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RESEARCH ARTICLE

Cold storage warehouse dynamics in India: Growth trends, regional disparities and Infrastructure gaps (2014-2023)

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Abstract

This study examines trends in the cold storage industry from 2014 to 2023, focusing on India within a global context. The global cold storage market is projected to reach $218.7 billion by 2026, growing at a compound annual growth rate (CAGR) of 12.7%. In India, the number of cold storage units increased from 6891 to 8653 during this periods, reflecting a CAGR of 2.13%, while storage capacity expanded at a CAGR 2.26%. The findings highlight significant regional disparities across India, with the Central region demonstrating the highest growth. Despite these advancements, considerable infrastructure gaps remain, particularly in the dairy (80% shortage) and fisheries (90% shortage) sectors, contributing significantly to post-harvest losses. The study emphasizes the importance of public-private partnerships, government incentives, and technological innovations to address these shortages. Strengthening cold storage infrastructure is crucial for reducing food wastage, improving supply chain efficiency, and bolstering food security. Key insights highlight the need for targeted investments in underdeveloped regions and underserved sectors to optimise the cold chain, reduce losses, and support India's agricultural productivity and economic growth.

Keywords

CAGR; cold storage industry; global trends; infrastructure gap; post-harvest losses

Introduction

Cold storage involves refrigerating perishable commodities at low temperatures to inhibit microbial activity and enzymatic reactions, thereby extending their shelf life (1). These systems can operate at sub-zero temperatures and are designed to handle large volumes of goods with precision, improving operational efficiency and reducing labour costs (2). Cold storage facilities play a crucial role in the global supply chain, particularly in the food and pharmaceutical industries.

Different types of cold storage units are utilized based on their specific purposes. Bulk cold stores (2°C to 8°C) use high-capacity refrigeration and automated systems to accommodate large-scale storage of produce, dairy, and meat.Multi-purpose cold stores offer modular refrigeration with adjustable temperature controls, making them suitable for a diverse range of products, including food and pharmaceuticals. Small cold stores and

mini units/walk-in cold stores (-2°C to -18°C) rely on basic refrigeration for short-term storage, primarily serving small businesses and retailers. Frozen food stores (-18°C) employ powerful freezing systems for the long-term preservation of frozen goods, such as meats and seafood. Controlled atmosphere (CA) stores (0°C to 14°C) incorporate advanced technology to regulate gases and humidity, effectively slowing the ripening process and extending the freshness of fruits and vegetables (3). Each type of cold storage unit is tailored to meet specific industry needs based on storage capacity and the sensitivity of the stored products. The various types of cold storage technologies and their uses are summarized in Table 1.

The global cold storage market has witnessed significant growth, driven by the increasing demand for frozen and chilled products (Global Cold Storage Capacity Report). These systems have evolved rapidly, incorporating technological advancements to enhance efficiency, ensures better quality control, and enable early detection of potential issues (4). Such advancements not only reduce the environmental impact of cold storage systems but also result in long-term cost savings (5).

Despite these advancements, many developing regions still lack sufficient cold storage capacity, which results in considerable food losses due to the inability to effectively preserve perishable goods. This issue is particularly critical in areas where post-harvest losses are significant. In such situations, investing in cold storage infrastructure becomes essential to reduce waste and ensure a stable supply of fresh produce, processed foods, and pharmaceuticals (NCCD, 2021).

The global cold storage market was estimated at USD 119.8 billion in 2022 and is projected to grow at a CAGR of 17.5% between 2023 and 2030 (6). Climate change further amplifies the need for efficient cold storage solutions, especially in developing regions. Rising temperatures and extreme weather events accelerate food spoilage and disrupt supply chains, making cold storage solutions increasingly critical. Tropical and subtropical regions, often characterized by frequent and intense heat waves, face heightened challenges in preserving perishable goods. By investing in robust cold storage infrastructure, these regions can mitigate the impacts of climate change, reduce post-harvest losses, and enhance food security for their growing populations. This study examines the cold storage industry in India and globally, focusing on growth trends observed between 2014 to 2023. By analysing growth rate in terms of the number and capacity of facilities, the study aims to predict future developments in the cold storage sector. Regional classification is utilized to examine the distribution of cold storage facilities, understand local market dynamics identify infrastructure gaps, and guide investment planning.

Furthermore, analysing infrastructure gaps helps pinpoint critical areas requiring investment and improvement in food storage and distribution. Addressing these gaps is essential for reducing food waste, improving economic efficiency, and shaping policy decisions to enhance food security and strengthen supply chain resilience. Consequently, this study provides a comprehensive overview of the current state and future prospects of the cold storage industry.

Materials and Methods

The secondary data related to cold storage warehouses in India was collected from various reputable sources, including databases, websites, published reports, and financial records. The top 5 countries, along with their respective capacities, were sourced from the Global Cold Storage Capacity Report, 2020, which was subsequently analysed and interpreted. Data on the current state of the sector in India from 2014 to 2023 was gathered and analysed using the CAGR. Additionally, the infrastructure gap was examined and interpreted.

This analysis identifies investment and development opportunities while highlighting challenges that must be addressed to enhance efficiency and capacity. Addressing these gaps allows the cold storage sector to better support food security and foster economic growth, particularly in underserved regions.

Compound annual growth rate

The CAGR is a term used in economics, business, and investing to describe the average annualised growth rate of compounding values over a specific time period (7). It is commonly employed to calculate the rate of increase in various factors such as area, population, number of units, employment, productivity, and capacity.

In this study, CAGR was used to assess the growth trends of cold storage systems, providing a clear understanding of how the number and capacity of these units evolved over time. This analysis facilitated the identification of investment opportunities, the assessment of market potential, and the development of effective policies to improve infrastructure. The formula used to calculate CAGR is:

$QA=Q0(1+r)ni$

Where,

QA= Projected number/capacity of cold storage

Qo = number/capacity of cold storage of the base year

r = Compound Annual growth rate (CAGR)

ni = Number of ith year to be projected i.e., i= 1,2,3."

Results

According to the latest available data, the global cold storage market was valued at approximately $89 billion in 2019 and is projected to reach $218.7 billion by 2026, reflecting a CAGR of 12.7% from 2020 to 2026 (8). The total capacities of the top five countries for the years 2016, 2018, and 2020 are listed in Table 2.

As shown in Fig.1, the United States consistently maintained the highest capacity from 2016 to 2020, followed by India, China, and Australia, which exhibited

Table 1. Different types of cold storage units

Types of Cold Storage	Technology	Use
Bulk cold stores	High-capacity refrigeration, automated monitoring systems	Large-scale storage of produce, dairy, and meat
Multipurpose cold stores	It is designed to store a range of products.	It is used to store food, pharmaceuticals and chemicals
Small cold stores	It is designed with Basic refrigeration, insulated walls	Short-term storage for small businesses and retailers
Frozen food stores	Sub-zero freezing, blast freezers	Long-term storage of frozen foods such as meat, seafood, and ready meals
Mini units /walk in cold stores	Self-contained refrigeration units with flexible sizing	Temporary storage for small businesses, restaurants, and laboratories
Controlled atmosphere (CA) stores	Atmosphere control (O_2, CO_2, humidity), airtight chambers	Long-term preservation of fresh fruits and vegetables, slowing ripening

(Source: 3)

Table 2. Top five countries and their total capacity (Million m3)

Countries	Capacity (2016)	Capacity (2018)	Capacity (2020)
United States	118.07	130.97	156.21
India	141.13	150.23	150.00
China	107.00	105.00	130.95
Great Britain	32.37	24.12	35.93
Brazil	16.83	19.06	19.45

(Source: 9)

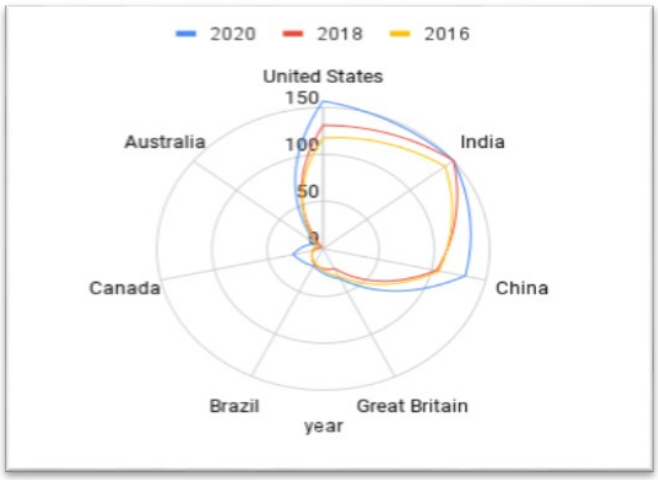

Fig. 1. Trend analysis of the top five countries in cold storage capacity *(Source: 9).*

varying degrees of growth. In contrast, Canada and Brazil experienced minimal changes in capacity, while Great Britain's position fluctuated.

The U.S. cold storage market continues to be driven by key trends such as the increased adoption of automation and advanced technologies, as well as the rising popularity of e -commerce, which has amplified the demand for faster delivery times (10). These factors have enabled the USA to retain its position as the global leader in cold storage capacity.

A radar chart was developed using the data presented in Table 2. The chart highlights a growing emphasis on cold storage capacity among the listed nations, primarily driven by the need for food preservation, pharmaceutical storage, and efficient supply chain management. In the U.S., advanced infrastructure supports its vast food and pharmaceutical industries. India, as a major food producer, is significantly expanding its cold storage capacity to reduce food losses and improve vaccine storage. China's rapid investments in this sector are fuelled by its growing e-commerce industry and export markets. In Great Britain, cold storage plays a critical role in ensuring food supply chain efficiency and aids in pharmaceutical distribution. Meanwhile, Brazil relies heavily on cold storage to maintain food quality, which is crucial for its large-scale agricultural exports.

Trend in the number and capacity of cold storage units in India

Cold storage plays a vital role in India's agricultural sector by reducing post-harvest losses and preserving perishable crops such as fruits, vegetables, and dairy products. These facilitates help extend the shelf life of produce, improve market access, and stabilize prices. Analysing cold storage trends in India is essential for assessing infrastructure growth and its impact on reducing food waste while supporting key sectors.

Table 3 highlights the trend in the number and capacity of cold storage units in India from 2014 to 2023, along with the coefficients of determination (R^2) and CAGR. Fig.2 show a steady increase in the number of cold storage units during the study period. In 2014, there were 6891 units with a total capacity of 31823700 MT.

Several government initiatives have significantly contributed to this growth. The Pradhan Mantri Kisan SAMPADA Yojana (PMKSY), approved in 2017, provided financial assistance for building modern cold storage facilities and enhancing cold chain logistics. By 2024, approximately 634 cold storage units were established under this scheme. Additionally, the Pradhan Mantri Matsya Sampada Yojana (PMMSY), launched in 2020, focused on developing cold storage infrastructure for

Table 3. Compound growth rate of number and capacity of cold storage units in India (2014 – 2023)

Year	Number	Capacity (MT)
2014	6891	31823701
2015	7129	32867458
2016	7645	34050359
2017	7645	34956991
2018	7916	36229675
2019	8064	36949607
2020	8186	37425097
2021	8229	37689292
2022	8361	38108816
2023	8653	39417231
R^2	**0.9539**	**0.9536**
CAGR	**2.13%**	**2.26%**

(Source: 11)

preserving fish and aquatic products.

Following the approval of PMKSY in 2017, the number of cold storage units increased to 7645, with a total capacity of 34956991 MT. The introduction of PMMSY in 2020 further boosted the number of units to 8186, with a capacity of 3742,097 MT.. In 2022, the Integrated Cold Chain and Value Addition Infrastructure scheme was introduced to promote end-to-end cold chain facilities, ensuring minimal losses from the farm gate to the consumer. By 2022, this scheme helped raise the total number of units to 8361, with a capacity of 38108816 MT.

As of 2023, the total number of cold storage units reached 8653, with a capacity of 39417231 MT. The data presented in Table 3 indicates that the number of units increased from 6891 in 2014 to 8653 in 2023, representing a CAGR of 2.13% with an R^2 value of 0.954. The capacity of these units grew from 31823701 MT in 2014 to 39,417,231 MT in 2023, reflecting a CAGR of 2.26% with an R^2 value of 0.954.

The slightly higher growth rate in capacity compared to the number of units suggests that not only are new facilities being established, but the average size of these units has also increased. This steady expansion can be attributed to several factors, including new market entrants, the geographical expansion of existing companies, and growing demand across various sectors.

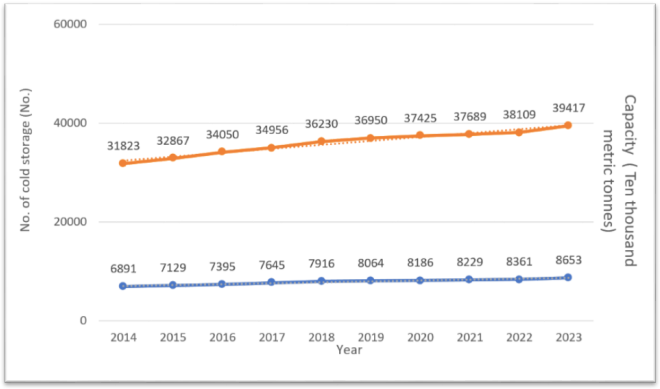

Fig. 2. Trends in the number and capacity of cold storage units in India from 2013 to 2023.

Regional classification of cold storage units

India is geographically divided into five regions namely, Central, North, South, East and West. Each region has distinct climatic and agricultural characteristics that influence the demand for cold storage facilities. These factors also affect the design requirements needed to preserve locally produced perishable products. The Central region comprises Chhattisgarh, Madhya Pradesh, Uttar Pradesh, and Uttrakhand. The North region includes Haryana, Himachal Pradesh, Punjab, Rajasthan, Chandigarh, Delhi, Jammu and Kashmir. The South region encompasses Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Lakshadweep, and Puducherry.. The East region includes Arunachal Pradesh, Assam, Bihar, Jharkhand, Manipur, Meghalaya, Mizoram, Nagaland, Odisha, Sikkim, Tripura, West Bengal, Andaman and Nicobar Islands. Finally, the West region includes Goa, Gujarat, and Maharashtra.

The number and capacity of these infrastructure distributed across these regions are presented in Table 4. From the Table 4, it can be concluded that the Central regions has the highest concentration of the units, with an average of 2786 units, growing at a CAGR of 1.54%. This is followed by the West and North regions, which have averages of 1472 and 1415 units, respectively, with CAGRs of 4.59% and 2.88%. Uttar Pradesh ranks first in terms of the highest number of cold storage units, followed by Maharashtra. The South region has an average of 1113 cold storage units, with a CAGR of 2.88%, while the East region has the lowest average of 1034 units, with a CAGR of 1.07%. Manipur and Nagaland have the fewest cold storage units.

Based on Table 5, it can be concluded that the Central region has the highest cold storage capacity among all regions in India. The four states comprising Central India, Chhattisgarh, Madhya Pradesh, Uttar Pradesh, and Uttarakhand, have an average cold storage capacity of approximately 16323748 MT, with a CAGR of 1.24%. Uttar

Table 4. Region-wise classification of number of cold storage units

Year	Number of cold storage units				
	CENTRAL	NORTH	SOUTH	EAST	WEST
2014	2,553	1,218	957	1,034	1,129
2015	2,628	1,261	978	1,053	1,209
2016	2,686	1,322	819	1,104	1,296
2017	2,743	1,372	1,016	1,117	1,397
2018	2,815	1,415	1,051	1,124	1,522
2019	2,828	1,451	1,061	1,127	1,597
2020	2,862	1,485	1,014	1,134	1,617
2021	2,881	1,504	1,091	1,136	1,617
2022	2,897	1,504	1,137	1,146	1,641
2023	2,967	1,616	1,220	1,151	1,699
Mean	**2,786**	**1,415**	**1,034**	**1,113**	**1,472**
R^2	**0.95**	**0.96**	**0.64**	**0.80**	**0.90**
CAGR	**1.54**	**2.88**	**2.88**	**1.07**	**4.59**

Table 5. Region-wise classification of capacity of cold storage units

Year	Capacity of cold storage units (MT)				
	CENTRAL	NORTH	SOUTH	EAST	WEST
2014	1,52,42,518	33,18,858	4,78,706	80,38,738	27,44,881
2015	1,55,81,549	35,04,536	25,75,277	81,12,418	30,93,678
2016	1,58,65,801	37,18,206	23,55,492	83,33,739	34,60,538
2017	1,60,84,233	38,46,664	27,60,869	83,77,321	38,87,904
2018	1,64,29,336	40,05,272	26,13,688	84,03,373	45,03,288
2019	1,65,11,075	41,63,920	30,46,072	84,26,165	48,02,375
2020	1,66,86,415	42,85,993	27,08,984	84,93,290	48,39,510
2021	1,68,04,070	43,85,144	31,48,278	85,12,290	48,39,510
2022	1,68,62,151	45,03,142	33,02,275	85,20,818	49,20,430
2023	1,71,70,330	47,67,355	37,69,953	85,50,796	51,58,797
Mean	**1,63,23,748**	**40,49,909**	**28,75,959**	**83,76,895**	**42,25,091**
R^2	**0.96**	**0.98**	**0.79**	**0.84**	**0.87**
CAGR	**1.24**	**3.83**	**4.37**	**0.64**	**7.10**

Pradesh leads in cold storage capacity, primarily due to its significant agricultural production, particularly of potatoes, and its strategic geographical location.

The East region ranks second in terms of cold storage capacity, with an average of 8376895 MT and a CAGR of 0.64%. However, states in the East regions, including Assam, Bihar, Jharkhand, Manipur, Meghalaya, Mizoram, Nagaland, Odisha, Sikkim, Tripura, and West Bengal, face challenges such as underdeveloped infrastructure, limited demand for processed goods, slower urbanization, and inadequate investment and government support.

The West and North regions have average capacities of 4225091 MT and 4049909 MT, with respective CAGRs of 7.10% and 3.83% (11). The Western region exhibits a higher growth rate compared to the East, driven by rapid economic development, substantial production of cash crops requiring cold storage, the expansion of e-commerce, robust supply chain networks, and effective government initiatives promoting cold chain infrastructure.

The South region has the lowest cold storage capacity, with an average of approximately 2875959 MT and a CAGR of 4.37%. This lower capacity is partly due to the tropical climate in the South, which allows certain crops to maintain a longer shelf life without refrigeration.

The expansion of cold storage facilities between 2015 and 2022 has significantly contributed to reducing post-harvest losses, particularly for commodities such as cereals,

pulses, oilseeds, and perishables. By extending shelf life and maintaining optimal storage conditions, cold storage systems effectively minimize waste and product deterioration. For instance, fruits such as apples and mangoes can be preserved for months when stored at temperatures ranging from -5°C and 13°C with relative humidity levels of 90-95%. Similarly, onions and potatoes benefit from cool, dry storage environments (12).

Proper cold storage can help reduce post-harvest losses by slowing down degradation processes, such as microbial growth and enzymatic activity that leads to spoilage. However, despite these advancements, significant losses are still observed in the perishable food sector, particularly in fruits and vegetables. This highlights the urgent need to expand and enhance cold storage infrastructure.

To reduce losses, ensure food security, and improve overall market efficiency in the agriculture sector, it is essential to develop storage facilities equipped with advanced technologies. The post-harvest losses for major crops and commodities are detailed in Table 6.

From Table 7, it is evident that cold storage infrastructure in India exhibits significant gaps across various product categories. For fruits and vegetables, the shortage is relatively small, with a 10% shortage in bulk cold storage and a mere 2% at the hub level, suggesting that the infrastructure in this segment is nearly sufficient. However, the dairy sector faces a severe shortfall, with an 80% gap, highlighting a critical lack of sufficient cold storage facilities (13).

Fig.3 further highlights that the fish sector is even more underserved, with a staggering 90% deficit, indicating the urgent need for infrastructure development in this area. The meat sector also experiences a moderate gap of 49%. These shortages in cold chain infrastructure, especially in the dairy and fish sectors, pose a substantial risk of increased wastage and inefficiencies, underscoring the urgent need for further investment.

Discussion

The USA ranks first in cold storage capacity, driven by advanced technological advancements. India, standing second in the global cold storage market, has witnessed steady growth in this sector, which plays a critical role in the country's food supply chain and economy. Over the past decade, the cold storage industry in India has achieved a compound annual growth rate (CAGR) of 2.26% in capacity and 2.13% in the number of units between 2014 and 2023. This growth highlights the rising demand across various sectors, particularly in food preservation and pharmaceuticals.

The regional distribution of cold storage facilities in India remains uneven, with the Central region leading in both the number of units and storage capacity. However, significant infrastructure gaps persist, particularly in the dairy and fish value chains, which face shortages of 80% and 90%, respectively, underscoring the need for substantial investment (14). Cold chain infrastructure plays an essential role in reducing post-harvest losses and

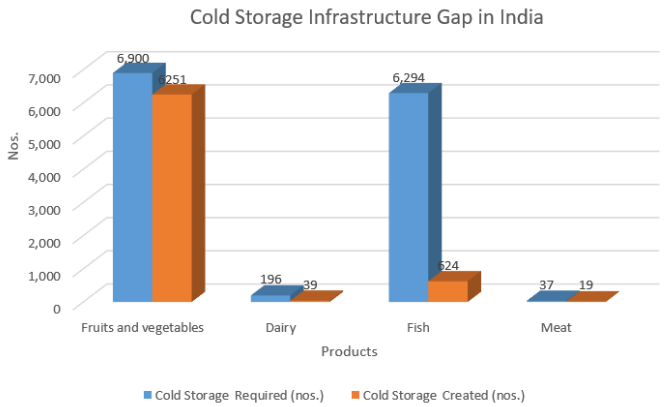

Fig. 3. Cold storage infrastructure gap in India *(source: 14).*

Table 6. Post-harvest losses of major crops and commodities

Commodities	Post-harvest loss (%)			
	2015	Percentage (%)	2022	Percentage (%)
Cereals	5.35	7	4.9	6.9
Pulses	7.4	9.6	6.2	8.8
Oil seeds	6.55	8.5	5.2	7.3
Fruits	11.3	14.7	13.5	19.1
Vegetables	8.5	11.7	8.25	11.6
Plantation Crops & Spices	4.55	5.9	4.3	6.1
Milk	0.9	1.2	0.9	1.3
Fisheries (Inland)	5.2	6.8	4.9	6.9
Fisheries (Marine)	10.5	13.7	8.8	12.4
Meat	2.7	3.5	2.3	3.3
Poultry	6.7	8.7	5.6	7.9
Egg	7.2	9.4	6	8.5
	76.85	**100**	**70.85**	**100**

(Source: 13)

Table 7. Cold storage infrastructure gap in India

Value chain	Cold storage required (nos.)	Cold storage created (nos.)	Gap (%)
Fruits and vegetables	6,900	6251	10%
Dairy	196	39	80%
Fish	6,294	624	90%
Meat	37	19	49%

(source: 14)

ensuring food security. Nevertheless, current limitations, especially in regions experiencing high post-harvest losses of fruits, vegetables, and fish, demand targeted improvements. Addressing these gaps will enhance supply chain efficiency, reduce food wastage, and strengthen resilience, ultimately benefiting India's agriculture and food sectors.

Conclusion

The Indian cold storage industry has experienced steady growth, driven by increasing demand for perishable goods and advancements in technology. Despite notable progress in expanding cold storage infrastructure, significant deficiencies persist, particularly in the dairy and fish sectors. Addressing these infrastructure gaps is vital for reducing post-harvest losses, enhancing food security, and fostering the growth of the agricultural sector.

Targeted investments in underdeveloped regions and underserved sectors are essential to optimize the cold chain, minimize food wastage, and support India's economic development. By utilizing public-private partnerships, government incentives, and technological innovations, will be critical in strengthening India’s cold storage infrastructure. Such efforts will contribute to creating a more efficient, resilient, and sustainable food supply chain, ultimately benefiting the nation’s economy and ensuring food security.

Suggestions

To expand the number of cold storage facilities in India, collaboration between the government and the private sector through Public-Private Partnerships (PPPs) is essential. Such partnership can help attract investments and provide incentives, including tax benefits and subsidies. The government is actively promoting PPPs to accelerate the development of cold chain infrastructure, particularly in underserved regions (15).

The industry stands to gain significantly by addressing key constraints, such as improving cost-effectiveness, refining marketing strategies, and optimizing location planning. Additionally, incorporating technological advancements and adopting sustainable practices can enhance operational efficiency while minimizing environmental impact.

As India continues to expand its cold storage capacity, there is considerable potential to reduce post-harvest losses and strengthen food security. Future developments in this sector are poised to play a crucial role in boosting agricultural productivity and supporting the country’s overall economic growth.

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Authors' Contributions

PA and MS conceived and designed the study and performed the experiments; MK analyzed the data, PA and SR wrote and corrected the paper and AG performed a critical reading of the manuscript.

Compliance with Ethical Standards

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Gemini AI to improve language. After using this tool/ service, the authors reviewed and edited the content as needed and will take full responsibility for the content of the publication.

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