about 30-35% lipids, with a high proportion of *omega*-3 fatty acids, particularly alpha-linolenic acid, which is beneficial for cardiovascular health. The seeds also possess 18-25% high-quality protein with a balanced amino acid profile and 30-40% dietary fiber comprising both soluble and insoluble fractions. They are rich sources of essential minerals such as calcium, phosphorus, magnesium, potassium, iron, and zinc. In addition, chia contains valuable antioxidants, including chlorogenic acid, caffeic acid, quercetin, and kaempferol, which help reduce oxidative stress and inflammation. These nutritional attributes

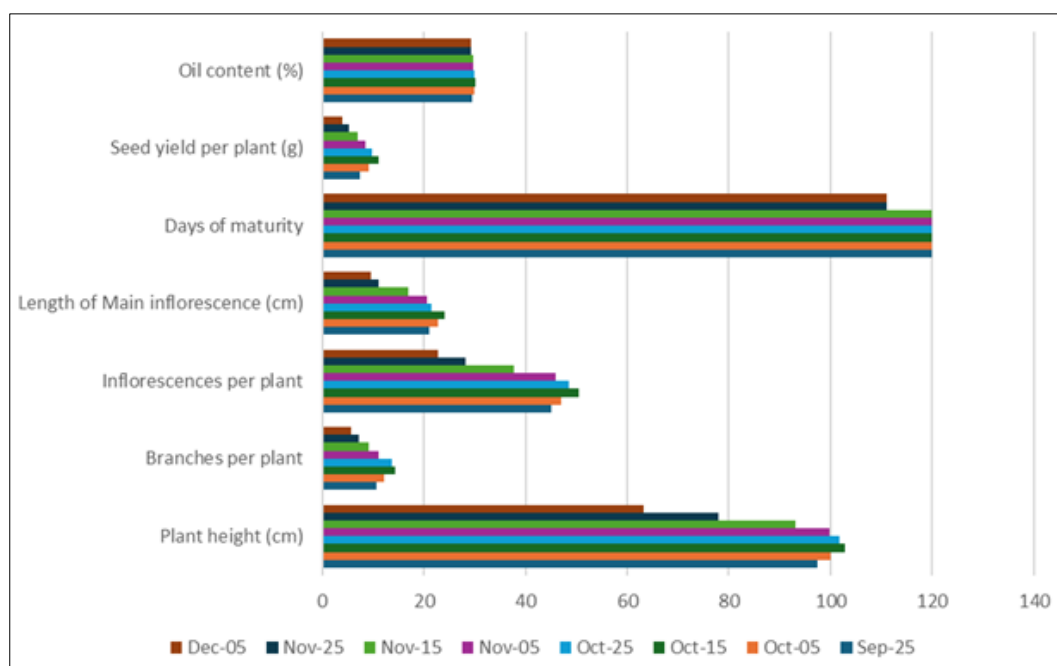
make chia an important crop for improving human health, nutritional security, and the development of functional food products, as meet by others food crops which are grown in winter and summer season (Garai and Patra, 2024; Zaman *et al.*, 2018, 2026, 2026a, 2026b, 2026c) [13, 113, 114, 131, 133, 134, 135]. Due to its high content of omega (ω)-3 and *omega*-6 polyunsaturated fatty acids (PUFA), chia seeds are a popular oil product. Long-chain FAs that are members of the *omega*-3 and *omega*-6 categories are alpha-linolenic acid (ALA) and linolenic acid (LA), respectively. LA and ALA are precursors of long-chain FA and are necessary for preserving the integrity of cell membranes (Mann and Truswell, 2007) [68]. Chia, which was formerly a staple diet for indigenous people in Guatemala and Mexico, is now cultivated

and sold for its antioxidant and *omega*-3 alpha-linolenic acid (ALA) content. It is now grown not just in America but also in Australia and Southeast Asia (Jamboonsri *et al.*, 2012) [56]. The traits and attributes were found to be influenced by the planting date, row spacing, and intrarow spacing. Plant spacing and the number of plants per hectare must be calculated while taking competition for light, water, and nutrients into account (Karim *et al.*, 2015; Yeboah *et al.*, 2014) [57, 108]. One of the most important factors influencing chia seed productivity when planting in a new climate is the timing of planting (Fig 4). Kundu *et al.* (2023) [59] found that planting technique and density affected chia (*Salvia hispanica*) growth and yield variation (Fig. 3).



Source: Kundu *et al.*, 2023 [59, 64]

Fig 3: Chia yield variation in caused by planting density (S1= 60 × 50 cm; S2= 50×50 cm; S3= 50×25 cm and S4= 50 ×20 cm).



Note: Chia seeds were planted during 2017 and 2018 of Rabi season on the mentioned dates in the figure

Source: Ram, M *et al.*, 2024 [98]

Fig 4: Impact of planting date on the growth, oil content, and seed output of chia (*Salvia hispanica* L.)

5. Climate resilience of chia

Chia is seen as an alternative crop for both preserving food security and reducing the effects of climate change due to its greater adaptation to a variety of agroclimatic settings (Herman *et al.* 2016) ^[54]. Chia (*Salvia hispanica* L.) has several traits that make it a viable crop in climate-changing environments where other crops would fail or experience severe production losses (Hedayetullah *et al.*, 2014, 2018) ^[37, 51, 52, 53]. During times of moisture stress, its deep and well-developed root system allows for the effective extraction of water from deeper soil layers, offering significant drought tolerance. Chia needs comparatively less irrigation than many traditional oilseed crops, which makes it appropriate for regions with limited water resources and rice fields. According to Singh *et al.* (2014) ^[104, 105, 106], 2014a, 2014b, 2025), food crops can thrive in a variety of soil. Chia may be grown in organic and sustainable agricultural systems since it requires less fertilizer and typically requires less pesticide treatments. It is a perfect climate-smart crop for diverse rice-based production systems, such as rice chickpeas in different sowing windows, because it also exhibits efficient resource utilization through increased water productivity, improved nutrient use efficiency, and effective exploitation of residual soil moisture (Seth *et al.*, 2020) ^[102].

Particularly in areas with large amounts of rice fallow land, chia (*Salvia hispanica* L.) has a great deal of potential for integration into rice-based cropping systems (Hedayetullah, M. 2023) ^[18, 25]. Due to a lack of irrigation facilities, large areas remain uncultivated following rice harvest. Chia can make good use of these fallows by growing on saved residual soil moisture, which lowers irrigation expenditures (Hedayetullah *et al.*, 2018e) ^[20, 21, 28, 29, 30, 31, 32, 35, 36, 47, 48, 49, 50]. Chia also contributes to the diversification of continuous rice monoculture, which frequently results in pest accumulation, soil deterioration, and ecological imbalance. Chia can increase farm profitability, diversify crops, and enhance resource efficiency. Additionally, chia can be successfully included into a variety of cropping sequences, including rice-chia-vegetables, rice-chia-green manure, rice-chia-sesame, and ricepulse-chia systems. More resilience against climate unpredictability, improved land use, and sustainable agriculture are all supported by such diverse production strategies.

6. Suitability for dirty soil, organic farming, and natural environments

Due to its minimal input requirements and flexibility to sustainable agricultural practices, chia (*Salvia hispanica* L.) is regarded as a highly ideal crop for natural and organic farming systems (Zaman and Hedayetullah 2026d; Hedayetullah and Patra, 2026) ^[123, 124, 125, 126, 127, 128, 129, 130, 132, 45, 46]. The crop is an environmentally benign choice for crop diversification in rice-based agricultural systems since it can be grown with less reliance on chemical pesticides and synthetic fertilizers. Because of its mild nutrient requirements, organic manures, compost, vermicompost, and other biofertilizers can be used effectively to maintain soil fertility and increase beneficial microbial activity. Compared to many traditional field crops, chia has a comparatively reduced incidence of major insect pests and diseases. It can also be cultivated like other crops in natural and organic farming conditions (Hedayetullah *et al.*, 2014a, 2014b, 2026) ^[37, 51, 52, 53]. This feature encourages the use of environmentally friendly pest management techniques based on botanical extracts, biological control agents, and integrated pest management techniques and lessens the need for chemical plant protection measures. According to Hedayetullah and Kundu

(2013, 2021) and Basu *et al.* (2015) ^[5], this compatibility with natural farming principles helps to increase soil health, conserve biodiversity, and reduce environmental pollution. Water from shallow tube wells and ponds in West Bengal, which are necessary for life-saving light irrigation in the winter and other seasons, has been shown to be contaminated with arsenic (Hedayetullah *et al.*, 2011, 2024, 2025) ^[39]. Winter adaptation of chia requires life-saving irrigation, and there may be a risk of arsenic contamination. There is now a premium market for organic chia seeds due to the growing demand for functional foods made in an organic manner worldwide. Customers are becoming more prepared to pay more for goods made using ecological practices and devoid of chemical residues. Thus, including chia into natural and organic farming systems can support climate-resilient and environmentally sustainable agriculture while giving farmers more revenue options (Zaman and Hedayetullah, 2026d, 2506e, 2026f, 2026g) ^[123, 124, 125, 126, 127, 128, 129, 130, 132]. Its inclusion in rice-based crop diversification programs may contribute significantly to long-term agricultural sustainability, nutritional security, and the development of high-value organic supply chains.

7. Techniques for controlling weeds and water in a rice-based cropping system

In rice-based cropping systems, weed control techniques have been implemented in both cropped and non-cropped regions (Dolai *et al.*, 2013; Biswas *et al.*, 2016; Dolai *et al.*, 2019, Kundu *et al.*, 2023) ^[11, 6, 10]. The key component of weed control in rice fallow is the use of broad spectrum techniques under the rice chickpea sequence (Kundu *et al.*, 2018, 2020; Hedayetullah, and Giri, 2021; Hedayetullah, and Kumar 2023, Kumar *et al.*, 2025) ^[62, 24, 25]. Rice, chia, and its methods for controlling weeds could be cost-effective. According to Hedayetullah *et al.* (2012, 2024), irrigation frequency and optimal water utilization are cost-effective and advantageous in terms of crop and water productivity. Weed infestation is more common in heavy soil than in light soil because there is always enough moisture (Zaman and Hedayetullah, 2022, Mudi *et al.*, 2026) ^[111].

8. Research Themes

It takes extensive and interdisciplinary research efforts to successfully accommodate chia (*Salvia hispanica* L.) in rice-based cropping systems under changing climatic circumstances. Even though chia has shown promise as a high-value, climate-resilient crop, a number of scientific and technological issues need to be resolved before farmers can use it extensively. To increase productivity, profitability, and sustainability, future research should concentrate on crop development, agronomic management, cropping system optimization, climate resilience, and mechanization. The creation of early maturing varieties should be given top attention in the field of plant breeding, especially for their integration into rice-based systems where there is sometimes little time for growth following rice harvest (Sengupta & Hedayetullah, 2018). Farmers can incorporate chia into current cropping sequences without impacting future crops thanks to short-duration cultivars that enable timely seeding and harvesting. The creation of cultivars that are insensitive to photoperiod is another crucial goal. The sensitivity of several current chia genotypes to day duration limits their production in a variety of agroclimatic locations. Therefore, breeding efforts should concentrate on creating cultivars that can function reliably in a range of latitudes and sowing windows (Zaman and Hedayetullah, 2025e, 2025f, 2025g,h) ^[112, 115, 116, 117, 118, 119, 120, 121, 122]. Increasing the crop's economic viability will also need the

creation of high-yielding lines with better seed quality, increased *omega*-3 fatty acid content, and increased resistance to biotic and abiotic stressors.

To fully realize the potential of chia cultivation, agronomic study is equally crucial. To maximize development and seed output while avoiding unfavorable weather during crucial growth stages, research is required to determine the best sowing dates under various agroclimatic situations. By establishing the proper dosages and timing of macro- and micronutrient application, including the incorporation of organic manures and biofertilizers, scientific nutrient management techniques should be standardized (Zaman and Hedayetullah, 2026, 2506a,b,c) [123, 124, 125, 126, 127, 128, 129, 130, 132]. To increase water-use efficiency, research should also concentrate on irrigation timing, especially in rice-fallow regions with scarce irrigation resources. Promoting chia as a climate-smart crop will need the development of water-saving farming techniques. The compatibility of chia with current rice-based agricultural systems should be assessed in cropping system research. To evaluate the effects of rice-chia rotations on soil fertility, insect and disease dynamics, resource use efficiency, and overall system productivity, long-term studies are required. To enhance soil health and environmental sustainability, chia should be used into conservation agriculture techniques such as crop rotation, residue retention, and limited tillage (Zaman *et al.*, d). Additionally, intercropping models that combine chia with vegetables, oilseeds, or pulses may offer more chances for risk mitigation and revenue diversification; these systems need to be thoroughly assessed.

Climate-related research should focus on improving the resilience of chia to future environmental challenges. The identification and development of heat-tolerant and drought-tolerant genotypes will help sustain production under rising temperatures and increasing water scarcity. Studies should also investigate the physiological and molecular mechanisms associated with stress adaptation. In addition, comprehensive carbon footprint assessments of rice-chia cropping systems are necessary to evaluate their contribution to greenhouse gas mitigation and sustainable agricultural development (Zaman and Hedayetullah, 2025, 2025a, 2025b, 2025c, 2025d) [112, 115, 116, 117, 118, 119, 120, 121, 122]. Another crucial area that needs attention is mechanisation, especially for large-scale farming. Plant establishment can be enhanced and seed waste can be decreased with the invention of precision sowing tools appropriate for the tiny size of chia seeds. Technologies for mechanical harvesting should be developed to minimise labour needs and harvest losses. To preserve seed quality and satisfy national and international market standards, effective technology for cleaning, grading, and processing seeds are also crucial. In order to establish chia as a viable and sustainable part of rice-based crop diversification plans in the changing climatic scenario, future research should take an integrated approach that combines breeding, agronomy, climate science, mechanisation, and socio-economic analysis. (Zaman and others, 2018a) [113, 114, 131, 133, 134, 135].

9. Future Scope under the Changing Climate Scenario

Agricultural systems need to implement robust and varied cropping techniques in light of the changing climate. Because of its low water requirements, capacity to thrive in rice fallow areas, and effective utilization of leftover soil moisture, chia has enormous potential for the future (Hussain *et al.*, 2024) [55]. It can increase climate resilience, boost nutritional security, and increase farm profitability. Chia is also a good fit for organic and natural agricultural systems, encourages crop variety, and supports sustainable intensification. Its growing domestic and

export demand further increases its economic importance. In eastern India, particularly the New Alluvial Zone of West Bengal, chia can become an attractive winter crop after kharif rice, provided suitable varieties and agronomic packages are developed. The integration of chia with rice-based systems can contribute significantly to the Sustainable Development Goals (SDGs), especially those related to food security, nutrition, climate action, and sustainable agriculture.

10. Conclusion

Rice-based farming systems are under enormous pressure from resource depletion, climate change, and declining profitability. Because of its exceptional nutritional value, drought tolerance, low input requirements, and growing market demand, chia (*Salvia hispanica* L.) is a good alternative for diversification. Incorporating chia into rice-based cropping systems can boost farmer income, utilize rice fallow areas, improve nutritional security, and increase resource efficiency. Its compatibility with natural farming, conservation agriculture, and organic production systems enhances its long-term sustainability even more. For adoption to be effective, however, coordinated efforts in varietal improvement, agronomic research, high-quality seed production, mechanisation, market growth, and supporting government laws are required. Future research should focus on developing regionally specific production methods and evaluating the long-term economic and ecological impacts of rice-chia systems.

Acknowledgement

The Department of Agronomy, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani and Param Nath Bhaduri Crop Research & Seed Multiplication Farm, Department of Botany, The University of Burdwan, Burdwan-713104, West Bengal, India, are gratefully acknowledged by the authors.

Conflict of interest

Authors have declared that no conflict of interest.

References

- Ahmed B, Hedayetullah M. Canary grass (Harding grass). In: Hedayetullah M, Zaman P, editors. *Forages of the World: Minor Forage Crops*. CRC Press; 2018. p. 47-54. <https://www.scribd.com/document/501970715/Forage-Crops-of-the-World-Volume-II>
- Ali NM, Yeap SK, Ho WY, Beh BK, Tan SW, *et al.* The promising future of Chia, *Salvia hispanica* L. *J Biomed Biotechnol.* 2012;171956.
- Barik AK, Hedayetullah M. Berseem (Egyptian Clover). In: Hedayetullah M, Zaman P, editors. *Forages of the World: Major Forage Crops*. CRC Press; 2018. p. 215-230. ISBN: 978-1-77188-684-0. <https://appleacademicpress.com/forage-crops-of-the-world-volume-i-major-forage-crops/9781771886840>.
- Basu B, Kundu M, Hedayetullah M, Kundu CK, Bandyopadhyay P, Bhattacharya K, *et al.* Mitigation of arsenic in rice through deficit irrigation in field and use of filtered water in kitchen. *International Journal of Environmental Science and Technology.* 2015;12(6):2065-2070. <https://DOI.org/10.1007/s13762-014-0568-1>
- Biswas U, Kundu CK, Kundu A, Mondal S, Biswas T, Hedayetullah M. Evaluation of bio-efficacy of 2,4-D Ethyl Ester 38 per cent EC for weed control in wheat. *Journal of Crop and Weed.* 2016;12(3):138-141. <http://cropandweed.com/archives/2016/vol12issue3/28.pdf>

6. Burman D, Mandal S, Bandopadhyay BK, Maji B, Sharma DK, Mahanta KK, *et al.* Unlocking production potential of degraded coastal land through innovative land management practices: a synthesis. *Journal of Soil Salinity and Water Quality*. 2015;7(1):12-18.
7. Coorey R, Tjoe A, Jayasena V. Gelling Properties of Chia Seed and Flour. *J Food Sci*. 2014;79(5):E859-E866.
8. Da Silva MR, Moraes EA, Lenquiste SA, Godoy AT, Eberlin MN, *et al.* Chemical characterization and antioxidant potential of Chilean chia seeds and oil (*Salvia hispanica* L.). *LWT-Food Science and Technology*. 2014;59(2):1304-1310.
9. Dolai AK, Hedayetullah M, Ghosh P. Eco-safe Management of *Parthenium hysterophorus* L. in Inceptisol. LAP Lambert Academic Publishing; 2019.<https://www.morebooks.shop/shop-ui/shop/product/978-620-0-28051-0>
10. Dolai AK, Hedayetullah M, Giri U, Ghosh RK. Herbicide management of *Parthenium* (*Parthenium hysterophorus* L.) in non crops land and its impact on soil micro-flora. 2013.<https://DOI.org/10.29321/MAJ.10.001258>
11. Fattah MA, Hedayetullah M. Gajar (Carrot). In: Hedayetullah M, Zaman P, editors. *Forages of the World: Minor Forage Crops*. CRC Press; 2018. p. 215-224.<https://DOI.org/10.1201/9781351167284>
12. Garai U, Patra S. Review of the effects of seed priming for improving seed germination, seedling establishment and yield on several pulse crops. *Journal of Stress Physiology & Biochemistry*. 2024;20(4):63-79.<https://www.researchgate.net/publication/385751235>
13. Giri U, Hedayetullah M. Text Book of Agricultural Heritage. Scientific Publishers; 2020.<https://www.scientificpubonline.com/bookdetail/text-book-agricultural-heritage/>
14. Giri U, Hedayetullah M, Saha A, Nanda MK, Bandyopadhyay P. Productivity and nutrient uptake of summer groundnut (*Arachis hypogaea* L.) towards different levels of irrigation and sulphur. *Journal of Crop and Weed*. 2014;10(2):248-251.https://www.researchgate.net/publication/281289833/Productivity_and_nutrient_upt
15. Giri U, Saha A, Hedayetullah M, Kar A. Evaluation of hybrid rice (*Oryza sativa* L.) varieties in north-eastern hilly region of Tripura. SATSA Mukhapatra - Annual Technical Issue. 2023;27:210-217.<https://satsawb.org/annual-technical-issue/27/FILE-NO-Y.pdf>
16. Hedayetullah M. Role of hydrogel in pulses production under rainfed rice fallow. In: Kumar N, Nath CP, Sah U, Praharaj CS, Singh NP, editors. *Sustainable Production of Pulses in Diverse Agroecosystem*. Scientific Publishers; 2022. p. 153-164.<https://www.scientificpubonline.com/bookdetail/sustainable-productionpulses-diverse-agro-ecosystem/9789390749775/0>
17. Hedayetullah M. Yield advantages of new technologies of chickpea in rice-fallow of Indo-Gangetic Plains Zone of West Bengal. *Irish Interdisciplinary Journal of Science & Research*. 2023;7(3):17-21.<https://DOI.org/10.46759/IJISR.2023.7302>
18. Hedayetullah M, Patra S. Indigenous and aromatic rice production strategies in a crop-diversified approach under natural and organic farming systems: A review. *International Journal of Agriculture and Plant Science*. 2026;8(2):319-330.<https://DOI.org/10.66856/ijaps.2026.8.2.8135>
19. Hedayetullah M, Bandopadhyay P. Deenanath grass (*Pennisetum*). In: Hedayetullah M, Zaman P, editors. *Forages of the World: Major Forage Crops*. CRC Press; 2018. p. 103-114.<https://DOI.org/10.1201/9781351167369-17>
20. Hedayetullah M, Banerjee S. Rhodes grass (Abyssinian Rhodes grass). In: Hedayetullah M, Zaman P, editors. *Forages of the World: Minor Forage Crops*. CRC Press; 2018. p. 65-74.https://www.researchgate.net/publication/328122685/Forage_Crops_of_the_World_Vo
21. Hedayetullah M, Barik AK. Influence of cutting and fertilizer management on growth and yield of fodder oats (*Avena sativa* L.). *Madras Agricultural Journal*. 2012;90(10-12):711-714.https://www.researchgate.net/publication/374535859/Influence_of_Cutting_and_Fer
22. Hedayetullah M, Dolai AK. Adoption of new technologies of chickpea in rice fallow of Gangetic alluvial regions of West Bengal. *Indian Biologist*. 2019;51(1):27-30.https://www.researchgate.net/publication/373469932/Yield_Advantages_of_New_Te
23. Hedayetullah M, Giri U. Integrated management strategies of Congress grass (*Parthenium hysterophorus* L.) under cropped and non-cropped areas. In: Nair N, Guha A, editors. *Integrated Pest Management Strategies for Sustainable Agriculture*. 2021. p. 339-348.<https://DOI.org/10.30954/ndp/intpest>
24. Hedayetullah M, Kumar N. Bio-efficacy of different POE herbicides for broad spectrum weeds management in chickpea (*Cicer arietinum* L.). *Journal of Food Legumes*. 2023;36(1):43-46.<https://DOI.org/10.59797/jfl.v36.i1.128>
25. Hedayetullah M, Kundu CK. Arsenic in Fodder Crops: Approaches for Mitigation in Food Web. LAP Lambert Academic Publishing; 2013.
26. Hedayetullah M, Kundu CK. Arsenic in food web: an alert for public health. *Biological Forum*. 2021;13(3):621-624.<https://www.researchtrend.net/bfij/pdf/107%20Arsenic%20in%20Food%20Web%20>
27. Hedayetullah M, Sadhukhan R. Production technology of relay chickpea under rice fallow for sustainable agriculture. *Journal of Agroecology and Natural Resource Management*. 2018;5(2):122-124.<https://krishisanskriti.org/Publication.html>
28. Hedayetullah M, Zaman P. *Forages of the World: Major Forage Crops*. CRC Press, Taylor & Francis Group; 2018.<https://DOI.org/10.1201/9781351167369>
29. Hedayetullah M, Zaman P. Johnson grass (Aleppo Grass). In: Hedayetullah M, Zaman P, editors. *Forages of the World: Major Forage Crops*. CRC Press; 2018a, p. 81-92.<https://DOI.org/10.1201/9781351167369/>
30. Hedayetullah M, Zaman P. Doob grass (Bermuda grass). In: Hedayetullah M, Zaman P, eds. *Forages of the World: Minor Forage Crops*. CRC Press; 2018b, 21-30.<https://DOI.org/10.1201/9781351167284/>
31. Hedayetullah M, Zaman P. *Forages of the World: Minor Forage Crops*. CRC Press, Taylor & Francis Group; 2018c.<https://DOI.org/10.1201/9781351167284>
32. Hedayetullah M, Zaman P. *Weed Management (Theory and Practice)*. Scientific Publishers; 2026.
33. Hedayetullah M, Akhtar J, Kumar N. Impact of frontline demonstration on yield and economics of chickpea (*Cicer arietinum* L.) under rice-fallow condition of West Bengal. *Journal of Food Legumes*. 2025;38(1):141-146.<https://DOI.org/10.59797/jfl.v38i1.1569>
34. Hedayetullah M, Bhattacharya B, Zaman P. Anjan grass (African foxtail grass). In: Hedayetullah M, Zaman P, eds. *Forages of the World: Minor Forage Crops*. CRC Press;

- 2018;55-64.
<https://DOI.org/10.1201/9781351167284/forage-crops-world-volume-ii-minor-forage-crops-md-hedayetullah-parveen-zaman>
35. Hedayetullah M, Chowdhury AR, Ghosh M, Hazra KK, Nath CP, Sadhukhan R, *et al.* Paira chickpea under rice fallow in lowland ecosystem of West Bengal, India. *Agricultural Research & Technology: Open Access Journal*. 2018;13(1):555870.
<https://DOI.org/10.19080/ARTOAJ.2018.13.555870>
 36. Hedayetullah M, Kundu CK, Islam S. Climate change threatens food crops across the world: An overview. In: Datta M, Daschaudhuri D, eds. *Climatic Variability: Impacts on Agriculture and Allied Sector*. New India Publishing House; 2014.
 37. Hedayetullah M, Kundu CK, Akhtar J, Hussain SS, Das S, Datta MK, *et al.* Actual evapotranspiration, water expense efficiency and grain yield of chickpea under varying irrigation regimes. *Legume Research*. 2024.
<https://DOI.org/10.18805/LR-5378>
 38. Hedayetullah M, Kundu CK, Basu B, Sarkar S. Effect of sources of irrigation water on growth and arsenic content in different fodder crops. *Journal of Crop and Weed Science*. 2011;7(2):244-246.
<https://www.cropandweed.com/archives/2011/vol7issue2/57.pdf>
 39. Hedayetullah M, Kundu CK, Devi NM, Das S, Tamang D. Deficit irrigation and source of water: Possible mitigation option of arsenic load in fodder maize and cowpea in Lower Gangetic Plain Zone of West Bengal, India. *International Journal of Environment and Climate Change*. 2025;15(4):477-487.
<https://DOI.org/10.9734/ijecc/2025/v15i44825>
 40. Hedayetullah M, Kundu CK, Rajbanshi B, Tamang D, Mondal S, Akhtar J, *et al.* Reduction of arsenic load in winter fodder crops as influenced by shallow tube well and pond water irrigation. *International Journal of Environment and Climate Change*. 2024;14(8):314-320.
<https://DOI.org/10.9734/ijecc/2024/v14i84352>
 41. Hedayetullah M, Majumder A, Kundu CK, Sarkar S. Yield and actual evaporation of forage crops under varying irrigation frequencies. *Journal of Agrometeorology*. 2012;14:228-232.
 42. Hedayetullah M, Mandal L, Mandal B. Bio-efficacy of different post emergence herbicides for broad spectrum weed management in transplanted rice (*Oryza sativa* L.) in Indo-Gangetic Plain Zone of West Bengal. *International Journal of Bioresource Science*. 2025a;12(2):225-231.
<https://DOI.org/10.30954/2347-9655.02.2025.9>
 43. Hedayetullah M, Mondal SI, Roy S, Giri U, Saha A, Patra S, *et al.* Crop diversification for nutrient, water, and stress management in Indian agriculture. *Journal of Advances in Biology & Biotechnology*. 2025b;28(6):355-365.
<https://DOI.org/10.9734/jabb/2025/v28i62400>
 44. Hedayetullah M, Patra S, Dolai AK, Hembram AK, De S, Mandal SI, *et al.* Comparative performance of traditional aromatic rice under organic and inorganic systems in West Bengal, India. *Archives of Current Research International*. 2026d;26(5):286-296.
<https://DOI.org/10.9734/acri/2026/v26i51892>
 45. Hedayetullah M, Patra S, Rahaman A, Mudi G, Roy S, Hussain SS, *et al.* Comparative analysis of natural and inorganic farming systems in India: Implications for crop diversity, sustainability, and productivity. *International Journal of Research in Agronomy*. 2026a;9(5S):413-425.
<https://DOI.org/10.33545/2618060X.2026.v9.i5Se.5608>
 46. Hedayetullah M, Sadhukhan R, Dolai AK, Bhattacharya B. Effect of different date of sowing and chickpea (*Cicer arietinum* L.) varieties in new alluvial zone of West Bengal. *Indian Agriculturist*. 2018a;5(2):122-124.
https://www.researchgate.net/publication/405232558/Comparative_analysis_of_natu
 47. Hedayetullah M, Zaman P, Kundu R. Pangola grass (Digit or woolly finger grass). *Forages of the World: Minor Forage Crops*. CRC Press; 2018d:39-46.
<https://DOI.org/10.1201/9781351167284-11/pangolagrass-digit-woolly-finger-grass-md-hedayetullah-parveen-zaman-rajib>
 48. Hedayetullah M, Zaman P, Mukherjee D. *Setaria* grass (African grass). *Forages of the World: Minor Forage Crops*. CRC Press; 2018e:3-12.
 49. Hedayetullah M, Zaman P, Sadhukhan R. Strategies for cultivation of chickpea in rice fallows under residual soil moisture. *Cutting Edge Technology for Agricultural Sustainability*. New India Publishing Agency; 2018e:343-349.
<http://www.krishisanskriti.org/Publication.html>
 50. Hedayetullah M, Zaman P, Sadhukhan R. Senji (Sweet clover). In: Hedayetullah M, Zaman P, editors. *Forages of the World: Minor Forage Crops*. Boca Raton (FL): CRC Press; 2018. p. 131-138. ISBN: 978-1-77188-685-7. Available from:
<https://www.taylorfrancis.com/books/edit/10.1201/9781351167284/forage-crops-world-volume-ii-minor-forage-crops-md-hedayetullah-parveen-zaman>
 51. Hedayetullah M, Zaman P, Singh V. Medicinal and aromatic plants are in danger due to climate change. *Popular Kheti*. 2014;2(3):208-213.
 52. Hedayetullah M, Zaman P, Giri U, Kundu CK, Bandopadhyay P. Effect of farm yard manure on forage yield of different crops in uncultivated waste land condition of West Bengal. *Indian Agriculturist*. 2014;58(1):45-48.
 53. Hedayetullah M, Zaman P, Singh V, Yadav SK, Nayyar MA, Siddiqui MW. Climate change and Indian agriculture. *Climate Change and Horticulture: Impact, Adaptation, and Mitigation*. Apple Academic Press; 2014.
 54. Herman S, Marco G, Cecilia B, Alfonso V, Luis M, Cristian V, *et al.* Effect of water availability on growth, water use efficiency and omega 3 (ALA) content in two phenotypes of chia (*Salvia hispanica* L.) established in the arid Mediterranean zone of Chile. *Agricultural Water Management*. 2016;173:67-75.
 55. Hussain SS, Ganie AA, Dar WA, Wani TA, Hedayetullah M, Baba JA, *et al.* The role of digital soil mapping in soil survey and agricultural planning. *International Journal of Plant & Soil Science*. 2024;36(9):438-449.
<https://DOI.org/10.9734/ijpss/2024/v36i94993>
 56. Jamboonsri W, Phillips T, Geneve R, Cahill J, Hildebrand D. Extending the range of an ancient crop (*Salvia hispanica* L.) a new ω 3 source. *Genet Res Crop Evol*. 2012;59:171-178.
 57. Karim MM, Ashrafuzzaman M, Hossain MA. Effect of planting time on the growth and yield of chia (*Salvia hispanica* L.). *Asian J Med Biol Res*. 2015;1(3):502-507.
 58. Kumar N, Nath CP, Hazra KK, Tripathi S, Dixit GP, Tiwari K, *et al.* Assessing post-emergence herbicides in chickpea (*Cicer arietinum* L.) for economic benefits, yield response, and weed control under different megaenvironments in India. *Field Crops Research*.

- 2025;333:110113.<https://DOI.org/10.1016/j.fcr.2025.110113>
59. Kundu CK, Datta MK, Biswas U, Devi NM, Das S, Hedayetullah M, *et al.* Effect of pretilachlor 50% EC on weed control of transplanted rice under alluvial soil of West Bengal, India. *International Journal of Environment and Climate Change*. 2023;13(12):198-204.<https://DOI.org/10.9734/ijecc/2023/v13i123676>
 60. Kundu CK, Hedayetullah M, Bandopadhyay P, Gunri SK, Basu B. Studies on the effect of different phosphorus levels on green forage yield of fodder cowpea (*Vigna unguiculata* L. Walp) varieties. *Journal of Interacademia*. 2011;15(3):410-414.
 61. Kundu CK, Hedayetullah M, Bera PS, Biswas T, Chatterjee S. Effect of nitrogen levels on different varieties of fodder teosinte (*Euchlaena maxicana* L. Schrod) in new alluvial zone of West Bengal. *Forage Research*. 2015;40(4):243-246.
 62. Kundu CK, Kundu A, Das Bairagya M, Labar A, Hedayetullah M, Pal S. Comparative studies on bio-efficacy and phytotoxicity of 2,4-D Ethyl Hexyl Ester 60% EC in sugarcane. *Multilogic in Science*. 2018;28(8):134-138.<https://www.thepharmajournal.com/archives/?>
 63. Kundu CK, Mondal R, Kundu A, Goswami S, Hedayetullah M. Studies on bioefficacy and phytotoxicity of different formulation of 2,4-D amine 50% SL in maize. *Journal of Pharmacognosy and Phytochemistry*. 2020;9(5):559-562.https://www.researchgate.net/publication/343994243/Studies_on_bioefficacy_and_phytotoxicity_of_different_formulation_of_2_4-
 64. Kundu CK, Anand NR, Banerjee H, Devi NM, Gunri SK, Nayak L, *et al.* Growth and yield variation in chia (*Salvia hispanica*) caused by planting method and density. *Indian Journal of Agricultural Sciences*. 2023;93(9):991-996.<https://DOI.org/10.56093/ijas.v93i9.123290>
 65. Mandal AK, Patra S, Mallick RB, Guha P. Seed invigoration treatment in rice for improved storability and comparative efficacy of treatments on field performance in system of rice intensification and conventional method. *Indian Agriculturist*. 2011;55(3-4):121-128.
 66. Mandal AK, Patra S, Mallick RB, Mahata A, Biswas J. Efficacy of seed treatment in rice (cv. Swarna Masuri) for improved germinability and comparative study on field performance by conventional and system of rice intensification (SRI) technology. *Crop Research*. 2011;41(1-3):227-232.https://www.researchgate.net/publication/405232558/Comparative_analysis_of_natura
 67. Mandal S, Burman D, Bandyopadhyay BK, Mandal UK, Sarangi SK, Mahanta KK, *et al.* Crop-fish integration through land shaping models for enhancing farm income under eastern coastal region of India. *Agricultural Economics Research Review*. 2015;28:47-54.
 68. Mann J, Truswell S. *Essentials of Human Nutrition* (3 Ed.). New York: Oxford University Press; 2007.
 69. Mudi G, Hansda A, Hedayetullah M, Layek U, Hansda NN. Weed control efficiency productivity and economics of chickpea influenced by planting geometry under new alluvial zone of West Bengal, India. *Plant Archives*. 2026;26(1):1641-1647.<https://DOI.org/10.51470/Plantarchives.2026.v26.supplement-1.221>
 70. Mukherjee A, Hedayetullah M. Sudan grass (Sudan sorghum). In: Hedayetullah M, Zaman P, eds. *Forages of the World: Major Forage Crops*. CRC Press; 2018:129-140.<https://DOI.org/10.1201/9781351167369-19/sudan-grasssudan-sorghum-anupam-mukherjee-md-hedayetullah>
 71. Mukherjee D, Hedayetullah M. Nonconventional legumes forage crops. In: Hedayetullah M, Zaman P, eds. *Forages of the World: Minor Forage Crops*. CRC Press; 2018:287-308.
 72. Muñoz LA, Cobos A, Diaz O, Aguilera JM. Chia seed (*Salvia hispanica*): an ancient grain and a new functional food. *Food Reviews International*. 2013;29(4):394-408.
 73. Murmu JN, Patra S. Traditional agriculture plays vital role in Santal culture. *International Journal of Creative Research Thoughts*. 2022;10(1):e355-e359.<http://ijcrt.org/viewfull.php?>
 74. Patra S. Review Study on the Maintenance of Improved Crop Varieties for Protecting Their Popularity in Seed Multiplication Systems. *Journal of Stress Physiology & Biochemistry*. 2025;21(2).<https://www.researchgate.net/publication/391750129>
 75. Patra S. Seed invigoration treatment in high-medium vigour rice (cv. Swarna Nasuri) for improved storability and comparative efficacy of treatment on field performances in system of rice intensification and conventional method. *Indian Biologist*. 2013;45(2):73-82.<https://www.researchgate.net/publication/404637569>
 76. Patra S. Field performance of different improved varieties of rice (*Oryza sativa* L.) in old alluvial soil of Burdwan, West Bengal. *Crop Research*. 2016;51(4-6):97-99.<https://gauravpublications.com/journal/crop-research/archive>
 77. Patra S. Effect of seed invigoration treatments for better storability of rice (*Oryza sativa* L., cv. MTU 1010) seed. *Indian Biologist*. 2016;48(2):51-53.<https://www.researchgate.net/publication/404703848>
 78. Patra S. Retention of germinability of rice crop (cv. MTU 1010) with botanicals and comparative study on field performances by employing Paddy-Cum-Fish technology and conventional method. *Indian Biologist*. 2016;48(1):15-21.<https://www.researchgate.net/publication/404678867>
 79. Patra S. Effect of pre-storage seed invigoration treatment in onion (*Allium cepa* L., cv. Agrifound Dark Red) for improved germinability and field performance. *International Journal of Current Microbiology and Applied Sciences*. 2017;6(6):478-482.<https://DOI.org/10.20546/ijcmas.2017.606.055>
 80. Patra S. Response of various seed invigoration treatments in high and medium vigour rice (*Oryza sativa* L. cv. IET-4094) seeds for improved germinability. *Crop Research*. 2017;52(1-3):1-3.<http://gauravpublications.com/>
 81. Patra S. A review on effect of seed invigoration treatments during storage on vigour, viability and productivity of major oil seeds. In: *Environmental Crisis in 21st Century: Towards Conscience and Sustainability*. 2021.<https://www.researchgate.net/publication/404743985>
 82. Patra S. Overview of the influence of environmental factors on seed performance. *GAU Research Journal*. 2022;47(2):82-88.<http://www.sdau.edu.in/detail/118554/gujarat-agriculturaluniversities-research-journal->
 83. Patra S. A review on management of seed borne diseases through seed multiplication strategies. *Biological Forum - An International Journal*. 2023;15(1):377-382.<https://www.researchtrend.net/bfij/bfij.php>
 84. Patra S. Review an investigation of the effects of macro and micro nutrients on the production of high quality seed.

- International Journal of Theoretical & Applied Sciences. 2023;15(2):16-21.<https://www.researchtrend.net/ijtas/ijtas.php>
85. Patra S. Seed multiplication of traditional varieties of paddy (*Oryza sativa* L.) for their protection in sustainable agriculture. Biological Forum - An International Journal. 2023;15(1):592-600.<https://www.researchtrend.net/bfij/bfij.php>
 86. Patra S. A study on vigour and viability of seed. AgriGate Magazine. 2025;5(1):883-897.<https://www.agrigatemagazine.com>
 87. Patra S. Panicle diversity of aromatic rice (*Oryza sativa* L.) under old alluvial soil of the Burdwan region. Farming & Management. 2025;10(2):96-99.<https://DOI.org/10.31830/2456-8724.2025.FM-167SN>
 88. Patra S. Role of seed hardening techniques in crops. AgriGate Magazine. 2025;5(2):313-323.<https://www.agrigatemagazine.com>
 89. Patra S. Recalcitrant seeds: A review of research on the key factors affecting and some important management strategies for extending longevity during storage. Journal of Stress Physiology & Biochemistry. 2025;21(1):190-205.<https://www.researchgate.net/publication/388990627>
 90. Patra S. Investigate the yield and other agronomic parameters of some rice landraces for the future rice breeding program. AgriGate Magazine. 2025;5(3):397-402.<https://www.researchgate.net/publication/391477092>
 91. Patra S, Saha A, Pal SC, Islam ARMT, Halder K, Srivastava AK, et al. Highlighting the role of traditional paddy for sustainable agriculture and livelihood: issues, policy intervention and the pathways. Discover Sustainability. 2025;6(1):181.<https://DOI.org/10.1007/s43621-025-00989-1>
 92. Patra S, Burman D. Maintenance of storability and enhancing productivity of rice crop by seed invigoration treatments in coastal region of Sundarbans. Vegetos. 2017;30(1):81-83.<https://DOI.org/10.5958/2229-4473.2017.00015.5>
 93. Patra S, Hedayetullah M, Dolai A, De S, Hembram A, Mondal SI. A holistic overview of research on the impact of farming techniques and processing steps on the nutritional quality of food crops. International Journal of Agriculture and Nutrition. 2026;8(4):46-51.<https://DOI.org/10.33545/26646064.2026.v8.i4a.438>
 94. Patra S, Hedayetullah M, Sharma R, Mudi G, Kayal S, Rahaman A, et al. Role of seed pelleting for improving seed quality and crop productivity. International Journal of Environmental & Agriculture Research (IJOEAR). 2026;12(6).<https://DOI.org/10.25125/agriculture-journal>
 95. Patra S, Mandal SI, Hedayetullah M. Pre-storage seed invigoration treatments and foliar application of micronutrients on seed germinability, vigor and field performance of wheat (*Triticum aestivum* L.) cv. UP 262. International Journal of Agriculture and Plant Science. 2026;8(2):49-53.<https://www.agriculturejournal.in/assets/archives/2026/vol8issue2/8073.pdf>
 96. Patra S, Guha P, Majumdar R, Mandal AK. Mid-storage seed invigoration treatments in rice (cv. satabdi) for extended storability and comparative study on field performances by employing conventional and system of rice intensification method. Indian biologist. 2012;44(2):29-37.<https://www.researchgate.net/publication/404670369>
 97. Rahaman M, Murmu K, Khandakar J, Bordolui SK, Hedayetullah M. Crop productivity and soil health in relation to the microbial population as influenced by different organic biostimulants in summer rice cultivation. ORYZA - An International Journal of Rice. 2022;59(2):194-204.<https://DOI.org/10.35709/ory.2022.59.2.9>
 98. Ram M, Meena RC, Ambawat S, Bhardwaj R, Kumar M, Meena DS, et al. Chia (*Salvia hispanica* L.) production potential in western India influenced by planting date and crop geometry. International Journal of Research in Agronomy. 2024;7(1):277-282.
 99. Roy S, Hedayetullah M, Mukharjee S, Sharma R, Kundu CK, Mandal B, et al. Enhancing the socio-economic empowerment of Jhumias in Mizoram through livelihood diversification strategies. Journal of Scientific Research and Reports. 2025;31(8):1130-1144.<https://DOI.org/10.9734/jsrr/2025/v31i83455>
 100. Sadhukhan R, Hedayetullah M, Zaman P. Grass pea (Indian vetch). In: Hedayetullah M, Zaman P, eds. Forages of the World: Minor Forage Crops. CRC Press; 2018. p 77-90.<https://DOI.org/10.1201/9781351167284-16/grass-peaindian-vetch-raghunath-sadhukhan-md-hedayetullah-parveen-zaman>
 101. Sengupta K, Hedayetullah M. Urad bean (Black gram). In: Hedayetullah M, Zaman P, eds. Forages of the World: Minor Forage Crops. CRC Press; 2018. p 155-168.<https://appleacademicpress.com/forage-crops-of-the-worldvolume-ii-minor-forage-crops/9781771886857>
 102. Seth S, Ghosh M, Nath R, Hedayetullah M, Nanda MK. Phenology, thermal indices and yield of chickpea (*Cicer arietinum* L.) varieties under different sowing dates in new alluvial zone of West Bengal. Journal of Food Legumes. 2020;33(2):127-132.<https://www.researchgate.net/publication/344492029/Phenology/thermal/indices/a>
 103. Singh AP, Majumdar S, Kumar GV, Emam W, Tashkandy Y, Hedayetullah M, et al. Evaluation of chickpea (*Cicer arietinum* L.) genotypes for genetic variability and mechanization potential under Gangetic plains. Journal of Animal and Plant Sciences. 2025;35(1).<https://DOI.org/10.36899/JAPS.2025.1.0017>
 104. Singh V, Hedayetullah M, Meher J, Jena BK. Non thermal methods of food processing after harvesting: An introduction. Journal of Interacademia. 2014;18(3):499-506.
 105. Singh V, Hedayetullah M, Meher J, Sahoo SR, Panda MK. Effect of slice thickness on recovery of ginger oil from dry ginger. Environment & Ecology. 2014;33(3A):926-929.
 106. Singh V, Hedayetullah M, Zaman P, Meher J. Postharvest technology of fruits and vegetables: An overview. Journal of Post Harvest and Technology. 2014;2(2):124-135.
 107. Ullah R, Nadeem M, Khalique A, Imran M, Mehmood S, et al. Nutritional and therapeutic perspectives of Chia (*Salvia hispanica* L.): a review. J Food Sci Technol. 2016;53(4):1750-1758.
 108. Yeboah S, Owusu-Danquah E, Lamptey JNL, Mochiah MB, Lamptey S, Oteng-Darko P, et al. Influence of planting methods and density on performance of chia (*Salvia hispanica*) and its suitability as an oilseed plant. Agric Sci. 2014;2(4):14-26.
 109. Zaman A, Hedayetullah M. Farming Systems and Sustainable Agriculture. Agrotech Publishing Academy; 2020.<https://agrotechbooks.com/product/farming-system-and-sustainable-agriculture/>

110. Zaman A, Hedayetullah M. Agricultural Heritage. New India Publishing Agency; 2020. <https://DOI.org/10.59317/9789395763936>
111. Zaman A, Hedayetullah M. Water Resource Development and Management. CRC Press, Taylor & Francis Group; 2022. <https://DOI.org/10.1201/9781003180494>
112. Zaman A, Hedayetullah M. Principles and Practices of Natural Farming. Kalyani Publishers; 2025. <https://kalyanipublishers.co.in/single-product.php?>
113. Zaman A, Hedayetullah M. Bio-remediation of arsenic problem for sustainable agriculture. In: Zaman A, Maitra S, eds. Cutting Edge Technology for Agricultural Sustainability. New India Publishing Agency; 2018. p.139-148.
114. Zaman A, Hedayetullah M. Agricultural sustainability for crop production. In: Zaman A, Maitra S, eds. Cutting Edge Technology for Agricultural Sustainability. New India Publishing Agency; 2018. p.247-263. https://books.google.co.in/books/about/Cutting_Edge_Technology_For_Agricultural.ht
115. Zaman A, Hedayetullah M. Farming Based Livelihood System. New India Publishing Agency; 2025.
116. Zaman A, Hedayetullah M. Deeksharambh (Induction-cum-Foundation Course). New Delhi Publishers; 2025.
117. Zaman A, Hedayetullah M. Management of Natural Resources. Asha Book Publishers; 2025.
118. Zaman A, Hedayetullah M. Compendium of Agronomy. Asha Book Publishers; 2025.
119. Zaman A, Hedayetullah M. Crop Production Technology - I (Kharif Crops). Narendra Publishing House; 2025. <https://www.nphindia.com/book/9789356515802/crop-production-technology-i-kharifcrops>
120. Zaman A, Hedayetullah M. Crop Production Technology - II (Rabi Crops). Student Press; 2025. https://www.researchgate.net/publication/404650556/Crop_Production_Technology_II
121. Zaman A, Hedayetullah M. Agri-Business Management (Theory and Practice). Asha Book Publishers; 2025.
122. Zaman A, Hedayetullah M. Agricultural Journalism (Theory and Practices with MCQs). Asha Book Publishers; 2025.
123. Zaman A, Hedayetullah M. Text Book of Horticulture (Theory and Practices with MCQs). Asha Book Publishers; 2026.
124. Zaman A, Hedayetullah M. Introductory Agroforestry. Daya Publishing House; 2026. https://www.researchgate.net/publication/404650184/Introductory_Agroforestry_Theo
125. Zaman A, Hedayetullah M. The Question Bank Series: Farming Based Livelihood System. Content Vives; 2026. https://www.researchgate.net/publication/390932474/Farming_Based_Livelihood_Syst
126. Zaman A, Hedayetullah M. Farming Based Livelihood System (Theory and Practice). New Delhi Publishers; 2026. <https://www.ndpublisher.in/files/1775197913Farming%20Based%20Livelihood%20Sy>
127. Zaman A, Hedayetullah M. Principles and Practices of Organic Farming and Conservation Agriculture. Asha Book Publishers; 2026. https://www.researchgate.net/publication/404445661/Principles_And_Practices_of_Or
128. Zaman A, Hedayetullah M. Ornamental Crops, Medicinal and Aromatic Plants (MAPs) and Landscaping. Asha Book Publishers; 2026. https://www.researchgate.net/publication/404500829/Ornamental_Crops_Medicinal_a
129. Zaman A, Firdous S, Hedayetullah M. Fundamentals of Soil Science (Theory and Practical). Bhavya Books; 2026.
130. Zaman A, Hedayetullah M, Ghosh A. Agricultural Marketing & Trade. Asha Book Publishers; 2026. https://www.researchgate.net/publication/404642809/Agricultural_Marketing_and_Tra
131. Zaman A, Hedayetullah M, Zaman P. Watershed management for agricultural sustainability. In: Zaman A, Maitra S, editors. Cutting Edge Technology for Agricultural Sustainability. New India Publishing Agency; 2018. p. 305-311. https://books.google.co.in/books/about/Cutting_Edge_Technology_For_Agricultural.ht
132. Zaman A, Hoque M, Hedayetullah M. Livestock and Poultry Management (Theory and Practice). New Delhi Publishers; 2026.
133. Zaman P, Hedayetullah M. Moth bean (Dew bean). In: Hedayetullah M, Zaman P, editors. Forages of the World: Minor Forage Crops. CRC Press; 2018. p. 91-100. <https://DOI.org/10.1201/9781351167284/>
134. Zaman P, Hedayetullah M. Turnip (Salgam). In: Hedayetullah M, Zaman P, editors. Forages of the World: Minor Forage Crops. CRC Press; 2018. p. 207-214. <https://DOI.org/10.1201/9781351167284/>
135. Zaman P, Hedayetullah M, Sengupta K. Fenugreek (Greek clover). In: Hedayetullah M, Zaman P, editors. Forages of the World: Minor Forage Crops. CRC Press; 2018. p. 121-130. <https://DOI.org/10.1201/9781351167284-19/fenugreekgreek-clover-parveen-zaman-md-hedayetullah-kajal-sengupta>